Nikolaj Wolfson *Editor*
Alexander Lerner · Leonid Roshal *Co-Editors*

Orthopedics in Disasters

Orthopedic Injuries in Natural Disasters and Mass Casualty Events

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ISBN 978-3-662-48948-2 ISBN 978-3-662-48950-5 (eBook)
DOI 10.1007/978-3-662-48950-5

Library of Congress Control Number: 2016934601

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer-Verlag GmbH Berlin Heidelberg

This book is dedicated to:
those who risk their lives while saving lives of the victims of uncontrollable natural disasters or man-made devastating accidents.

Foreword

The reader of this treatise has the privilege of reviewing the most definitive and complete analysis of trauma treatment extant. The particular discussion of mass trauma and crisis management is special, all-inclusive, and current.

This reference book will be a "must have selection" for all medical centers, trauma surgeons, and even general orthopedists around the world. The editor-in-chief, Nikolaj Wolfson M.D., conceived, planned, and organized this book, with input from his associate editors, Alex Lerner, M.D., and Leonid Roshal, M.D. This compilation is a necessary addition to all previous trauma studies. I know of no other trauma book that combines these particular qualities that can serve as a current review, handbook, resource book, as well as a teaching tool.

Enjoy your discoveries, as you make a "trip" through this trauma and large-scale crisis management guide, as I have. Also, make sure your area trauma centers have a copy for their rapid reference source for this much needed information.

Los Angeles, USA — Chadwick F. Smith
January 5, 2016

Chief Editor and Author

Nikolaj Wolfson MD, FRCSC, FACS, is an orthopaedic surgeon from San Francisco, California.

His medical career started as a young military surgeon and from the battle-field it evolved into the field of orthopaedic surgery.

After receiving MD from Sackler School of Medicine at Tel Aviv University, he completed training in orthopaedic surgery at the University of Western Ontario in London, Ontario, and a fellowship at the University of Toronto in Canada. Following his academic practice in Canada and the USA, in addition to a Chairmanship position at the Regional Trauma Center in California, he is now in private practice at the California Pacific Medical Center in San Francisco specializing in orthopaedic reconstruction, trauma, and limb salvage surgery.

Dr. Wolfson's involvement with disaster medicine started in 2010 when he participated in disaster relief following the earthquake in Haiti. Working on the ground as part of the University of Miami team and US Navy was a turning point in his professional views and commitments.

Shortly after the devastating tragedy in Haiti, he initiated and founded the "Orthopaedics in Disasters" program at SICOT, the oldest international orthopaedic organization, where he is on the Trauma Committee and is a member of the Foundation Board. He has organized numerous national and international courses on the subject of Orthopaedics in Disasters. Dr. Wolfson is on the editorial board of a number of medical journals and NGOs.

"I was fortunate to learn from the best, and am proud to be life-time student of medicine."

Author Biography

Alexander Lerner, M.D., Ph.D.
Director, Department of Orthopedic Surgery, Ziv Medical Center, Zefat, Israel

Clinical Professor, Faculty of Medicine in Galilee, Bar-Ilan University, Israel

More than 30 years clinical experience in field of reconstructive orthopaedic surgery, correction of the limb deformations, treatment of non-unions and mal-unions, limb salvage after extensive tissue loss, management of severe trauma, including war injuries, chronic osteomyelitis, and limb elongation.

Author of Books:

- A. Lerner, D. Reis, M. Soudry. Severe Injuries to the Limbs. Staged Treatment. Springer – Verlag. Berlin – Heidelberg. 235 p., 2007.
- A. Lerner, M. Soudry. Armed Conflict Injuries to the Extremities. A Treatment Manual. Springer-Verlag. Berlin-Heidelberg. 407 p., 2011.

Seventy publications in field of orthopaedic and plastic reconstructive surgery.

Chairman of sessions and invited lecturer at international conferences and courses in Germany, Swiss, the USA, Italy, Austria, Turkey, Russian, Japan, Czech, Macedonia, China, Bulgaria, and Greece.

Co-founder of Asian Trauma Association (Shanghai, 2005).

Editorial board member of Polytrauma (Russia) and Chinese Journal of Traumatology (China).

Author Biography

Prof. Leonid M. Roshal, MD, PhD, Dr.Sc (med)
is an organizer and the President of the world's unique pediatric institution – Clinical and Research Institute of Urgent Pediatric Surgery and Trauma which is situated in Moscow. He is also an organizer of the only specialized pediatric team (Dr. Roshal's Brigade) which provides urgent surgical help to children in disasters. Its members work as volunteers in local hospitals nearby disaster sites. Prof. Roshal personally helped children-victims in large natural and technogenic disasters in 16 countries of the world, in wars at the both sides of the front (Serbia and Croatia, Armenia and Azerbaijan, in Chechnya, in Israel and Palestine (Gaza), after the revolution in Romania). He personally negotiated with terrorists and provided medical help to hostages in the Dubrovka Theatre (Nord-Ost) in Moscow and in the school in Beslan. He helped children after the terroristic act in Kaspiysk (Russia).

Dr. Roshal was called by international journalists "Children's Doctor of the World." He was conferred the titles "European of the Year – 2005" (Reader's Digest), and "The Star of Europe – 2005" (BusinessWeek). For almost 10 years, he was a Board Member of the World Association for Disasters and Wars (WADEM) and has organized a special section at WADEM congresses for discussing the topic "Children, Disasters and Wars." Prof. Roshal has proven that medical help to children in disasters must be provided by pediatric specialists. He has certificates, gratitude diplomas, orders, and medals of many countries of the world.

Acknowledgments

To all those who have made this project come through, with gratitude and love:

Our colleagues from many countries, who shared their unique experience and expertise

Springer editorial team for professionalism and patience

Unique group of people that gave their time and talents in every step of this project making:

Angelina Alekseeva, Head of International Department in Clinical and Research Institute of Urgent Pediatric Surgery and Trauma in Moscow, Russia: thank you for help with the Russian chapters that cover most of the pediatric trauma

Dennis Bashaw, Medical Librarian from San Joaquin General Hospital in French Camp, California: you are the real gold of the San Joaquin Valley

Dmitry Laptev, B.A., Psychology, University of California, Davis, California: for your dedication and kindness

Inna Dubchak, Ph.D.: one of the creative minds and very special and dear friend

Kate Kharshan, an artist in life and in her dreams

Patricia Hill, for ongoing linguistic support

And of course **Luba Troyanovsky** for tolerating my absence from casual life and for allowing me to fly far and high.

Wishing and praying for your lives being disasters-free.

Contents

Part I

General Overview of Disaster and Mass Casualties Management: Organization

1 Introduction

Nikolaj Wolfson

How can we measure disaster if we don't feel it? We hear that a tornado wiped out hundreds of homes in Oklahoma. A Category 5 hurricane left thousands without food or shelter in the Caribbean. But what if we don't live in those places? Can we truly equate disaster's presence if it does not affect our own?

On January 12, 2010, the tangibility of the calamity could not have been more real. Haiti was at the forefront of international news as the worst earthquake in the nation's history hit. With an epicenter not far from Port-au-Prince, more than 200,000 were dead and many more were seriously wounded. I quickly understood how desperately unprepared we were, how unprepared we all were. General practitioners and expert surgeons were similarly overwhelmed by the number of patients injured with pathology that was significantly different from what we saw day to day.

Patients presented with crush syndrome, amputations, closed and often open infected fractures. This trembler undoubtedly created a disaster, but more importantly, shed light on the absence of disaster readiness. Aside from what nature had brought on, the rest of the world began to understand what disaster really meant. Disaster is not created solely by an earthquake, nor is an earthquake instantly disastrous. Disaster is the collective result of infrastructural, political, and cultural weaknesses that exacerbate nature's course.

Immediately following the Haiti earthquake, I spent time on the ground as part of a field hospital and later with the United States Navy Ship, "Comfort." Since then, I have also taken part in the recovery efforts of two major events: the 2015 Nepal earthquake and a major military conflict in the Middle East.

The lack of practical knowledge I felt we had, both situational and universal, was the trigger for this project. The chapters that follow may be helpful for those who treat patients in mass casualty events related to natural or man-made catastrophes, all of which are heavy realities in our society. But the everyday is just as important to address, because disasters are not restricted to any one people, geographical area, or time. For that reason, I have elected to include expertise from orthopedic surgeons from as many nations and regions of the world as possible. Using a global approach when treating patients is critical to creating optimal, yet personalized, care that is based not only on the pathology of the injury, but also on external factors, such as the region's existing health care system and the nation's culture.

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_1

Most of the contributors to this book have extensive experience in the orthopedic field. Some are young and upcoming in this arena. They are not all from academia, yet the practical applications they discuss are invaluable. There is no one style of writing, and each approach is unique to the experience. Each author's expertise is widespread and imperative for the international community.

Disaster relief experts from all over the world have been working on this subject for quite some time. Leaders in educational and disaster management programs representing Great Britain, Hong Kong, Israel, Egypt, Russia, China, Sweden, and the United States have honorably participated in the writing of this book.

One expert approach to military trauma comes from France, where Napoleon's doctor, Baron Dominique Larrey, introduced the "Triage" long ago. Sweden and the United States have been on the cutting edge of education surrounding military medicine. Israel, facing war and terror-related injuries, has developed a robust program for national terror trauma preparedness and has built a humanitarian field hospital to treat thousands of people victimized by regional military conflicts.

In addition to practical applications, the succeeding chapters also highlight instances and treatment of irregular injuries seen almost exclusively in catastrophic events. For example, crash injuries are not foreign to trauma surgeons, but crush syndrome is not often seen or treated by even the most experienced traumatologist, let alone a community physician. Blast injuries are uncommon and difficult to treat in urban medical facilities or field hospitals; handling a large number of patients simultaneously can be easily overwhelming, particularly when the trauma is severe. Amputations for traumatized or mangled extremities are anything but simple in places where the amputee cannot be supported; in this situation, having an adequate prosthesis makes a life of difference. However, resources like these are not copious in all parts of the world. We use every effort to save as many lives as possible, but it is important to also recognize the value of saving one life.

The complexity of disaster injuries often requires multidisciplinary expertise. In some of my own experience, it has been clear that a cohesive team is key to providing the best care possible to as many victims as possible. Earthquakes, such as the one in Haiti, demonstrate the need for team care efforts, especially for distinct injuries like crush syndrome. Professor Daniel Reis, my longtime friend and mentor, and his colleague nephrologist, of Haifa, Israel, were among the first to emphasize the uniqueness of crush syndrome and the high risk of infection associated with its presence if surgical intervention is undertaken. Wound care and vascular reconstruction were covered by one of the best centers in the United States to deal with microvascular surgery. American medical military experts have also addressed blast injuries that result in devastating damage to extremities.

Managing mangled extremities and deciding to salvage or amputate the affected limb is always one of the most challenging decisions in mass casualty events. Several experts have addressed this specifically difficult topic. Two orthopedists from Vienna, Austria, described their approach to limb salvage, while an expert from India's Ganga Hospital described his extremity trauma score as a predictive amputation tool. Turkish colleagues have shared their imperative experience treating bone defects and osteomyelitis, and several partners from the University of Southern California have contributed to our knowledge about infection prophylaxis in orthopedic trauma. These are only a few expert panelists whose experiences have, and will continue to, affect the way orthopedic traumatologists treat disaster injuries.

However, using modern technology is not always an option. When disaster strikes in an austere environment, the ability to adapt is as critical as fundamental medical knowledge. An orthopedic surgeon and his colleagues from Indonesia describe how to best manage this precarious situation. External fixation, the go-to method for multiple fractures or delayed trauma, is one of the most important treatment tools in damage control surgery. Experts from Israel, Armenia, and the United States address this subject further.

In many disasters, the nature of orthopedic trauma—specifically crush and blast injuries—requires a staged approach, paying careful attention to soft tissues. Introduced by the Navy as "damage control," this concept was popularized by our German colleagues and is an important model for the treatment of a variety of injuries. Performing amputations of extremities is a prime example of utilizing the "damage control" approach, as deviating from this method can lead to devastating complications, such as wound infection, and even death. This book's editor and other colleagues describe this imperative concept.

The readers of this book are also fortunate to collect expertise from world-renowned professor and pediatric surgeon, Leonid Roshal, Doctor of the World. Professor Roshal and his partners from Moscow have shared their unique experience of caring for pediatric disaster injuries, and their skills are well supplemented by a surgeon and team from Philadelphia, Pennsylvania.

Additionally, experts dealing with tsunamis and nuclear disasters write about crucial mass casualty events and rescue efforts in Japan, and very skilled surgeons from Hong Kong provide specialized insight on hand trauma. An EMS professional from San Francisco discusses the realistic possibility and actuality of California earthquakes and their aftermath in another section.

Some of the following chapters have been purposefully combined and written by authors from different countries. It is my hope that this merge will facilitate a healthy and collaborative bond between authorities of orthopedic trauma, rather than establish a distinction between individuals. The goal is to unite the way both experts and citizens perceive and respond to disaster.

Disaster's magnitude may not be fully measured if we don't feel it firsthand, but if we ask the right questions, we may begin to understand the extent of its effects. BBC's Michael Buerk described the Ethiopian famine that lasted from 1983 to 1985 as "hell on earth." Buerk's news report shocked the world, as images of the starving population roused the public into action. Unprecedented donations and benefit concerts kept the famine in the public eye, but experts had predicted the dearth almost 18 months earlier. The combination of nature's will, political instability, and government conflict had given us a warning but few paid attention. Hugh McKay, director of Save the Children, asked everyone who might have wondered: "How much lead time does the world's conscience really need?"

The same happened in Haiti. Patrick Charles, a geologist and former professor at the Geological Institute of Havana, predicted the Haiti earthquake more than a year before it occurred. Charles wrote, "Conditions are ripe for major seismic activity in Port-au-Prince. The inhabitants of the Haitian capital need to prepare themselves for an event which will inevitably occur…" Politics, corruption, and social unrest were the underlying causes of what yielded a disaster. Nature could not be prevented, but the nation's groundwork limited inhabitants' successful response. An active approach that promotes a positive reform starts with political, economic, and cultural stability.

That is to say, why must we have a reactive response to disaster instead of a proactive one? After every major disaster event, the elucidated lesson is how to cope preemptively for the next one. Disaster response must focus on building nations and progressing processes to help the world cope with and prepare for inevitable calamities.

2 Epidemiology and History of Natural Disasters and Mass Casualties

Sakal Kiv, Nathan Douthit, Avram Shack, and Seema Biswas

2.1 Introduction

So far in just 13 years of the twenty-first century, we have seen a full range of man-made and natural disasters. Climate change [1, 2] has been implicated in the severe weather responsible for floods in England and Wales [3] and India [4] and hurricanes on the Atlantic coast of the United States [5], but still more worrying is the effect of climate change on more chronic weather patterns affecting the monsoon rainfall and rice crop in India [6] and droughts occurring across sub-Saharan Africa expanding the desert further south [7]. According to Eichenseher,

> In 2012, monsoon floods displaced nearly 9 million people in India, 15 million in China, 11 million in Pakistan, and 6 million in Nigeria, according to a new report from the Swiss-based Internal Displacement Monitoring Centre. IDMC estimates that in 2012, 32.4 million people around the world lost their homes to natural disasters. The bulk of these were in Asia and Africa, but North Americans were not immune. And on the opposite side of the same coin: The summer of 2012 saw debilitating drought around the world, which was in part to blame for a rise in food prices. (Scientists made the link then between drier than normal conditions, including an anemic monsoon season in Asia, and climate change.) [8]

Thus, natural disasters now seem to occur with alarming regularity in areas made vulnerable already by conflict, political instability [9], poverty [10], and a failure to develop in spite of years of financial aid [11, 12]. As Didier Cherpitel, former General Secretary of the IFRC, reminds us, "Disasters seek out the poor and ensure that they stay poor" [13]. A study of the epidemiology of disasters is impossible without a survey of the conflicts in the world at any time. According to the Institute for Economics and Peace, conflict and insecurity across the world have increased by 5 % since 2008 [14]. In addition, no study of the effects of disasters can ignore the fact that disaster management must work to improve infrastructure and build capacity for vulnerable populations (Figs. 2.1 and 2.2).

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_2

Fig. 2.1 An overview of displaced populations due to violent internal conflict in 2014. Reproduced with permission [76]

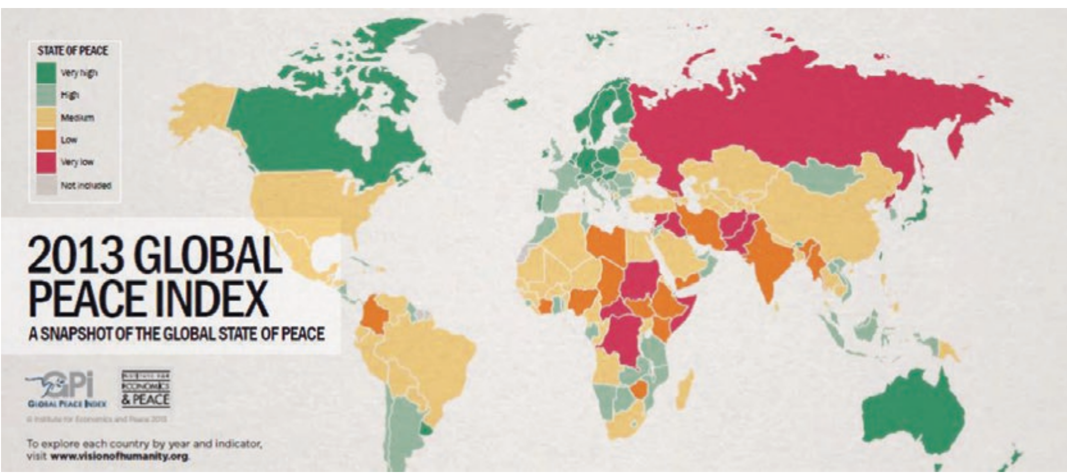

Fig. 2.2 The current state of global peace and conflict. Reproduced with permission [14]

2.2 The Study of Disasters and the History of Disaster Response

We shall look more closely at the definition of terms used in disaster management in Sect. 2.3, but whether induced by natural or *man-made* (also known as *technological*) hazards or conflict in complex emergencies [15], disasters disrupt the functioning of communities that lack the capacity to cope with hazards, resulting in human suffering and material loss [16, 17].

Many organizations study disasters. These organizations emerged from the initial work of Saylor and Gordon [18] in the study of the epidemiology of disasters in the late 1950s [19]. Since then, the role of these organizations, the Centre for Research on the Epidemiology of Disasters (CRED) and the UN Disaster Relief Office (UNDRO), for example, in following weather patterns, geopolitics, and the movement of populations, has been crucial in disaster planning and the provision of an early response, which has become increasingly sophisticated. An early example of the changing nature and increasing complexity of disaster response emerged from the response by the humanitarian community to the Nigerian blockade of the Biafra during the civil war of 1967. The blockade and the difficulties of humanitarian relief resulted in mass starvation. Airlifts of food were complicated by allegations that aircraft were also flying in arms, responsible for prolonging the war, escalating the death toll and contributing, with a policy of attacks on civilians, to the suffering and death of thousands. From this conflict evolved a media and public more aware of the notion of a complex emergency, a humanitarian sector able to respond more rapidly to disaster, and Médecins Sans Frontières (MSF) International, one of the most influential humanitarian organizations of the modern era [19].

The need to focus on epidemiological assessment in the study of the impact of disasters was reinforced by the response to cyclones in East Pakistan (now Bangladesh) in 1970, responsible for over 500,000 deaths [20–22]. In response to the massive loss of life, which was attributed to a lack of warning, with many people apparently killed in their sleep, the scale of devastation in East Pakistan, the ensuing war with West Pakistan, and civil war in Cambodia, as well as other natural disasters during the same period, the United Nations began a study of disaster relief and prevention which led to the creation of the United Nations Disaster Relief Office (UNDRO) in 1971. UN member states were to contribute to the reconstruction of damaged countries [23]. In 1973, the Center for Research on the Epidemiology of Disasters (CRED) was founded in Belgium [24]. CRED, in collaboration with the World Health Organization (WHO), collects historical data on all disasters worldwide and records the number of casualties and people affected. Their work, and that of similar organizations, serves three purposes: the identification of areas of vulnerability in the world through objective vulnerability assessment, the determination of priorities in disaster preparedness, and decision making in order to reduce the impact of future disasters.

Other agencies have been established to study the epidemiology of disasters and endeavor to predict and produce early warnings of disaster. The Agency for Technical Cooperation and Development (ATCD) established the drought early warning system in Uganda and Kenya and led community-managed disaster risk reduction throughout Africa and Asia to reduce the vulnerability of populations [25]. The Group on Earth Observations (GEO) is a body tasked with "understanding, assessing, predicting, mitigating, and adapting to climate variability and change" and "improving weather information, forecasting and warning" [26]. The GEO does this by strengthening and integrating existing warning systems in order to provide global warning systems for drought, famine, wildfire, hydrometeorological hazards, and disease [27]. PreventionWeb (http://www.PreventionWeb.net) is a compendium of resources for disaster prevention.

The 1990s were designated by the UN as the *International Decade for Natural Disaster Reduction* (IDNDR). The UN Office for Disaster Reduction was opened in 1999 with the mission to coordinate disaster response and develop early warning systems [28]. In 2006, the *Developing Early Warning Systems Checklist* was implemented for use by communities in disaster preparedness aimed to make substantial gains in the education and empowerment of local communities, build capacity, reduce vulnerability, detect hazards early, and reduce risk [29].

2.3 Terminology Used in Disaster Management

Central to understanding the epidemiology of disasters is familiarity with the terminology used in disasters. The disaster equation in Fig. 2.3 [30] highlights some of the terminology used. Other terminology relates to the Disaster Management Cycle (Fig. 2.4 [30]) and to disasters related to conflict.

Disaster Risk and Disaster Equations

$$\textbf{Disaster Risk} = \textit{Hazard} \times \textit{Exposure} \times \frac{\textit{Vulnerability}}{\textit{Capacity}}$$

$$\textbf{Disaster} = \textit{Hazard} + \textit{Vulnerable People}$$

Risk= *the possibility of loss, injury, death or other consequence*

Hazard= *a destructive phenomenon or event*

Exposure= *duration and/or extent of a hazard*

Vulnerability= *susceptibility to damage or harm by a hazard*

Capacity= *the ability to respond to needs created by a disaster*

Fig. 2.3 Disaster risk equations and current terminology in disaster management. Reproduced with permission [30]

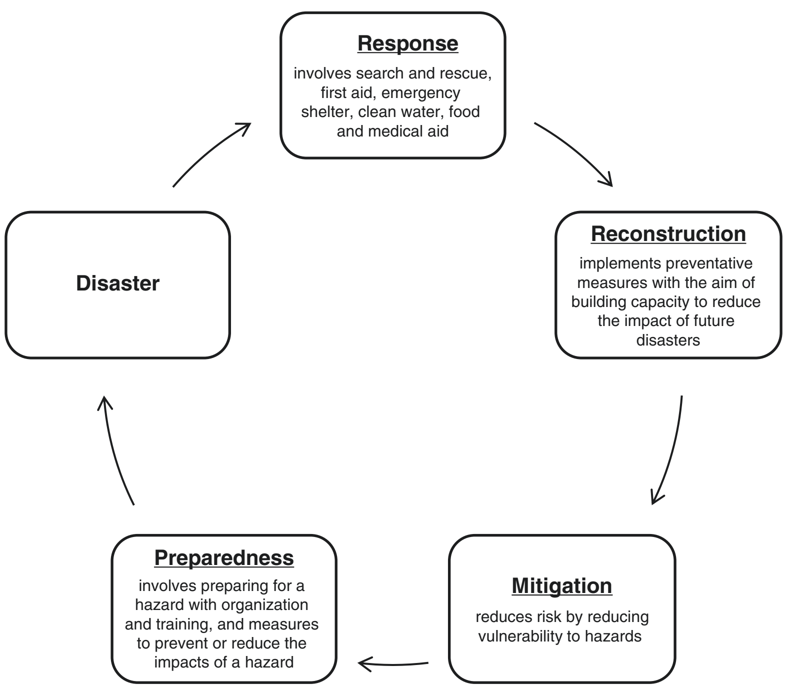

Fig. 2.4 The disaster cycle [See section 2.3.4]. Reproduced with permission [30]

2.3.1 Hazard

A hazard may precipitate a disaster. UNISDR defines a hazard as a *dangerous phenomenon, substance or human activity resulting in the loss of life or injury, damage to property, the loss of livelihood and public services, social and economic disruption, or environmental damage* [31]. Natural hazards include earthquakes, tsunamis, floods, avalanches, cyclones, epidemics, and plagues. Man-made hazards include famine, the displacement of populations, and industrial or transport accidents [32].

2.3.2 Vulnerability

Vulnerability describes the circumstances of a community exposed to the effects of a hazard. Poverty and conflict are some of the environmental and social factors crucial to the vulnerability of a community.

2.3.3 Capacity

Capacity is directly related to preparedness and describes the ability of a community to withstand disaster [33]. As we discuss later in this chapter, building capacity is fundamental to the development of nations, the empowerment of communities, and the prevention and resolution of conflict. Political stability and economic progress are integral to infrastructure and not only maintain but, ultimately, protect populations. The difference in impact of a hazard in a developed versus a developing nation is commensurate to the level of development and infrastructure.

2.3.4 Disaster Cycle

2.3.5 Mass Casualty

Disasters result in mass casualty because medical and supportive services become overwhelmed.

2.3.6 Humanitarian Crisis

Any event that threatens a large community of people, especially to such an extent that an international response beyond the mandate of a single agency or country is required, is referred to as a humanitarian disaster or humanitarian crisis [34].

2.3.7 Complex Emergency

A complex emergency ensues when disaster and conflict are superimposed. These situations are characterized by extensive violence and loss of life; displacement of populations; widespread damage to societies and economies; the need for large-scale, multifaceted humanitarian assistance; the hindrance or prevention of humanitarian assistance by political and military constraints; and when there are significant security risks for humanitarian relief workers [34].

2.4 Factors That Influence the Epidemiology of Disasters

The study of the epidemiology of disasters has taught us that hazards are often rooted in history and linked to climatic and seismic changes. Populations exposed to these hazards are made vulnerable by political instability, poverty, and other circumstances that reduce their capacity to cope.

2.4.1 Climate Change

The debate implicating climate change in the incidence of disasters continues but there is evidence that extreme events are related in part to climate change.

> There is low confidence in observed trends in small spatial-scale phenomena such as tornadoes and hail; there is low confidence in any observed long-term (i.e., 40 years or more) increases in tropical cyclone activity (i.e. intensity, frequency, duration); there is medium confidence that some regions of the world have experienced more intense and

> longer droughts; …there is limited to medium evidence available to assess climate-driven observed changes in the magnitude and frequency of floods at regional; …it is likely that anthropogenic influences have led to warming of extreme daily minimum and maximum temperatures at the global scale […and to] increasing extreme coastal high water due to an increase in mean sea level. [35]

From 1956 to 2005, the number of disasters has risen tenfold and the consequent economic losses have increased 50-fold [35]. Global temperatures are expected to rise 2–4 °C in the coming century [36] and all indications are that this will have a disproportionate effect on populations vulnerable to the extremes of climate (e.g., drought and floods) and areas already poor and dependent on small-scale subsistence agriculture, such as equatorial Africa [2]. The Intergovernmental Panel on Climate Change [37] has reported an increase in the flooding of rivers, an increase in the number and intensity of Northeast Atlantic extratropical cyclones, and an increase in the intensity of tropical cyclones. These changes, should they continue until 2100, will lead to North America suffering damages of 26 billion USD every year, East Asia suffering damages of 15 billion USD per year, and the region of Central America and the Caribbean suffering 10 billion USD in damages per year [38]. In terms of the loss of life, these storms will be catastrophic if poor countries are not assisted in the development of infrastructure, disaster mitigation, and disaster preparedness.

The disasters of climate change are not confined to "natural" devastation. Ongoing conflict in the Sudan has been attributed to increasing drought and desertification. The region of Darfur is beset with complex social and political problems, exacerbated in turn by population growth in an area of exploited resources with major long-term reduction in rainfall. Lasting peace is threatened in the region unless long-term food and water security can be attained, specifically for the rural populations in the growing desert of the North [39].

In terms of disaster mitigation, the World Meteorological Organization's (WMO) early warning systems seem to have made a difference. In spite of the rise in disasters over a 65-year period, "the reported loss of life has decreased from 2.66 million (over the decade 1956–1965) to 0.22 million (over the decade 1996–2005), due, in particular, to increasingly accurate early warnings." The objective of the WMO is "to reduce by 50 %, by 2019, the associated 10-year average fatality of the period 1994–2003 for weather-, climate- and water-related natural disasters" [35].

2.4.2 Urbanization and Deforestation

In the next few decades, most of the world's population growth will be in urban areas in low- and middle-income countries. As disasters increase, these urban dwellers become more and more vulnerable to disaster damage. According to Brown, humanitarian assistance director of Global Communities,

> The urban family is hit disproportionately hard by disaster because those items the family most needs are increasing in price at the same time when the family has less money to spend on them. The urban poor, particularly migrants, often lack financial social and physical assets (i.e. money, connections and property) to rely upon when there is a reduction of or interruption in income or when a price shock reduces the purchasing power of that income. Urban livelihoods patterns are oftentimes more complex and interrelated than farm-based rural livelihoods and rely on the functioning of markets. [40]

Urbanization has also been tied to deforestation [41]. As populations expand, they increase the demands on agriculture and housing, causing the conversion of forest into farmland and homes [42]. Unabated, this will eventually cause land exhaustion and soil erosion. The potential consequences are famine and large-scale flooding [43] (Fig. 2.5).

2.4.3 Poverty

"Poverty is the single most important factor in determining vulnerability: poor countries have weak infrastructure, and poor people cannot afford to move to safer places" [44]. Many of the factors and vulnerabilities we go on to discuss are exacer-

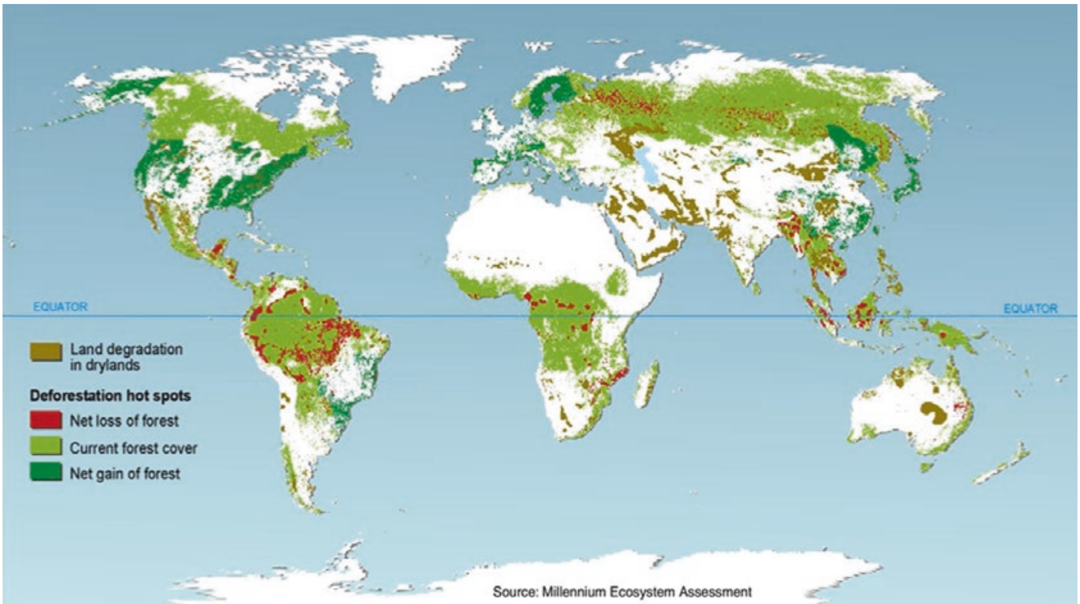

Fig. 2.5 Current state of deforestation. Reproduced with permission [77]

bated by poverty and in turn poverty is what results after decades of conflict, political turmoil, economic sanctions, and trade and commercial exploitation. In the Indian Ocean Tsunami of 2004, it was the most impoverished populations who were impacted the most [45]. Already poor, rural fishing communities on the coast lost even the basic resources essential to their survival in countries where incomes are relatively low, poverty is high, and economically marginalized populations continue to increase; the tsunami only exacerbates these problems, thus contributing to increasing disaster vulnerability in the region [45].

2.4.4 Political Instability

Despite warnings almost a year earlier, in June 2011, the US Famine Early Warning [46] System said of the famine in East Africa,

> This is the most severe food security emergency in the world today, and the current humanitarian response is inadequate to prevent further deterioration [46].

Seven million people in East Africa were in danger of starvation, a number that would swell to at least 13 million by the end of the year [46]. In Ethiopia and Kenya, the response to the famine came earlier than in the past, and was also more efficient than in the past, in spite of a lack of preparedness leaving Kenya with little warning, or the opportunity to scale up the 2012 Hunger Safety Net Program [47]. In Somalia, on the other hand, the absence of a central government accompanied by the rise of militant groups and clan-based violence led to the extreme severity of the famine. This prevented accurate reporting and media coverage, prevented the migration of populations to safer locales, and prevented the access of aid organizations to the populations in most urgent need. The Somalia famine "was not a natural phenomenon, but rather the product of human-made factors, including lack of governance, political instability and conflict" [48]. In central Somalia alone, 260,000 deaths are estimated to have occurred due to the famine [49].

2.4.5 Conflict

Figure 2.6 illustrates the rise in global conflict over the last century. Civilians have become the main casualties of war. Civil wars and intrastate

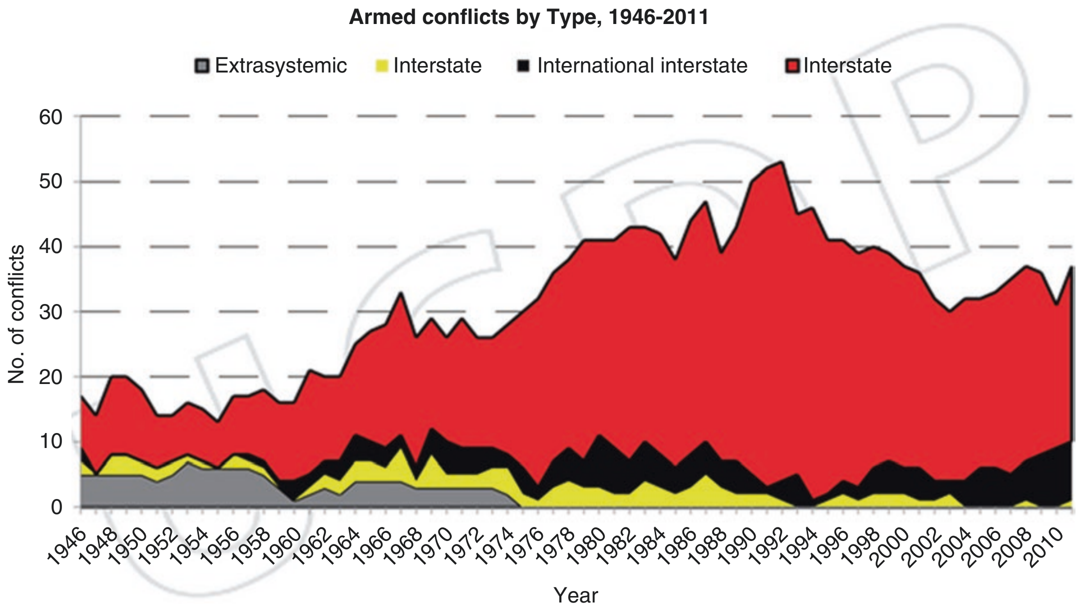

Fig. 2.6 Rate of types of armed conflict in the years 1946–2011. Reproduced with permission [50]

insurgency far exceed the number of conflicts between nations. The economic viability of nations at war is catastrophically affected by prolonged political instability and a failure of long-term investment and development [50]. It is said,

> In situations of weak states, unequal distribution of resources, unstable social relations, a history of violence, and the existence of continually excluded subordinate groups, the emergence of mobilized resistance or 'political entrepreneurs' who organize for violent conflict is more likely to occur. The consequences may be political breakdown, civil war, inter-group riots, acts of violence, mass protests against the state, and in the worst instances crimes against humanity. [51]

Superimposed on conflict and poverty is the complex emergency—catastrophe born of conflict and compounded by what might, at first glance, appear to be natural disaster—rains that fail which result in drought and famine, in actuality, arising from decades of underinvestment, poverty, and political strife.

Scheumer-Cross [9] described the devastating effect of conflict on the public-health infrastructure in the Democratic Republic of Congo. In 2007, 57 % of the population had no access to safe drinking water and 54 % lacked access to medical services. And, somehow, in the study of disasters, we see conflicts continue. As Alix-Garcia says of Sudan,

> If land and resources were not the initial cause of the conflict, they have certainly been manipulated so as to perpetuate it [52].

The resulting mass displacement of peoples, urbanization, growth of slums, destruction of state institutions, unemployment, criminality, violence, and despair ensure that the capacity to cope with disaster is diminished [10]. The ethnicity of the vulnerable population is sometimes no accident. Harris says,

> In some situations, the government may be party to a conflict, inherently politicizing its decision making about how it manages disaster risk…. In certain contexts, governments neglect particular regions or ethnic groups, making them more vulnerable to the effects of a disaster [53].

2.4.6 Migration and Displacement of Vulnerable Populations

The Internal Displacement Monitoring Centre estimates that during 2012, 32.4 million people were displaced worldwide by disasters, with

98 % of displacements related to climate and weather hazards. Ninety-eight percent of those displaced were in developing countries [54], most of whom are women and children [55]. At the moment the UN estimates that 8,000 people are leaving Syria every day. They join 2.2 million registered refugees already outside the borders. The effect on bordering nations is significant and in itself constitutes a humanitarian emergency. Inevitably, as Kett [55] predicts, tented camps, temporary settlements that may become permanent, and even private residences, as we see in Lebanon, where several families are put up in a single house, suffice as shelter. The burden on host countries may be overwhelming—the Al-Zaatari camp in Jordan alone costs half a million USD every day to run and is itself in crisis, difficult to manage, difficult to police, and expanding every day [56].

Myanmar has seen decades of multiethnic conflict. The emergence of further ethnic conflict as democracy takes hold has seen attacks on ethnic Rohingya where over 140,000 people were displaced a year after the 2012 intercommunal violence. Their exposure to the cyclones that periodically hit coastal Bangladesh and Myanmar places them in harm's way. They do not have any place to go. Due to the lack of suitable land for shelter, the UN Refugee Agency (UNHCR) has had to build shelters on stilts over rice fields. These displaced people are more vulnerable to the coming rains and floods than the normal population [57].

2.4.7 Failure of States to Develop Post-conflict

In Haiti in the early 1990s, arming sections of the youth became a "favored political strategy" for rival political factions keen "to protect their political and economic interests." Violence flared significantly in the 2006 elections, during which "children were recruited to carry weapons and drugs, women were raped and kidnapped as sex slaves, and innocent civilians were caught in the crossfire of gang wars and turf battles." In response, the Haitian National Police and the UN Mission cracked down on gang leaders, a coalition government was formed, and international donors began to fund development projects within the country. Some neighborhoods were neglected, further fueling tensions and slowing progress. This failure to adequately develop was further complicated by the devastating 2010 earthquake. Prisoners escaped and violent criminals returned to their neighborhoods. An understaffed police force was overwhelmed by the reemergence of violent crime, fueled by intense poverty and destruction of property [58]. "Many of the chronic human rights problems [were] exacerbated by the quake, including violence against women and girls, inhuman prison conditions, and impunity for past human rights abuses" [59].

2.4.8 Global Finance and Trade Agreements

Exactly how global finance keeps developing countries poor is complex. A range of financial forces conspire to keep populations poor: high interest borrowing and lending, national debt, unfavorable trade agreements, punitive economic policies, lack of investment, economic exploitation, political sanctions, political alliances with governments, and corruption. We know that political stability and disaster are inevitable consequences.

Developed nations (the G8) follow a capitalist economic model. Free-market economics aims to make money through smart investments. Foreign investments benefit from resources in developing countries that are easy to exploit and form a large semiskilled labor force, inexpensive to employ. The governments of developed nations directly help poor nations for strategic reasons (access to minerals, oil, and geopolitics to maintain an advantage in the "community of nations"). Financial investments are usually administered by the government of the developing nation. The International Monetary Fund (IMF) and the World Bank seek to make sound long-term investments in infrastructure, but they typically have to pay foreign companies to execute infrastructure projects. The resulting flow of capital is, therefore, to provide the best return for investors, not to help the poor. Those nations that want to emerge from poverty require a stable government that invests in its people. In recent years the one scheme that has had meaningful impact on the poor is micro-finance: the money went directly to the poor.

After the financial crises in the 1980s and 1990s, the World Bank began the promotion of foreign ownership of national banks in developing countries, with the purpose of increasing lending to the private sector and building infrastructure within developing countries. In reality, however, foreign banks are more likely to avoid risky investments and put money into government projects instead of long-term, high-risk investments such as manufacturing. It has also been shown that foreign banks tend to lend in foreign currencies, which causes the export of savings from developing countries, economic dislocation, and higher levels of economic instability [60]. Since 1999, poor countries that are seeking concessionary loans and debt relief have had to submit Poverty Reduction Strategy Papers. These schemes started with good intentions, i.e., increasing personal ownership and promoting economic partnership, but they have failed because of a focus on the discussion and development of plans rather than their implementation, operation within depoliticized "pseudo-realities" where donors assumed that whatever was decided would be what is implemented, and legislation that countries had no interest in enforcing [61].

Free markets also ensure capital flight (i.e., investment, human resources, and the educated flee the country) and low wages, and corrupt governments work to expand profit margins at the expense of developing the nation. In Free Trade Agreements, "each country retains its own external tariffs vis-a-vis the rest of the world, while simultaneously admitting goods produced in the two partner countries duty-free" [62]. These agreements are favorable for two equivalent economies, promoting partnership and increasing trade. Some imbalanced Free Trade Agreements, however, prevent poor countries from development. "The richer, stronger economy always wins—particularly in Free Trade Agreements (FTAs), which often remove the poor country's right to use tariffs and quotas to protect its own industries and farms from cheap imports" [63]. This can be seen in the Free Trade Agreement signed between the United States, the Central American countries, and the Dominican Republic. "The consequences for Honduras have been terrible: the number of rice producers has dropped from 25,000 to fewer than 2,000; employment, direct and indirect, has fallen from 150,000 jobs to 11,200; production has contracted by 86 % in 11 years; food dependency is now over 90 %; and hard-currency expenditure on rice imports has risen from $1 to over $20 m annually" [64].

2.4.9 Failure of the International Community and Humanitarian Aid

Far too often, international aid is judged by its intentions and not by its effectiveness, especially in the long term.

> Instead of breaking the "endless cycle of poverty," foreign aid has become the opiate of the Third World. [International donors] have encouraged Third World governments to rely on handouts instead of on themselves for development. No matter how irresponsible, corrupt, or oppressive a Third World government may be, there is always some Western government or international agency anxious to supply it with a few more million dollars. By subsidizing political irresponsibility and pernicious policies, foreign aid ill serves the world's poor. [11]

A failure of accountability for funds given in humanitarian aid may result in funds being used to increase arms purchases [65], to support corrupt governments [66], and to fail the very people humanitarian agencies seek to serve—the vulnerable. In the 1980s, the governments of both Ethiopia and Congo sold humanitarian food supplies in order to increase arms production [12]. In 2008, the World Bank and a United States oil consortium ended a partnership with the government of Chad because the government was spending increasingly greater amounts of the profits from the partnership on military expenditure and not on poverty reduction within the country, despite earning over $1 billion in 2008 alone [67]. According to one NGO leader, "The damage has already been done…Chadians can only now cry because the oil money has not contributed to improving their living conditions but rather to fuel armed conflict" [68].

Humanitarian aid has lacked accountability, and the data regarding aid accountability remains remarkably slim [69]. The UK's Department for International Development and the US Agency for International Development have been funding Ethiopia's "Protection of Basic Services" program, which is being used for the forced resettlement of tribal peoples. These populations are being moved for the construction of the Gibe III Dam and land grabs for plantations. Survival International reports that half a million tribal people in Kenya and Ethiopia are likely to be adversely affected by these projects. The British and American populace has remained silent on these issues [70]. These consequences may be broadened to the effect of aid on a more international level. Despite over 1 trillion USD in aid delivered to sub-Saharan Africa, living conditions have not drastically improved over the past 50 years. "Such failings can be explained by corruption in aid agencies and African governments. The consequence is that income is being redistributed from the poor to kleptocratic elites, creating corruption-poverty spirals. Foreign aid can then be counter-productive" [71].

While their financial donations may support corrupt regimes, humanitarian aid organizations, both governmental and NGOs, are not themselves immune to the corruption that accompanies any position of power. In 2010, the amount of humanitarian spending was estimated at almost 17 billion USD [72]. This corruption was visible in Save the Children's response to the 2004 Indian Ocean Tsunami. Having hired corrupt contractors who built flimsy, unsafe housing, the NGO was left with hundreds of houses left to build. This resulted in an anti-corruption committee for the organization that inspected 44 cases with 39 cases resulting in termination or prosecution [73]. Some NGOs, however, remain closed off to the idea of being public about corruption cases for fear of donors hesitating to give to them [72].

Conclusion

During the Ethiopian famine from 1983 to 1985, Michael Buerk's news report [74] that described the situation as "hell on earth" shocked the world, and images of starving men, women, and children galvanized the public into action. Through donations, an unprecedented £50–70 million (78–109 million USD) was raised and high-profile charity events such as the Band Aid concerts and albums kept the famine in the public consciousness. Famine, however, had been predicted up to 18 months in advance, and Hugh McKay, director of Save the Children, asked what we might all have wondered, "How much lead time does the world's conscience really need?"

The BBC news report described the famine as "biblical." David Rieff looked back, "The hunger was thus an affliction, the result of age-old poverty and of a drought that was the product of nature, not human beings" [75]. The root causes of the famine were the political instability and conflict between the government and rebel forces and that aid money generated helped to fund a forced resettlement of 600,000 people, something that was "at least in part a military campaign, masquerading as a humanitarian effort" [75].

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3 Warfare Medicine: Historical Perspectives

Katarina Silverplats

3.1 War-related Orthopedic Injuries

3.1.1 Introduction

The need for surgical care of survivors after warfare is part of the story of civilization [1]. Military conflicts are often characterized by specific injuries or pattern of wounding [2]. Throughout the history of warfare, changes in weaponry have produced changes in the nature of war-related injuries [3]. Depending on what kind of weapon and protection used, the injuries and number of survival differ. When weapons technology improved, surgeons were forced to rethink their interventions and treatment to make more soldiers survive [1].

The introduction of gunpowder in European warfare in the fourteenth and fifteenth centuries marked a new era of wound patterns and managements of wounds [5–7]. In recent conflicts this has been replaced by fragmenting and explosive weapons causing blast injuries. The improvised explosive device (IED) has been extensively used in current conflict in Afghanistan. The injuries caused by IEDs are very extensive and complex thorough a combination of the blast wave, penetrating fragments, and rapid body displacement. The most severe injury caused by IED considers being the open blast fracture to pelvis. These injuries are almost often associated with multiple trauma injuries [2, 8, 9].

Of the traumatic orthopedic injuries presenting today, approximately 50–77 % of war wounds are musculoskeletal injuries [5, 10–16].

Combat-related spinal injuries have been recorded since ancient Greek and Egyptian warfare [18]. However, until the introduction of gunpowder, most combat-related spinal injuries were immediately fatal or untreatable. In conventional recent warfare (Korea, Vietnam, Gulf War I), the incidence of spinal injuries remained close to 1 % of all combat casualties [19].

In the current conflicts of Operation Iraqi Freedom and Operation Enduring Freedom, spinal combat casualties accounted for 7.4 % of all casualties. Most of these injuries (83 %) resulted from explosions reflecting modern warfare with IED-related blast injuries [20].

3.1.2 Ancient Warfare BC

The documentation of military medical history begins with the war between Sumer (current Iraq) and Elam (current Iran) in 2700 BC near Basra. It is believed that the Sumerians were the first to develop the idea of professional soldiers. The earliest written records of wound treatment

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_3

were found in Sumerian carvings [4]. This period of history was marked by almost constant wars following a major development in military technology and armament. The first historical evidence of soldiers wearing helmets, made of copper, appeared during this period. The helmet was developed for protection against "the mace" the oldest effective weapon of war [21]. It was the first weapon designed specifically for killing humans. A mace is a blunt weapon formed as a club that uses a heavy head on the end of a handle to deliver powerful blows. The first mace used caused blunt trauma and head injuries. When armament for the soldiers developed with body armor the head of the mace was shaped with flanges or knobs to allow greater penetration of plate armor. When the armament became more effective, it drove the mace from the battlefield.

The sickle-sword replaced the mace and became the primary weapon of the Sumerian and Egyptian armies. To protect the soldiers against the new weapon, development of the first body armor, called "armored cloaks" was made. The cloak was produced of either cloth or thin leather sowed with metal disks with raised spines. It was the first representation of body armor.

In the Trojan War between 1260 and 1240 BC, wounding patterns and outcome were correlated with mechanism of injury. The mortality for injuries because of swords was 100 %, for spears 80 %, for slingshots 67 %, and for arrows 42 %. These high mortality rates suggested that surgeons were unable to treat the soldiers close to the point of injury [4]. They could only treat those who survived after the battle had concluded, comparable with the concept "Golden Hour" that means the patient has to receive resuscitation within the first hour after a severe injury [22].

Hippocrates, "the father of medicine," lived during the Persian War (499 BC–449 BC). He stated that war was "a proper school for surgeons and he who would become a surgeon should join the army and follow it" [23]. He was one of the first to describe amputation of an extremity. He also used traction for treatment of fractures [24].

3.1.3 Warfare AC

Gunpowder was introduced in the fourteenth and fifteenth century. It was first used in the battles at Algeciras (1344–1368) and caused more complex injuries with raised prevalence of shattered extremities, associated burns, and complicated wounds. Weapons used earlier had been able to penetrate skin and soft tissue but not enough force to break bones [4, 7].

In the sixteenth century, the development of firearms in conventional warfare dramatically increased the severity and complexity of battle injuries [3]. Gunshot wounds caused severe gross tissue destruction and open fractures. These wounds were often contaminated with foreign material such as in driven clothing, armor, missile material, bone, and wood.

Most of the soldiers were killed in action, but for the survivals the destructed, contaminated tissue was an excellent medium for infection [1, 24].

Throughout the 1700s, surgical intervention focused on management of soft tissue injuries, control of bleeding, repair of muscles, reduction of dislocations, fracture alignment by splinting, and avoidance of sepsis [25].

Primary amputation, because of infected gunshot wounds and complex fractures, was the recommended solution as lifesaving military surgery through the sixteenth to eighteenth centuries [26].

3.1.3.1 Napoleonic War (1803–1815)

Most wounds during the Napoleonic war were either from musket balls or cannons. Unrifled muskets caused mostly localized injuries. However, cannons, canisters, and bombs were effective and led to extensive shattering of wounds associated with high rate of amputations. Dominique Jean Larrey, Napoleon's chief surgeon, believed that an immediate amputation in the most forward surgical areas was the only real choice for soldiers who had suffered badly broken bones. Statistics from the war shows that of all the men who underwent post-battle amputations, only a third of them survived [25, 27].

3.1.3.2 The American Civil War (1861–1865)

Because of better weapons, better transport and better surgery the American Civil War became a turning point in the history of military medicine. Anesthesia with ether or chloroform became standard and organizations for the transport and care of casualties were developed [25, 27]. Nevertheless there were lots of catastrophic injuries caused by the slow-moving Minié Ball (cylindrical lead bullet) used during the war. When it hit bone, it expanded and caused large, gaping holes, splintered bones, and destroyed muscles, arteries, and tissues beyond any possible repair, resulting in massive amputations or death. Almost 70 % of projectile wounds involved an extremity and of those 30 % resulted in amputation [3]. Those shot with them through the body, or the head, would not be expected to live. If the soldiers survived, the delay for treatment could be a day, maybe two, allowing the wounds to become infected. The most common surgery in the American Civil War was amputations; more than 50,000 amputations were performed. They also attempted the first open reduction, in fractures, using internal fixation [25].

3.1.3.3 Boer War (1899–1902)

Boers used German Mauser rifles which were known for creating clean wounds with lesser tissue destruction, paradoxically rendering small-arms fire less damaging to the tissue. In addition, the very dry, infertile soil carried a lower bacterial load than was typical of cultivated areas where European battles were typically fought, so secondary tetanus and gangrene were less common.

Amputation rate was not as high as in earlier warfare. British Army surgeons found that mortality and morbidity were lower if the wounds were left open and if limbs remained attached rather than being amputated [3, 27].

3.1.3.4 World War I (1914–1918)

During the industrial revolution, the development of weapons dramatically increased.

World War I became known as the "machine gun war." After shrapnel wounds, the massive killer was undoubtedly the machine gun which was called at the time "the most murderous weapon ever invented" and it is estimated that fully 80 % of all British ground casualties were caused by the machine gun. The death rate of femur fractures caused by battlefield injuries was approximately 80 %. The British orthopedic surgeon Robert Jones introduced his uncle's splint (Thomas splint) to immobilize the fractures in battlefields. Thanks to that the mortality rate due to femur fractures was reduced to approximately 20 % [28].

Numerous advances in surgical techniques occurred during World War I. Debridement of complex wounds, followed by open treatment with antiseptic techniques and delayed closure, became so refined that amputation rates decreased dramatically during the war [4, 29]. Surgeons also started to repair joint injuries as an alternative to amputation [25]. The need for rapid surgical care of war wounds was confirmed. Fast evacuation from injury scene to surgical treatment was associated with improved outcome [29]. The invention of X-ray, by Wilhelm C. Roentgen, helped in the management of trauma injuries [4].

3.1.3.5 World War II (1939–1945)

Advances in triage and transport, management of shock, and treatment of infectious diseases marked World War II. The introduction of antibiotics and progress in surgical techniques distinguish trauma treatment in World War II. Lessons learned during World War I were applied in World War II, including delayed primary closure, pedicle flaps, and external fixations for fractures [4, 27].

Medics were trained and equipped to control blood loss and administrate analgesics at the injury site. Thanks to development of vascular surgery and research about the metabolic response to trauma, many life and limbs were saved. The British started a national blood banking program, a collection, and storage system and Soviet scientists showed that plasma could be effectively used to treat patients in shock. As the war progressed, use of whole blood to treat shock became more prevalent [27].

Antipersonnel mines were first used on a wide scale in World War II. Stepping on a blast antipersonnel mine caused foot and leg injuries and secondary infections usually resulted in amputation. For amputated patients, many post-war amputation centers were built. In the centers research on both development and use of prosthetics is housed.

3.1.3.6 Korean War (1950–1953)

The Korean War led to numerous advances in medical system and patient treatment. Body armor that would allow mobility and protection was developed and widely used for the first time [31]. Helicopters were used for the first time in warfare to transport patients directly to the Mobile Army Surgical Hospital (MASH). Time from injury to surgical treatment decreased; 58 % of soldiers wounded in battle received medical care within 2 h of injury and 85 % were treated within 6 h. Vascular surgery with use of vein grafts to repair arterial injuries became routine in Korean War reducing the amputation rates to its lowest level in twentieth-century combat [4]. Resuscitation with whole blood transfusions increased during the war for patients in shock. Unlimited amounts of whole blood were available everywhere for the first time in the history of warfare [27, 29]. The mortality rate because of battle wounds dropped to 2.4 % comparably with 4.5 % in World War II [4, 25]. The most common battle injuries were penetrating wounds (57 %) and fractures (23 %). Combat medics started to resuscitate wounded before they were transported with helicopter. To control bleeding, tourniquets or pressure dressings were applied. Fractures were splinted and immobilized [1]. Surgical debridement within 2 h of injury and every 48–72 h was performed and the wounds were left open. The level of soft tissue injury and not the fracture level determined the amputation level.

Thousands of American veterans suffered frostbite during the extreme cold temperatures in Korea during the war years. The main objective for the surgeons was to save the black and gangrenous limbs of their patients from the amputations that would have been almost automatic during World War II. They concentrate on maintaining circulation in the damaged part. Where whole hands would once have been amputated, fingertips were now removed [30].

3.1.3.7 Vietnam War (1959–1975)

Continued advancements occurred in the management of combat casualties in the Vietnam War. Medical support was well organized from the beginning of the war, resulting in the best medical care of combat wounded ever recorded. Patients received emergency treatment on the battlefield, including hemorrhage control, wound dressing, respiratory control, and often intravenous fluid administration. Routine helicopter evacuation from battlefield reduced time from injury to surgical treatment by 1–2 h. The first "critical care air transport" was used 1966, focused on burn care [16]. Thirty-one percent of wounded arrived at hospital within 1 h and 86 % within 4 h [4, 29]. The majority of wounds were caused by high-velocity small arms, from mines and booby-trap bombs, 67 % of injuries involving the extremity. Orthopedic surgeons tried to classify wounds initially on the basis of the weapons causing them. Bullets caused wounds varying in severity from small soft tissue punctures to complete destruction and amputations of limbs. Uncomplicated perforating soft tissue wounds were the most common. Fragment wounds were mostly caused by grenades, known as "pepper-pot" injuries, causing fractures and damage to soft tissues, nerves, and vessels. Land mine injuries were very common and caused damage to the extremity by blast. These injuries were the worst and caused extensive damage to bone and soft tissue, shattering of the talus was common, and bacterial contamination was a serious problem. General principles for treatment were adequate wound excision, adequate drainage, immobilization, antibiotic therapy, and secondary closure [17].

3.1.3.8 Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (ODI)

Advances in medical care and improvements in both body and vehicle armor have in combination increased a wounded soldier's odds of survival, from 76.4 % during the Vietnam War to 90.4 % in Iraq.

Extremity injuries continue to account for the majority of all combat wounds [10, 32]. About 75 % of all wounds sustained in OIF and OEF are caused by explosive weapons, such as IED, landmine, mortar, bombs, and rocket-propelled grenades [11, 14]. About 50 % of wounds are penetrating injuries and half of them are fractures, of which 82 % are open [32].

Traumatic lower extremity amputation caused by IEDs has become the signature injury of the conflict in Afghanistan [9]. It has also been an increase in number of casualties with very proximal traumatic lower extremity amputations with associated pelvic trauma [2].

Despite the injuries, often IED related, surgeons try to do “limb-saving surgery” instead of primary amputation.

3.2 Military Health System

3.2.1 Introduction

Historically during conflicts tremendous medical advances have been made to save lives of many soldiers who otherwise would have died at the combat fields [33].

The term “role” or “echelon” is used to describe the stratification of the different levels in which medical support is organized. The terms are closely related but not exactly interchangeable. The patient may not necessarily pass through each level of care during treatment and evacuation.

3.2.2 Role I–IV Levels of Care for NATO

Role 1 medical support: A small unit that includes the capabilities for providing first aid, immediate lifesaving measures, and triage. It will also contribute to the health and well-being of the military force through the provision of guidance in the prevention of disease, non-battle injuries, and operational stress.

Role 2 medical support: Normally provided at a larger unit and farther forward, depending upon the operational requirements. It will be prepared to provide evacuation from Role 1 facilities, triage and resuscitation, treatment and holding of patients until they can be returned to duty or evacuated, and emergency dental treatment.

Role 2+ level medical support: Capabilities to perform emergency surgery and essential postoperative care.

Role 3 medical support: Provided by field hospitals of various types. It includes additional capabilities, including specialist diagnostic resources, specialist surgical and medical capabilities, preventive medicine, food inspection, dentistry, and operational stress management.

Role 4 medical support: Provides definitive care of patients. This level of care is highly specialized, time consuming, and normally provided in the country of origin. It comprises surgical specialists, medical procedures, reconstruction, rehabilitation, and convalescence [34].

3.2.3 Echelons I–V of Care for US Forces

Level I Echelon of Care: Combat medic and Battalion Aid Station. The first medical care a soldier receives is provided at this echelon. Medical care is provided by an individual (self-aid, buddy aid, combat lifesaver, or combat medic) or by personnel in a treatment squad and consists of immediate first aid and transport. First aid include treatment of exsanguinating hemorrhage (early tourniquet and application of topical hemostatic) and pneumothorax (needle decompression), maintaining the airway (oral intubation, cricothyroidotomy), preventing shock, protecting wounds, immobilizing fractures, and other emergency measures, as indicated.

Triage outcome at level I is either return to duty with treatment needed or evacuate from the battle zone to the level II echelon of care.

Level II Echelon of Care: Forward surgical center or FSC of the field hospital. Life- and limb-saving surgery is done in this level. Evacuation to level III care occurs as soon as possible, within 24 h, after treatment.

Level III Echelon of Care: Provides the highest care in the combat setting for the US forces and are capable of further definitive care. Level III provides triage, resuscitation, transfusion, initial surgery, definitive and reconstructive surgery, and postoperative and intensive care. From this level the patient either return to duty or is evacuated within 48–72 h to level IV echelon of care.

Level IV Echelon of Care: A definitive surgical capability within the actual theater of war but outside the combat zone.

Level V Echelon of Care: Major trauma center with teaching and research, highly specialized, provides reconstruction, rehabilitation, and convalescence [35].

3.2.4 Development of the Military Field Hospital

Field hospitals are mobile medical units that temporarily take care of casualties on-site before they can be safely transported to more permanent hospital facilities. From the beginning it consisted of shelters near the front lines and in later years developed into containerized modules comparable with civil hospitals. The oldest precursor of field hospitals was provided by Spanish Queen Isabella in the end of the fourteenth century during the war of Iberia [27].

In the Battle of Fontenoy (1745), the British army provided the first "flying hospitals." Tents with surgeons were arrayed behind the line of battle, waiting for the wounded. Still the problem was to transport the wounded to the hospitals.

The change in field hospital during the nineteenth century was their increased use for performance of more complex surgical procedures.

Evacuation of wounded in battle was a major headache for all armies of the Napoleonic era.

Usually the injured had to be left on the field until after the battle was over and even then evacuation was slow. Many men died agonizing deaths after lying injured on the field for hours or days [33].

Dominic Jean Larrey, war surgeon in the Napoleonic army, introduced the "ambulances volantes" (flying ambulance) for transport of wounded from the battlefield to the surgeons. He designed horse-drawn wagons contained equipment necessary to perform surgical procedures and placed them close to the front line. These "ambulances volantes" were precursors to the field hospitals that originally were called ambulances [5, 36]. Thanks to the mobile hospitals, mortality in battlefield decreased in Napoleons armies [5, 37].

Jonathan Letterman, Medical Director of the Army of the Potomac, American Civil War, is known today as the "father of battlefield medicine." He established mobile field hospitals to be located at division and corps headquarters. His system enabled thousands of wounded men to be recovered and treated during the American Civil War [1, 24].

In World War I the field hospitals consisted of 100–150 beds operated in tents or in expediently buildings. They were mobile by truck and sent to the battle line to perform triage, stabilization, and evacuation to the base hospital outside the battle zone.

In the latter half of the nineteenth century, the development of anesthesia, antisepsis, and X-ray brought new opportunities for field surgery [27].

Modern field hospitals, reconfigured to Combat Support Hospitals (CSH), provide the highest care in the combat setting. It includes specialist diagnostic resources, specialist surgical and medical capabilities, preventive medicine, food inspection, dentistry, and operational stress management. Because they are large and relatively difficult to move, CSH are not the front line of battlefield medicine. CSH also have become a major element in planning for nonmilitary disasters around the world and used by civil authorities.

3.2.5 Development of the Mobile Army Surgical Hospital (MASH)

World War I gave birth to the concept of MASH. During the war it became obvious that the time of transport of patients to field hospitals was too and because of that many soldiers lost their lives. Hospital equipment and mobile surgical teams were transported in trucks across the front. Originally the

MASH units were equipped to move on their own [38]. The use of the MASH units allowed medical personnel to remain closer to the front and minimizing transport time of the wounded [39].

Dr. Michael DeBakey, surgeon in US army, was the one that established the concept of MASH. When the Korean War (1950–1953) began, new MASH units were developed rapidly to provide surgical resuscitation within 10 miles from the front line [1]. Since World War II, MASH units have been deployed in every major US military conflict.

The units continued to operate into the Vietnam War and Operation Iraqi Freedom. The 212th MASH was the last unit in the US Army [38]. Combat support hospital is the successor to the MASH unit.

3.2.6 Development of the Forward Surgical Team (FST)

The need for resuscitative surgery capability on the battlefield, easy to insert, light weighted, and transportable, led to the development of the FST. The FST is designed to provide initial resuscitative surgical support, within 1 h, to a forward combat unit on the battlefield. The FST typically includes 20 staff, surgeons (general surgeon and orthopedic surgeon), nurses (critical care, anesthetists and OR nurse), combat medics, and technical personnel. However, the number of personnel is highly dependent on the unit it is supporting. The Air Force and Army Special Operations units have used smaller versions of the FST which have extremely limited capabilities and undertake interventions only in the event of hemodynamically unstable patients with vascular injury, penetrating abdominal injuries, and penetrating chest trauma with hemothorax.

Dr. Charles Rob, surgical consultant, serving in the Royal Medical Corps in the British Army, pioneered the first airborne FST to render emergent medical services to paratroopers fighting in North Africa in World War II [40, 41]. In the US Army Medical Corps during World War II, Dr. Robert Zollinger developed mobile surgical units, more robustly built than the British FST, equipped to perform 100 surgical procedures [42, 43]. Before the US Army started to use FSTs, MASH or CSH was the only mobile surgical unit available, both located far from the front.

The wars in Afghanistan and Iraq witnessed the first widespread use of forward surgical teams [43]. Thanks to FST units, lives are saved for severely wounded casualties who would not survive evacuation to CSH or MASH level.

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4 Emergency Medical Services

Robert Dudgeon

4.1 Introduction

Emergency medical services. Prehospital care. The act of providing care to the sick and injured prior to their arrival at a healthcare facility is as old as medicine itself. What's changed over the decades is the formalization of the process and the establishment of highly trained technical experts specializing in providing short-term advanced care and transportation. Using a range of medical providers ranging from physicians to individuals trained in basic first aid, these systems have become an integral part of the modern healthcare system by bringing a predictable level of care to the field and delivering a patient with at least some level of assessment and immediate interventions already performed to a medical center. While the level of care and sophistication of these systems tend to be more advanced in first-world countries, the communities in developing countries provide what they can with available resources. It has always been the natural tendency of humans to help each other in times of need. So, while we have created a community expectation of professional prehospital care in the industrialized world, one cannot underestimate or overlook the efforts in the most remote and primitive places. If a healthcare system exists, a method to help and transport the ill and injured will have almost always evolved.

While the range of services delivered is wide and the methods are as diverse as the communities they serve, there are several aspects of providing care in the prehospital environment that transcended politics, local custom, and geography. A fair amount of ingenuity is required, there are always limitations to the care provided or the procedures performed, and finally, the environment is largely uncontrolled and providers must contend with the elements, less than ideal patient positioning and the often real risk of personal injury. All these challenges exist under ideal conditions in EMS. When factoring in mass casualties from a localized event or widespread disaster, the challenges increase exponentially and, as one might expect, the level of services degrades as resources become scarce and demand increases.

Through the course of the following pages, the intent of this chapter is to provide a snapshot of the models in use around the world, an idea of the capabilities, and finally a look at what changes one can expect during mass casualty events.

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_4

4.2 EMS: What Is It and Why Does It Concern Me?

4.2.1 Mission

The core mission of EMS has been and will always be the safe delivery of patients from where they are to medical care. Depending on resources, the overall healthcare model of a region, and technical ability of personnel, that mission can take on very different identities and be performed in a myriad of ways. Globally, everything from handcarts to helicopters move the ill and injured on a daily basis. Destinations range from world-class medical centers to clinics operating in the middle of war zones. Sometimes simply a doctor, nurse, or technician in the patient's home constitutes effective completion of the mission. It all depends on the circumstances. No one way will work everywhere.

4.2.2 Community and EMS

Local laws and customs contribute heavily to community expectation and standard of care thresholds. EMS is not a packaged, generic service that communities adopt; it's an output stemming from community expectation, societal custom, resource availability, and, yes, a little bit of medical science. It's not one size fits all – even neighboring towns can have different customs of practice that affect the overall delivery model. The reasons behind these seemingly broad disparities are mostly practical – operating in the field has always been an exercise in adaptation. The prehospital environment has equal parts chaos, luck, and skill within a framework of laws, customs, and resource availability.

Regardless of whether the personnel are world-class surgeons or the local bartenders with basic first aid training (which is a true story), working in the field poses challenges far beyond clinical presentation. In addition to the aforementioned factors of environment, location, and safety, the most basic consideration is simply that providers operate as guests in someone else's environment. There exists a delicate balance in playing the role of guest while assuming control of a scene and managing care successfully. On the street or in someone's home, medical providers are rarely in charge, usually responsible for the patient's well-being, but vested with little or no power to control assets or direct non-medical personnel to ensure the needs of their charge are considered or acted upon. More often than not, personnel must rely on the art of influence rather than power of authority.

4.2.3 Components of an EMS System

The components of an EMS system include dispatch, first responders (in some areas, especially in the United States), EMS providers, receiving facilities and specialty care centers, and a quality improvement program that studies each component, as well as the combined system, to continually evaluate and refine practices.

The focus of this chapter is on the provider level and a general overview of the care provided. However to not mention, the other components leave out key parts of EMS that combine to provide high quality care in the vast majority of instances.

4.2.3.1 Dispatch

A dispatch center is a specialized office that receives requests for service from the public, triages the patient's condition, determines the location, and assigns appropriate resources. In the modern EMS system, calls are routinely screened using criteria to determine the nature of the problem and determine the patient's acuity. Those factors then become resource determinants aimed at providing an appropriate response for the patient's condition. Understanding that information obtained on the phone or through third parties, the determinant criteria are always buffered with a slight bias for over response (more or higher level resources, faster or higher priority response) versus under response. Finally, many dispatcher centers commonly provide pre-arrival instruction to assist callers in performing lifesaving interventions such as CPR or bleeding control.

4.2.3.2 First Responders and Special Teams

In the United States, early EMS systems utilized basic technicians on fire engines to respond "first" to calls for the simple reason that often there were more fire stations than ambulances in a community. It was a stop gap measure to get basic care to a patient in advance of an ambulance. Today the practice continues in many areas and the level of care provided is often equal to that in the transport. Additionally systems have added non-transport specialty teams that assist with everything from heavy rescue and high-angle technical rescue to advanced care teams that respond when called and assist other providers with additional resources or protocols not otherwise available in the field. It's important to note that not all communities use fire-based first responders. It's entirely based on how a community organizes EMS and whether or not the local fire departments are willing to accept a medical role.

4.2.3.3 Providers

Providers are discussed in more detail later, but for general discussion purposes, provider refers to the response, treatment, and transport functions of EMS. Transport is usually provided using specialized ground or air vehicles.

4.2.3.4 Hospitals and Specialty Care Centers

Hospitals are, of course, an integral part of EMS. One might argue that the point of EMS is to extend hospital level of care to the patient's side and begin assessment and intervention sooner. In some instances this ideal continuum of care exists, particularly when discussing specialty care centers such as trauma centers or heart attack centers. In those situations the EMS providers have a clearly defined role and the receiving hospital has structured their intake procedures to dovetail with efforts initiated in the field.

4.2.3.5 Quality Improvement (QI)

QI in EMS is much the same as any other medical organization. Medical directors with experienced support staff watch trends, evaluate practices, and review cases. From there training plans and policy or protocol refinements are developed.

4.3 Military and Civilian Innovation

There are numerous authoritative works on the origin and evolution of EMS, each delving in to the science, logistics, and legal changes leading to our modern understanding of prehospital care. The goal of this section is far less lofty. Here the intent is simply to illustrate how innovation and shared experiences in one world influenced the other for the betterment of patient care.

The crux of EMS evolution as it relates to disasters in particular lies in at intersection of military and civilian medicine. Many modern trauma management techniques are directly attributed to the desire of militaries to save combatants. Conversely, many methods pioneered in the civilian world have led to improvements in battlefield medicine – and as those advanced techniques are adapted to the mobile, high-stress environment of the battlespace, the cycle of innovation continues and those adaptations are seen in civilian EMS. The need for portable, reliable, durable advanced medical devices in the military directly contributed to the evolution of civilian versions we see in use every day – both inside and outside hospitals. The point is that there is a direct and beneficial relationship between military medicine and EMS (as well as many other aspects of medicine, but this chapter focuses on EMS).

The innovations need not be high tech to benefit either environment. Take the humble tourniquet, for example. Long banished from first aid and prehospital training as dangerous, thanks to a resurgence in use by the military and documented reduction in mortality from severe extremity trauma, it is now returned as a front-line treatment in EMS. In Boston we saw one of the first examples of routine use in a civilian population after the Boston bombing and, while the analysis of that event continues, the assumption is that lives were saved. First responders and bystanders alike used belts and other improvised tourniquets to staunch bleeding in blast-damaged extremities. Tourniquets are a lesson from the earliest days of modern asymmetrical warfare, where terrorists' preferred weapons are limb-destroying explosive devices. As the military adopted the old school tourniquet, so did their civilian counterparts. If one wants to understand where civilian EMS is going, stop and study what works in the battlespace. Look at what equipment, techniques, and challenges the military medical corps navigate and innovate through. You'll likely find everything from reliable portable ventilators to rapid laboratory analysis machines made for the field to the humble tourniquet. The pioneers of the battlefield often lead the way for street providers in every major city.

The modern EMS world benefited from innovations pioneered in Vietnam and other post-WWII conflicts. The use of highly trained nonphysician personnel with advanced equipment performing medical interventions in the field evolved from the need to rapidly treat and transport soldiers from the front line to the aid station and then to a forward hospital. Many of the first paramedics received their initial training in the military and translated those experiences into civilian encounters. The use of utilitarian helicopters and ambulances in the military led to specialty vehicles designed solely to provide a mobile workspace for prehospital care. The primitively equipped corpsman's medical satchel has led the way to durable specialized packs filled with supplies optimized for field use. Morphine syrettes from WWII serve as a precursor to modern preloaded syringes, removing several small pieces of equipment needed to administer injections and making the unit infinitely more portable, less difficult, and safer to administer.

The bidirectional flow of innovation between military and civilian providers serves to create and prototype solutions faster than ever before, ultimately getting lifesaving ideas into common practice in months rather than years. In many cases the innovation revolves around equipment and practices already in use. Simply applying them differently potentially leads to positive changes in efficacy, personnel safety, and patient outcome.

Today we see specialized forward surgical teams (FST) in use in the Middle East – performing lifesaving surgical repairs closer to the point of injury than ever before. In that model, the surgeon and a very small team bring the operating room to the patient. Is this idea "new"? Of course not. Doctors going afield and placing themselves in harm's way occurred from the very beginnings of medicine. What's unique is the formalization and specialization of the team. Their equipment and protocols pave the path forward for trauma centers in the civilian world to form similar teams. Today, when inextricably trapped patients cannot be freed, surgeons sometimes must perform field amputations. Generally speaking these are ad hoc events, with equipment and staff cobbled together in the moment and deployed with EMS personnel who may not be familiar with the hospital personnel or the procedure. Forming civilian FSTs and establishing a training regimen allow for prescripting processes and reducing errors. Reduced response time, familiarity with the procedures, and trust built through shared experience stand to greatly benefit the patient outcome. Further, improvement of the overall process largely eliminates the need for constant field improvisation.

4.4 Models of EMS Delivery

4.4.1 Provider Entities

Generally speaking, EMS provision falls into three models: government owned and operated, privately owned and operated, or public-private partnerships. Within these three broad categories exist three subsets: standalone mission-specific EMS organizations, hospital-based organizations, or EMS as a function of another organization. Each of the nine possible delivery models offers distinct advantages and disadvantages. Additionally staffing models increase the variability of delivery systems by introducing different levels of professional ability and paid or volunteer (or a combination thereof) people. As one can see the possible models become nearly endless. This speaks to the uniqueness of a localities' EMS system.

4.4.2 Levels of Training

Rather than spend time delving into the pros and cons of each model (again, there are plenty of authoritative works on the topic and even more opinion papers and articles discussing which is best), the focus on provider capabilities will likely be of most value. Typically the three most common levels of training in EMS are physician, advanced technician (nurse, paramedic), and basic technician. As one might assume, the more advanced the provider, the broader the range of conditions and associated treatment options are. If a system relies on physician (or nurse practitioner/physician assistant) response, it's not uncommon for a patient to receive treatment the field and not be transported. At the other end of the spectrum, the basic technician has neither training nor authorization to treat and release most patients. The middle category realizes the broadest variations in scope as each locality has different laws related to what nonphysician advanced providers may do and the conditions under which they may do them. For the purposes of this discussion, nurses and paramedics, as well as other operating with some degree of training beyond basic first aid but not a physician, are considered "advanced technicians." These individuals are the core of modern EMS, often providing quite sophisticated care to those in need. The distinguishing factor between them and physicians (recognizing that physicians also work within an acquired training hierarchy) is independent decision making. In almost all cases, the advanced technician works under medical control of a physician. Either through on-site supervision, remote consultation, or standing orders, advanced technicians must work within the confines of their scope and orders.

4.4.3 Physician Staffed Resources

Physician-based staffing generally pairs a doctor with an advanced technician such as a nurse or paramedic and sometimes a driver as well. Once arriving at a scene the doctor examines the patient, determines a treatment course, and begins care. The patient may be transported but it's not a requirement. As a doctor, the provider may prescribe medication, instruct the patient to schedule a follow-up appointment, or utilize a different form of transportation to seek further care at a clinic or hospital. From a management perspective, this model offers the most flexibility and overall utility in the field. Since transport isn't always needed and things like medications can be prescribed on-site, this model also offers the best EMS tool to manage emergency department capacity and directly distribute patients to appropriate departments or services. The downsides of this model include cost, lengthy time on task, and, depending on funding source, revenue generation. Generally speaking, professional staff cost more than technical staff, but one must also consider the cost of equipment and supplies without which the doctor will be less effective and the service provider will not realize the full benefit of utilizing professional staff. Due to more detailed assessments, treatment options, and instructions, assignments involving doctors tend to take longer. That makes a given squad less available to the overall system, which can lead to increased staffing needed to meet emergency demand. EMS is a time-sensitive business, so having calls stacked in queue waiting for a resource to send can lead to deaths. Given the high cost of such models, those systems that rely on revenue generation may not be able to sustain this level of service. Systems that do utilize physicians tend to be government owned and operated and funded by a national health system or similar government subsidy. In the United States, these models are rare due to rules around billing for EMS. It is almost entirely dependent on transport of the patient, so providers are actually discouraged from adopting this model in favor of less flexible models that contribute to the growing problem of emergency department overcrowding. One is most likely to find this model in practice in industrialized nations with government-operated healthcare systems due to the expense and that this type of healthcare system will realize the highest return on investment from this model.

4.4.4 Advanced Technician Staffed Resources

Utilizing advanced technicians, such as nurses or paramedics, offers better efficiency top the EMS provider but potentially less to the system as a whole. By limiting the scope of practice and the overall time spent on task, the provider realizes more resource availability. Unfortunately this model merely shifts the higher level assessment and care to a hospital. The benefit of more, cheaper resources available to the system is offset by the associated increase in patients entering hospital emergency departments. For the very narrow band of critical patients, this model works well however for the much greater demand generated by nonurgent illness or injuries; the most common model of EMS delivery taxes community health resources. In order improve the overall utility of this model, some areas are beginning to provide more family medicine-type services and not transporting every patient, but that level of maturity is still fairly rare.

Advanced technicians have significant training in emergency medicine, pharmacology, and interventions related to emergency care. Using advanced airway interventions, intravenous infusions, and medications commonly associated with acute cardiac and respiratory emergencies, this model evolved from the desire to improve out-of-hospital cardiac arrest survival and increase trauma care in the field. Other complaints, such as abdominal pain or altered mental status, that require more in-depth assessment and diagnostic studies must be transported in all cases, even those in which a physician might be confident of a diagnosis with no more studies. The limitations of the field environment, coupled with risk of misdiagnosis (and in some cases liability), make it difficult to craft policies and protocols to guide advanced technicians' practice. However as technology makes diagnostic equipment smaller, cheaper, and more reliable in the field, the hurdles become lower. Today, telemedicine consultation occurs regularly between doctors in remote locations and specialists in larger urban medical centers. When the bandwidth, security, and availability of wireless data networks evolve to a point that the same high-level telemedicine consultation is achievable in the field, it may finally be possible to safely expand the scope of advanced technicians.

4.4.5 Basic Technician Staffed Resources

The basic technician model is the cheapest and easiest to implement, but offers virtually no efficiency to the healthcare system as a whole. The primary purpose is to transport those who are unable to transport themselves. In areas without alternatives, this model saves thousands of lives each year. In fact, for many communities in the first and third world, these basic providers, many of them volunteers, serve as the only reliable link to advanced care available and are invaluable to the community. Typically these crews carry equipment to immobilize spine and for extremity injuries, basic bandaging, and oxygen administration. Trained in first aid, basic assessment skills, and CPR, these providers rely on their ability to extricate, package, and transport patients without delay.

Most industrialized areas rely on a combination of the aforementioned models to meet the needs of the community. By triaging requests for service, utilizing criteria designed to match the appropriate level of service to the request communities can create solutions best suited to their healthcare system and their demand.

4.5 EMS in Practice

4.5.1 Normal Operations

Normal operations pair one resource to one incident. The patient and family receive all of the attention of the team and the patient is transported to the most appropriate facility (or not, depending on the staffing model). On arrival the EMS team provides a thorough report on their observations, findings, and treatment initiated. This scenario, which is by far the most common and comfortable interaction for all, must change when resources become scarce or demand is too high.

4.5.2 Disaster Operations

During disasters, everything changes. Patient care shifts from 1:1 to 1:many. Scarce resources are routed to the most likely to survive. Those requiring intense care may be considered expectant and provided palliative care only. Medical staff will learn very little information from field crews. As with any other system, when stretched EMS must flex to accomplish the core mission with reduced capacity. Planning in advance is critical – one must know what laws, regulations, and customs are immovable and which can adapt in crises. One must have a strong understanding of what the outer limits of acceptable treatment are with regard to expectant patients and further clearly define what that means. During disasters people react differently and make decisions that, in retrospect, seem absurd. Because they didn't contemplate the situation, plan for it, and practice, they fail.

4.5.3 Disaster Planning in EMS

In crises, people do what they did yesterday. If yesterday's practices didn't include known contingencies for dealing with disasters, then the person is left with no tools and will struggle to find a solution. Some will adapt quickly and assume leadership roles, engaging his or her peers and solving problems. Others will simply stop. Still others will panic and act irrationally. Only one of the aforementioned scenarios results in lives saved. The bottom line is that disasters must be planned for and practice changes identified in advance and drilled regularly. Even better is to incorporate those practice changes into everyday thinking wherever possible.

Most EMS systems have a mass casualty plan. The plan identifies how patients will be triaged and distributed. It identifies a command and control structure. It identifies practice changes and treatment options in some cases. Unfortunately most such plans focus on the "what" and spend very little in the "how." How does one set up the command and control structure? How does one request resources? How does one know when to implement the plan and when to demobilize? In both emergency management and EMS, planners long ago discovered that they could produce a high-level plan that seemed to meet the needs of "planning." Regrettably, without addressing the "how" and ingraining the processes into a workforce time and again, the best plans failed to guide the response. People reverted to what they knew. What they did yesterday. They adapted what they knew to the current situation – sometimes effectively and sometimes not.

The key is to not only plan at a high level but to consider the execution of the plan and script the "how" into daily practice. For example, lowering the activation threshold and empowering people in the ranks to activate a plan and implement the command and control functions and utilize the triage and distribution strategies mean that personnel will think about and use the plan far more often. By making the plan scalable, people become familiar and comfortable with the "what" as well as the "how." Then during a major emergency, when they default to what they did yesterday, they'll have a strong foundation to solve problems and adapt the known plan to the current situation.

It's not enough to contemplate the technical aspects of disasters. Contemplating the human factors and organizational behavior factors is crucial.

4.6 Summary

Exploring EMS and all the factors contributing to the success or failure of a system constitutes a growing catalog of work measured in volumes, not a mere six sections. If there are any key insights to extract from this chapter, they are:

- EMS is a reflection of the community served; it is therefore different from place to place.
- The core mission of EMS unites patients with a broader healthcare system.
- Innovation is key to EMS evolution, and there is no better place to learn about trauma innovation than the battlefield.
- EMS staff are people and therefore plans, practices, and procedures must consider human factors and empower them to act.
- Disaster planning is crucial.

5 Treatment Capabilities of Field Hospitals at War and Mass-Casualty Disasters

Vladislav Dvoyris, Yitshak Kreiss, and Tarif Bader

5.1 Introduction

The changes in warfare during the past decades have greatly affected all aspects of combat. The introduction of improved weaponry and ammunition has altered the types of injuries and the severity and numbers of casualties seen in battlefield, while improvement in prehospital and combat casualty care and transportation has allowed the evacuation of injured soldiers to trauma centers, thus saving more lives.

During the 2006 Israel-Lebanon conflict, rockets fired by "Hezbollah" reached as far as 50 km within Israel, thus endangering a vast civilian population and compromising the operational ability of several major hospitals, including a level I trauma center in Haifa.

In the era of globalized media and intercontinental transportation, the ability to reach out to mass-casualty disasters within a short time span has increased greatly. Such outreach to areas affected by disasters and often suffering of damaged or missing infrastructure and medical abilities require the establishment of self-sustaining medical facilities that will be able to provide the necessary care at the field level.

In this chapter, we will focus on the treatment capability of a modern field hospital in the battlefield and in mass-casualty scenarios, based on the vast Israeli experience from the recent years. The chapter will deal with the structure and function of such facilities, the human resource demands, the capability of field hospitals to triage and treat orthopedic injuries on-site, and ethical dilemmas arising during the operation of such a facility.

5.2 Field Hospitals: A Historical Perspective

Medical teams have escorted armed forces in the battlefield throughout the history of modern warfare. However, these mobile teams were small and of limited capabilities, and injured soldiers were usually transferred to local medical facilities and often left to die. Lack of surgical facilities and anesthetics has turned battle injuries to almost certainly lethal or at least greatly crippling,

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_5

due to radical amputations. During Napoleonic warfare, the highest priority was given to patients that had a chance for the quickest recovery, while the severely wounded were left on the battlefield until the battle concluded [1]. In 1799, Napoleon Bonaparte had unsuccessfully sieged the fortress of Acre and eventually left, leaving wounded soldiers behind at the Carmelite monastery in Haifa. Unfortunately for them, the wounded were slaughtered by the Ottoman army shortly after Napoleon's retreat.

A great innovation to field medicine and surgery was introduced in mid-nineteenth century by the Russian surgeon Nikolai Pirogov. Pirogov was the author of a new anatomical atlas, "Topographic Anatomy of the Human Body," based on three-dimensional sections of frozen cadavers, which facilitated a great improvement in the precision of surgical operations and served as a base for further development of modern surgery. In 1847, during the armed conflict on the Caucasus, Pirogov was the first surgeon in the world to use ether under field conditions. However, it is his work during the Crimean War of 1853–1856 that established Pirogov as the father of combat medicine. Being the chief surgeon of Sevastopol, a Russian seaport under a French-British siege, Pirogov was also the first to use plaster bandages, thus obviating unnecessary amputations in many wounded soldiers. However, his key achievement was the establishment of a triage system, according to which the wounded were sorted at first aid stations and evacuated to a field hospital or to the rear, according to wound severity [2].

During the US Civil War, a military ambulance service and forward aid stations were formally established by Charles Tripler and Jonathan Letterman, dedicating personnel to retrieve casualties who could benefit from emergent medical treatment, before the battle concluded. In 1862, the US army ambulance corps has been established, allowing for a much faster evacuation of casualties from the battlefield [3].

At the same time, the improvement in transportation and the expansion of railroad networks throughout Europe led to the development of hospital trains, allowing the performance of field surgery on the move. The British army was the first to use such trains during the Crimean War. Hospital or sanitary trains saw action during the Civil War in the United States and the Franco-Prussian War of the 1870s and were subsequently used on a greatly expanded scale during the First World War.

While the Russian and German armies continued to use sanitary trains during the Second World War, the US military had by then introduced a novel type of field hospital – the portable surgical hospital (PSH). This new unit of 25 beds had stationary and deployable versions and was able to medically support a battalion or a regiment. It consisted of 29 personnel, among them 3 surgeons and an anesthesiologist. The equipment and supplies of such a unit had to weigh no more than the personnel could transport, and thus only the most useful equipment was included in these hospitals, which proved as a shortcoming in the field. Meanwhile, a group of consultants led by Col. Dr. Michael DeBakey recommended the establishment of auxiliary surgical groups (ASGs). Such groups, consisting of 2 surgeons, an anesthesiologist, a surgical nurse, and two technicians, could follow military units in combat and provide surgical care in the battlefield.

The Mobile Army Surgical Hospital (MASH) was an improvement of the ASG, first established in August 1945 and finally deployed during the Korean War. Ten MASH units supported four divisions (~80,000 soldiers) stationed throughout Korea. They were assisted, for the first time in history, by the air force that provided small Bell H-13 helicopters for medical evacuation. The wounded were placed on skids outside the helicopter, thus limiting the treatment during transport, yet allowing relatively prompt arrival to the MASH unit [4]. The concept of field triage had also undergone major improvement – primary triage was performed at battalion aid stations, where nurses and general physicians were to decide whether to evacuate the wounded or treat them locally. Those evacuated to MASH units were triaged further, but the limited capabilities of these units precluded the management of a large influx of wounded men. Patients requiring specialized medical therapy were evacuated to specialty centers following primary stabilization, while the triage within the MASH itself followed the motto "Life precedes over limb, function over anatomical defects."

Their great functionality resulted in continued operation from the Korean War up until 2006, when the last MASH was deactivated. However, the Vietnam War brought further improvement with the introduction of the Medical Unit Self-Contained Transportable (MUST). These units offered expanded capability, which allowed for the establishment of radiology, pharmacy, and dental services in the field hospital.

During the Gulf War, the larger Combat Support Hospitals, CSH, were deployed together with MASH units. While the MASH units maintained their relatively small size and mobility, the CSH units were large and could include up to 200 hospital beds and 3–4 operating tables. Smaller components of the CSH, the forward surgical teams (FSTs) with 1–2 operating tables and a very limited number of beds, were deployed at the frontline, while the CSH itself had to stay in the rear due to its size. Eventually, most MASH units were replaced by the much more flexible FSTs. The last MASH of the US military continued operations from 2003 to 2006, during operation "Iraqi Freedom."

5.3 Field Hospitals of the Israeli Medical Corps: Structure and Function

The Israeli experience is unique; due to the country's small size, major specialty hospitals are never too far from the battlefield, and thus most wounded individuals will require only primary stabilization and preparation for transport to the rear. Moreover, during the time of an emergency, any or all the hospitals in Israel may operate under martial law and act as military medical facilities – including discharge of civilian patients or diversion of patients between hospitals, according to the orders of the military medical command [5]. The Israeli Ministry of Health has issued a directive aimed at redirecting the patient flow to emergency departments best able to care for them. This directive was employed in Haifa, Israel, during the 2006 Lebanon conflict that lasted approximately a month and during which the metropolitan area was hit by some 80 missiles. The constant monitoring and actions taken by the Ministry of Health and the Surgeon General of the Medical Corps, who was responsible for the evacuation of wounded soldiers, allowed proper provision of critical care while preventing an overflow of the emergency departments [6].

Field hospitals deployed during warfare within Israel's borders or in close proximity to them are usually the size of an FST or MASH. Recently the Israeli Defense Force (IDF) has acquired a new field surgical hospital the size of a typical CSH; however it hasn't yet been employed in the field during warfare. In the 1973 Yom Kippur War, division-level surgical teams served mostly as intermediate stations – the wounded were to arrive there following primary triage done by a battalion level physician and after further triage and stabilization were transported to civilian hospitals. Notably, in the Sinai front during this war, the wounded were to stay longer while waiting for airborne evacuation to the rear, and still, only 3 % of the wounded actually underwent surgery in the field hospital. The key indication for immediate surgery was an unstable condition of the wounded, due to massive hemorrhage, clinically deteriorating peritonitis, extensive damage to limbs or to arteries supplying limbs, and injuries endangering the respiratory tract [5].

In spite of the fact that a large-scale field hospital was not deployed in Israel, the IDF Medical Corps is well prepared for such a scenario. The Israeli government has made a strategic decision that the Medical Corps should be constantly ready to dispatch an ad hoc field hospital anywhere in the world within a short period of time, based on active duty and reserve servicemen put on alert. In addition to operating during warfare, the Israeli field hospital is also a means of providing humanitarian aid to civilian populations. Several unique capabilities were added to the hospital in line with this strategy. These special capabilities will be discussed; however this chapter shall primarily focus on the common, generic characteristics in all modes of operation.

The IDF airborne field hospital may act as an independent medical facility with surgical and critical care capabilities, as well as a backup facility for a nearby regional hospital, in which case the field hospital team will perform the triage and operate the trauma care facilities jointly with the local surgical team. During independent operation under warfare conditions, the hospital is capable of admitting up to 150–200 casualties a day and performing up to 4 surgeries simultaneously and providing intensive care to up to 12 patients. In times of warfare, the hospital shall only stabilize the patients before transferring them to a larger civilian facility, and thus its inpatient capacity is limited to 80 beds. The organizational structure of the hospital is depicted in Figs. 5.1 and 5.2 and Table 5.1.

The IDF field hospital structure follows several principles, which provide for maximal operational flexibility:

A. *Basic logistic independence* – the field hospital is well equipped for a 4-day long independent operation, including food, water electricity generators, communication devices, security measures, and transportation vehicles. The medical equipment and facilities allow the operation of an emergency room, adult and pediatric inpatient wards, an operating room, a laboratory and an imaging facility, and even the deployment of mobile medical teams. Medical equipment and pharmaceuticals are defined according to the nature of the disaster or epidemic. Several motor vehicles are flown in together with the hospital; however there will always be a need to utilize locally provided vehicles, due to limited airplane capacity. Resupplying and personnel exchange is performed by additional flights to be dispatched during the course of operation.

B. *An integrative approach and a multidisciplinary professional team* – the personnel usually includes specialists in orthopedic surgery, general surgery, infectious diseases, and internal medicine, as well as mental health officers. Pediatricians, neonatologists, and gynecologists should be part of most mission teams, especially those that expected to replace dysfunctional obstetric services. The IDF Medical Corps holds a list of reserve physicians of various medical specialties that

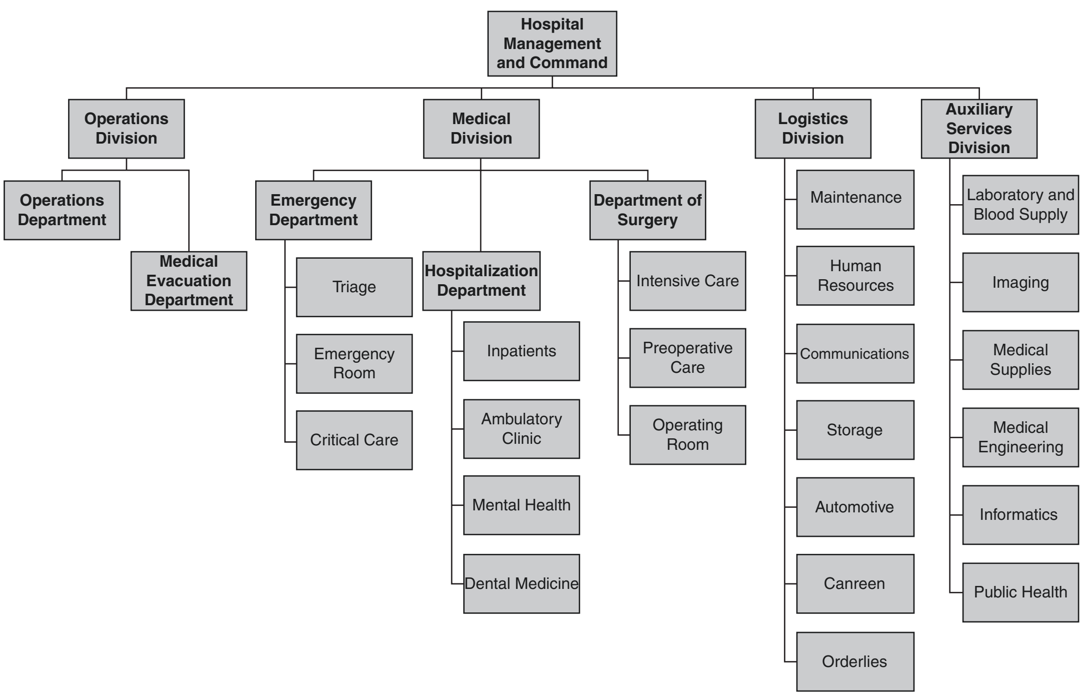

Fig. 5.1 Israeli airborne field hospital – general organizational chart

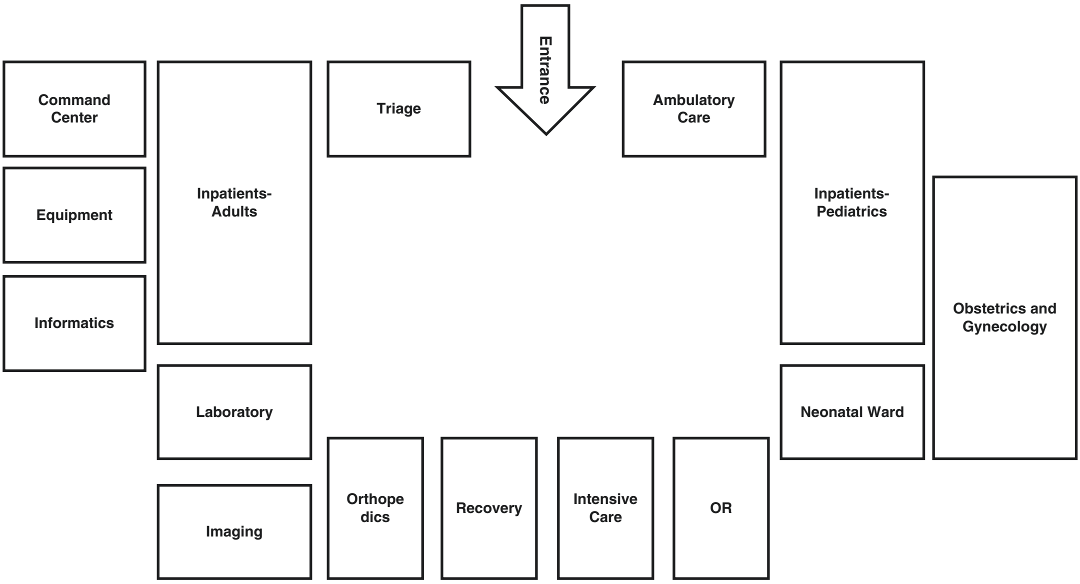

Fig. 5.2 Schematic map of the Israeli field hospital deployed in Haiti in 2010

Table 5.1 Staffing of the Israeli field hospital deployed in Haiti in 2010, by departments and medical specialties

Sector	Personnel	N
Physicians		44
Orthopedic surgery		7
General surgery		5
Pediatric surgery		1
Ear, nose, and throat		1
Ophthalmology		1
Anesthesiology		4
Obstetrics and gynecology		3
Internal medicine		7
Infectious diseases		2
Pediatrics		7
Family medicine		4
Diagnostic radiology		1
Psychiatry		1
Nurses		27
Medical engineers		2
Public health practitioners		2
Pharmacists		2
Radiology technicians		2
Laboratory technicians		3
Social worker		1
Medical informatics personnel		2
Other paramedical personnel		36
Total field hospital staff		**121**
Auxiliary staff – kitchen; ordinance; maintenance; communication; security; search and Rescue; and forensics		**109**

may be ready to man a field hospital on a short notice, and thus only limited time is needed to assemble a medical team from active duty and reserve physicians, nurses, and paramedical personnel.

C. *Versatility* – the effective ratio of physicians vs. nurses and auxiliary personnel to be deployed is 1:3, and the need for additional nurses, orderlies, and stretcher bearers may be fulfilled by employment of local staff (see below). Nursing tasks may also be performed by medics and paramedics. All members of the team should be capable of and motivated to perform duties additional to their main specialty [7].

D. *Improvisation and creativity* – these were employed many times in the operation of Israeli field hospitals, starting from landing in a location other than planned due to ground situation, continuing in the establishment of ad hoc medical wards, improvising neonatal incubators, and finding unorthodox medical solutions to complex problems that arise during operation [8].

E. *Collaboration with local and foreign personnel* – international collaboration requires direct open communication and includes coordination, sharing of knowledge and equipment, and jointness – expressed by working side by side, locals and foreigners, civilians within a military unit or soldiers working under a civilian umbrella [9].

F. *Checklists for medical supplies* – the existence of checklists allows faster dispatch of the medical teams. Medical supplies will be gathered according to these lists, and additional lists will be created in each case to answer the special needs at the area of deployment.

G. *Laboratory and blood bank* – the Israeli field hospital is equipped with a mobile digital X-ray unit and a laboratory capable of providing hematologic, blood chemistry, and microbiology tests, as well as a small bank of blood for transfusions. A blood bank is a crucial modality, as in areas of disasters blood donors are hard to find and in some previous cases hospital personnel had to serve as donors for their patients. Moreover, a capacity for resupplying the bank with blood from the country of origin should exist. Recently, the IDF medical corps pioneered the use of freeze-dried plasma (FDP) in prehospital settings. The current protocol includes FDP transfusions as close as possible to the point of injury, even at the level of the advanced life-support (ALS) provider. FDP is nowadays distributed to all on-call medical units in the IDF and is available at field hospital settings as well [10].

H. *Imaging and medical records* – in recent opportunities such as the Haiti field hospital, novel information technologies were used to facilitate medical treatment. A novel medical information system was designed in order to provide accurate up-to-date information about the patients and workflow, as well as to ensure the keeping of medical records even during a mass-casualty disaster. As the hospital standard equipment included a digital X-ray machine, a picture archiving and communication system (PACS) was also included in the software. The whole system was based on a mixed wired and wireless network and interconnecting laptop-based workstations and managed by a software engineer and two network managers [11].

I. *Infection control* – in field conditions, this is a major issue that, if not properly taken care of, can jeopardize the entire operation of the hospital and the safety of its patients and personnel alike. It should be further stressed that the hospital operates inside army tents without air-conditioning or flooring, in areas without a running water supply, and with limited access to showers and toilets [12].

1. *Surgical facilities* – the operating room is located in a partially enclosed, air-conditioned tent, floored with an airline cargo pallet. Reusable surgical instruments should be manually cleaned, soaked in a disinfectant, and finally sterilized in a steam autoclave.
2. *Toilet facilities* – usually chemical latrines would be used in the field. There should be a clear separation between staff and patient latrines, and in case of leakage, the runoff should be channeled outside hospital premises.
3. *Disease prevention* – tetanus-toxoid vaccination is recommended for admitted patients with tetanus-prone wounds.
4. *Pest control* – in pest-infested areas, it is necessary to supply hospital personnel with repellant sprays. In Haiti, the tents were equipped with mosquito nets and sprayed three times daily with a chlorine and quaternary ammonium based solution. Warfarin-based rodent baits were also spread through the hospital camp.
5. *Human and biological waste disposal* – waste was collected in two locations at the hospital perimeter, both an adequate distance from the kitchen and hospital facilities. Biological waste was placed in biohazard bags and concentrated in one location only. All waste was removed once or twice daily to a closed facility. Nonmedical garbage was gathered in a separate location and removed once daily for disposal. Human bodies and body parts were temporarily concentrated in a dedicated facility and eventually removed to a local cemetery.

J. *Orientation, standardization, and quality control* – the field hospital should be joined by local assistants and keep constant contact with the local government and military command. The command and control team shall meet continuously to establish treatment standards and make ethical decisions that must be taken due to limitations in hospital resources. An ethics committee should decide on each case, thus relieving the individual physician from the burden of determining a patient's fate [13]. Reconnaissance of the area is another important part of the orientation – the medical team should see and understand the scale of the disaster and the dwelling conditions of their patients.

This capability has so far been implemented several times in humanitarian missions, one of the most successful of which was in Haiti, following the 2010 massive earthquake that devastated the whole island state. The Haiti mission was special both due to the scale of the field hospital deployed and due to its remote location.

An airborne field hospital had been previously deployed by the IDF Medical Corps in Armenia (1988), Zaire (1994), and Turkey (2000). In Zaire, the field hospital treated Rwandan refugees that survived a massacre and were suffering from lethal epidemics. In Armenia and Turkey, as well as in Haiti, the field hospitals were deployed following devastating earthquakes which had destroyed much of the countries' own infrastructure. In these cases, search and rescue teams of the IDF Home Front Command joined the medical teams in an effort to save lives.

5.4 The Haiti Experience: An Airborne Field Hospital in Action

In disaster areas there is often a need to establish medical facilities at all treatment levels – from primary medical teams, through large medical centers and to specialty centers to which complex cases would be referred. The field hospital should be manned by medical professionals of various specialties, and the command and control team should coordinate their interaction toward the achievement of best possible results, given the limited available resources.

A 7.0 magnitude earthquake struck Haiti on January 12, 2010. Despite its distance (6000 miles from Israel), the Israeli government decided to dispatch a medical humanitarian mission to provide advanced medical care to the wounded. The medical team was on its way to Haiti less than 3 days after the earthquake. Its deployment lasted only 8 h, and the hospital admitted its first patient 89 h after the earthquake onset. In previous cases, the gathering of the medical delegation and its dispatch and deployment (within the Near East) took 48–72 h [8].

An assessment of the medical needs and infrastructure in the disaster area is an important step in the preparations for an ad hoc hospital deployment. However, delegation of an assessor takes time – a critical asset in disaster medicine – and often the situation changes so quickly that the assessment findings would prove irrelevant by the time the field hospital had arrived. On the other hand, deploying a large medical delegation without prior assessment may jeopardize the whole operation. Thus, a short assessment is usually done prior to the deployment, allowing the field hospital to be deployed rather quickly. A special assessment team was on its way to Haiti 11 h after news of the earthquake reached Israel. Its actions on the ground proved crucial, enabling the landing of Israeli military planes in Haiti and providing a suitable deployment area [14].

For the next few days, until the arrival of larger and more complex medical facilities, the Israeli hospital became the largest and most comprehensive medical facility in Port-au-Prince. The local medical system was completely dysfunctional.

The hospital was deployed in tents at a soccer field and consisted of 121 medical personnel – 44 physicians, 27 nurses, and 50 paramedical personnel (Table 5.1). Additional 109 personnel supported the operation, providing ordinance, kitchen, and logistics services. In addition to these units, a search and rescue team operated outside the hospital in search of survivors buried under the rubble. An auxiliary forensics team was located in a dedicated area in the hospital.

With a hospitalization capacity of 72 beds and the aforementioned advanced diagnostic and life-support equipment, the IDF hospital served as a secondary center for severe injuries and remained operational for 10 days. Previous deployments of field hospitals have shown that a 2-week period is optimal for the stay of given medical personnel, and longer periods of deployment would require a “change of guard” [8].

During the period of its deployment, the Israeli field hospital in Haiti treated 1111 cases [15]. Sixteen births were delivered, some of them via C-section. More than 300 surgeries and more than a 1000 X-rays were performed.

The most complex injuries arrived to the Israeli hospital within the first 48 h of its operation. A great number of patients with severe musculoskeletal injuries were admitted to the hospital, most of them suffering from compound fractures of the limbs, crush injuries, open and closed fractures, and traumatic amputations. Almost all of the injuries were accompanied by infection, as the wounded spent the first 2 days after the earthquake outdoors. Therefore, prioritization of treatment was needed in order to maximally utilize the hospital’s resources [15]. The number of cases and their complexity urged an establishment of a triage approach that would allow proper function and resource management of the hospital. At the first stage, the hospital operated in a mass-casualty mode, and triage was performed by senior physicians. As available resources were scarce, the first triage dilemma was not whether to treat the patient immediately or not – rather, the triage had to deal with the mere ability of patient admission and treatment [14].

In order to cope with this extremely frustrating situation, we accepted new patients as soon as space became available, performed essential surgery, and discharged the patients sooner than we would have wanted to in order to make room for new arrivals. Being well aware of the risks of not providing adequate postoperative care, we came up with the idea of notifying each “light” hospital and other health facility that for every patient referred to us for higher level of care, it would have to be willing to accept one of our patients for immediate postoperative management in exchange. This enabled us to maximize the throughput of our operating room by increasing the number of operations and procedures we were in a unique position to perform, while ensuring that our patients were not “abandoned”.

At the second stage, a decision had to be made regarding the possibility to save these patients’ lives, as patients with the greatest urgency and lowest chances of survival often require a great expenditure of resources. An additional consideration was the potential for rehabilitation – as rehabilitation facilities were scarce in Haiti even before the disaster, the prospects for rehabilitation after severe injury were very low. Mainly patients in critical condition with chances of survival were referred to the ICU, due to its limited capacity [15]. Thus, the patients receiving care were those deemed most likely to benefit from the treatment [14]. An ad hoc ethics committee, consisting of three senior physicians, dealt with every such case individually [13].

The primary triage process upon admission to the hospital consisted therefore of three key questions:

1. *How urgent is the patient’s condition?*
2. *Are the hospital’s resources adequate to fulfill the patient’s needs?*
3. *Given that the necessary care is available and will be provided, can the patient’s life be saved?*

In order to concentrate on treating injuries caused directly by the earthquake, an orthopedic treatment station was transformed into an additional operating unit, thus doubling the surgical capability. Together with the Colombian surgical team operating within the Israeli hospital, 3–4 operating rooms were occupied around the clock [14].

In the first days of operations, several patients with crush syndrome were admitted to the hospital.

All of these developed acute renal failure, and although conservative treatment was provided, most of these patients eventually died. Acute renal failure is a common complication of crush syndrome, with a mortality rate of 80 % – however, renal replacement therapy (RRT) administered shortly after the injury can significantly improve the survival chances of these patients. In cases where hemodialysis is not available due to lack of equipment or aseptic conditions, short-term peritoneal dialysis may be considered [16].

The hospital's policy of relatively early discharge allowed it to treat more than 100 patients a day using a capacity of only 72 beds. The post-discharge management was to be performed by the United Nations and other relief organizations, and later, when additional resources and larger mobile hospitals became available, a referral of patients for further treatment became possible.

5.5 Summary

The Israeli airborne ad hoc hospital may serve as a good example for deployment of a field hospital in mass-casualty settings. The lessons learned from its latest deployment in Haiti may serve as important guidelines in the preparation for the next event of such kind. However, every mass-casualty event has unique characteristics, and an independently operating comprehensive medical team must be well equipped and prepared for every possible scenario.

The Haiti lessons were recently implemented in a field hospital operating on the Israel-Syria ceasefire line at the Golan Heights. Established in response to the influx of injured Syrian civilians arriving at the border and seeking medical assistance, the hospital unit provided initial triage and life-saving procedures, later transferring the severely wounded to Israeli civilian hospitals.

After the 7.8 level earthquake which struck Nepal in April 2015 and caused ~9,000 deaths and over 23,000 injuried, an Israeli field hospital was deployed as a standalone facility a mere 82 hours after the earthquake. The hospital was located in Katmandu, next to the Birendra Military local Hospital.

The medical team consisted of 126 personnel, including 45 physicians and 29 nurses, alongside all other facilities which were similar to the Haiti field hospital. The hospital operated for 11 days, in the course of which more than 1600 locals were treated – 85 of them were operated on, and 8 babies were delivered in our labor room [17].

In March 2011, a 9.0 magnitude earthquake struck the Tohoku region of Japan. It was the most powerful recorded earthquake ever to have hit Japan, and the tsunami waves triggered by it reached heights of up to 40 m. More than a million buildings in northeastern Japan collapsed fully or partially, leaving more than 15,000 people dead and several thousand injured. The IDF medical delegation, consisting of 53 medical personnel, opened up a clinic in Minamisanriku, which included surgical, pediatric, and maternity wards, as well as a pharmacy and a lab. In this case, the delegation arrived more than 2 weeks after the disaster, and its main goal was to support the damaged medical infrastructure of the region.

Similarly, in November 2013, the IDF airborne field hospital was deployed to the Philippines following a devastating typhoon, which resulted in thousands of dead, tens of thousands of wounded, and millions of displaced citizens. The Israeli team arrived in the Philippines 4 days after the disaster and treated 2686 patients, including 848 children, in the course of its 2-week stay. In this case, the hospital was not deployed as an independent trauma facility – rather, its proximity to an existing local hospital allowed treatment of wounded and chronic patients alike. Airborne field hospital deployment during mass-casualty disasters has provided valuable experience to the hospital team. After successfully operating in distant locations with severely damaged infrastructure, the field hospital has proven itself ready for almost any situation in Israel and abroad. Continued operation and sharing of experience will undoubtedly contribute to the body of knowledge regarding field hospital deployment in times of war and peace, refinement of field triage and critical care capabilities, and enhancement of international collaboration in disaster relief operations.

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6 Role of Government and NGOs

Emily Ying Yang Chan and Wilson Li

6.1 Introduction

Large-scale disaster relief response consists of a complex interplay among multiple and multidisciplinary actors. While the local government and the affected population are the primary stakeholders, in the face of major calamities so are foreign governments sending aid, international organizations (such as the United Nations and its affiliates), nongovernmental organizations (NGOs) and their donors, and so-called hybrid organizations, such as the various arms of the Red Cross and Red Crescent movement (like the ICRC and IFRC) [1]. While speed is certainly crucial in providing disaster relief, immediate action, if uncoordinated, may not be necessarily relevant, appropriate, or even beneficial. In order to provide effective and relevant relief, governments (both the host and those sending aid) and NGOs involved in humanitarian assistance should recognize the roles and responsibilities of each of these players in order to make full use of the already limited resources that can be immediately mobilized in these crisis situations and to avoid duplication (Fig. 6.1). In this chapter, we are going to examine and debate the role and identity of governments, NGOs, and other humanitarian aid players in providing disaster relief.

6.2 Stakeholders

6.2.1 Local Government

Normally, the local government is empowered with the legitimate authority to initiate disaster relief operations and to mobilize preexisting resources available toward such an effort. Its ability to focus on different laws, regulations, and policies can provide a platform for different agencies and units in the society to work together. In addition, the government holds an important role in providing relevant information and resources to properly plan and coordinate, and eventually evaluate, the relief process. It is also important to highlight the fact that the local government has a pivotal role in calling for and accepting foreign aid if necessary, especially

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_6

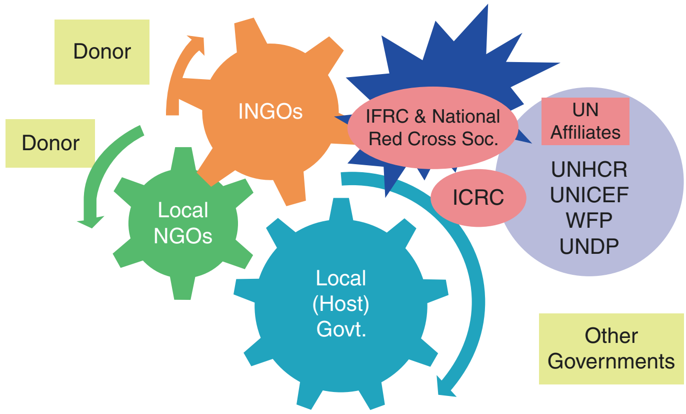

Fig. 6.1 The complex interplay of governments, UN entities, and NGOs in disaster relief

when the national rescue and medical facilities are overwhelmed. The government should act as the voice of its citizens to express their needs during and after a disaster [2, 3].

Of note, there are various levels in the government and civil society (local community groups, the private business sector, and local branches of international groups) who may be involved with the disaster management efforts, and they are all part of the vast network for disaster rescue, relief, and rehabilitation [9]. Stock piling of life-saving drugs in vulnerable areas; strengthening of the medical supply system with powers for local purchase; real-time situational assessment and reviewing the status of response mechanisms in known vulnerable pockets; ensuring adequate availability of personnel in disaster sites; reviewing and updating precautionary measures and procedures; dispensing with postmortem activities, disinfection of water bodies, sanitation maintenance and drinking water sources, and immunization against infectious diseases; and ensuring a continuous flow of information are also important roles in which civil society in a disaster-affected community has to engage [4, 8].

For many high-income countries, such as Australia and the United States, federal coordinating bodies for the management of disasters and emergencies have been formed preemptively to improve disaster relief preparedness. The Emergency Management in Australia serves as Australia's key national organization for disaster management, while the Federal Emergency Management Agency (FEMA) is its counterpart for the United States. Parallel to these national organizations are provincial or state emergency services that support the efforts of federal agencies, ensuring national security and safety of the citizens. In the United States, the Citizen Corps organizes volunteers to assist in preparing the community for emergency response through "public education, outreach, and training" (Citizen Corps 2011). It is a grassroot strategy to bring together government and community leaders, ultimately involving the citizens, in disaster preparedness. Although this program is administered locally, it is directed by the federal Department of Human Services in the United States.

Meanwhile, in middle- and low-income contexts, the disaster management systems are less defined and more variable. While the government still holds the key responsibility of disaster-response activities, often the lack of a robust structure or basic healthcare system has rendered the overall coordination of disaster relief more challenging. The typical pattern of system development in these contexts is usually based on reaction to crisis and events, rather than advanced planning. With experience, new regulations and disaster preparedness systems may be enhanced after a disaster. According to the India Orissa Review 2004, the role of the local government at the state and district levels includes the identification of areas prone to epidemics and natural disasters; identification of appropriate locations for testing laboratories;

listing and networking with private health facilities; developing a network of volunteers for blood donation with blood grouping data; strengthening of disease surveillance; ensuring regular reporting from the field level workers and its compilation and analysis; formation of adequate number of mobile units with trained personnel; testing facilities, communication systems, and emergency treatment facilities; identification of locations in probable disaster sites for emergency operation camps; training of medical personnel; arrangement of standby generators for hospitals; listing of vehicles that will be requisitioned during emergencies for transport of the injured; and other preparedness activities before any disaster.

Moreover, in recent years, there has been a shift in emphasis in both contexts, from disaster cycle management to disaster spectrum-based strategic risk management and reduction planning. There is also a marked change from a government-led approach, to greater civil society involvement and decentralized community participation. More research, knowledge, and training focusing on procedures and processes for dealing with emergencies and disasters have been developed. For example, New Zealand adopts the "4Rs" approach to disaster management: reduction, readiness, response, and recovery (Ministry of Civil Defence and Emergency Management 2006). The responsibility for emergency management shifts from local to national organizations in accordance with the magnitude and nature of the disaster. Many countries have increased the formulation of laws and regulations in the area of disaster relief and management. After 9/11, the Homeland Security Act, with its far-reaching policies and intrusive procedures, was introduced in the United States. The United Kingdom responded to crises by introducing legislation such as the Civil Contingencies Act 2004, "…which legislated the responsibilities of all category one responders regarding an emergency response." Again, legislation mandated and enabled different levels of government and society to be involved with regional forums and activities of the local authority.

6.2.2 Military and Uniformed Services Groups

Although there seems to be a trend for most disaster and humanitarian emergency response actors to distance themselves from the military, due to the logistical support and capacity which military groups might offer, relief operations still frequently work closely with the uniformed services. Some important relief-related functions which the military are able to offer include security surveillance and briefing, convoy support, guidance on local security, technical assistance, and access to remote areas, ports, and airfields. For relief operations with surgical activities, military facilitation will further enhance the level of material access and logistical capacity (e.g., the setting up of field-based hospitals) to perform surgically related procedures.

6.2.3 Foreign Responders

When medical needs in an affected community are beyond the capacity of the host government, foreign medical teams often offer help. The foreign country contribution might be in terms of bilateral (country to country), multilateral, and/or multidisciplinary involvement. The nature of these activities might range from pure financial donor-recipient relationship to direct technical assistance on the ground. Recent examples of multilateral effort include the earthquake in Haiti and hurricane Ketsana in the Philippines, which both highlighted a few substantial gaps in the coordination and leadership of such a good-willed response [10]. Although these foreign medical teams brought along much-needed important resources and expertise, support from the international community, limited understanding and knowledge of the local context of the catastrophe (culture, religion, custom), insufficient expertise to prepare a strategic vision for post-disaster recovery, and failure to coordinate among stakeholders during emergency relief and recovery resulted in suboptimal outcome or even major chaos (Fig. 6.2). Some common key challenges that emerged were very limited interaction

Consider (and avoid) the Seven Sins of Humanitarian Medicine,
as articulated by Welling et al (World J Surg (2010) 34:466-470)

The Seven Sins of Humanitarian Medicine	
#1	Leaving a mess behind
#2	Failing to match technology to local needs and abilities
#3	Failing of NGOs to cooperate and help each other, and to cooperate and accept help from military organizations
#4	Failing to have a follow-up plan
#5	Allowing politics, training, or other distracting goals to trump service, while representing the mission as “service”
#6	Going where we are not wanted, or needed and/or being poor guests
#7	Doing the right thing for the wrong reason

Fig. 6.2 Possible problems committed by foreign medical teams (Consider (and avoid) Welling et al. [16])

between the government with local community groups and the private business sector; implementation of a large number of different and conflicting need assessments; camp-type registration systems; and uncoordinated national and international humanitarian actors, including the mass media (Fig. 6.3).

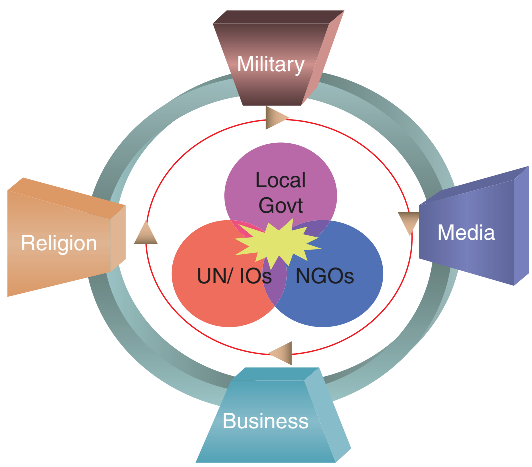

Fig. 6.3 Zone of collaboration/coordination among different humanitarian actors

In recent years, a new movement has been developed by countries who have intentions to deploy their medical teams to respond to disasters overseas. International advocates are arguing for “foreign governments” sending their Foreign Medical Team to register these FMTs, as the first step on the road to quality assurance. Providers of teams are encouraged to be formally registered internationally in order to promote accountability and a consistent level of training, equipment, and preparedness that meets an agreed international professional and ethical standard. In regard to providing Emergency Humanitarian Assistance as a whole, an international governing body is suggested to set out guidelines and standards, as well as to approve or accredit training in the provision of such. It should also gather data to guide further development and to improve future accountability. Similarly, when emergency surgical service is provided, a governing body should set out the minimal requirements, guidelines, and standards of practice and approve appropriate training. The aim is for each country to have a national register for FMTs if they wish, so that they only deploy the registered teams, and the host country will only receive registered teams in case of a disaster. Ideally, there are regionally based teams that can be mobilized within short notice and with full knowledge of regional cultural sensitivities [14]. These setup should be guided by the experience of disaster-prone countries. It was under such background that the United Nations Disaster Assessment and Coordination Team (UNDAC) was formed, with On-Site Operations Coordination Centre (OSOCC) set up during crises, providing field handbooks and other practical guidelines for disaster relief [20].

A meeting of experts in December 2010 in Cuba identified the need for a continued international initiative. A FMT Concept Paper was drafted to address the general concerns of accountability, quality control, coordination, and reporting, as well as the specific concerns of clinical competency, record keeping, and follow-up. It recommends the establishment of a Foreign Medical Teams Working Group (FMT WG) that oversees international registration of foreign medical teams. In 2011, the Foreign Medical Team Working Group (FMTWG) met for the first time, with WHO as the host Agency, and the World Association for Disaster and Emergency Medicine (WADEM) representing the academic institutions. Representatives of Global Health Cluster, of selected main global providers of FMT, of two designated NGOs, of bilateral agencies supporting actively this initiative, of two countries having been affected by the most recent mass casualty sudden-onset disasters, and of academic institutions engaged in this field were invited to this working group. Individual experts from other organizations or institutions might be invited on a case-by-case basis in subsequent meetings.

The Working Group commits itself to adherence to a minimal set of professional and ethical standards and work in support of the national disaster response. It also seeks to foster on-site coordination with, and accountability to, local health service framework, helping with operational coordination, cooperation and record keeping, data collection, data sharing, and appropriate reporting. Its objective is to ensure that FMTs are working only to the competencies for which they are recognized in their own country of origin. Another goal is to support the development of a uniform reporting system to facilitate later analysis, securing an organized exit strategy agreed with local health providers. It is hoped that the group will work through international agencies and associations, including WHO, IFRC/ICRC, and other hybrid organizations, INGOs, civil defense organizations, and other stakeholders, so that the international registration of providers of FMTs will be inclusive and transparent.

6.2.4 United Nations Affiliates

The following organizations directly or indirectly affiliated to the United Nations are involved in international disaster relief work.

The World Health Organization consists of the ministers of health from all of the member countries of the United Nations. It sets policy and standards, provides consultants in many medical fields, and often becomes involved in major disease eradication and disaster relief efforts. The organization is organized into five regions.

The World Bank is a major United Nations affiliate that works independently and with governments and is involved extensively in health development initiatives of all types. It developed an index of disability, which now is being used by many groups to measure the need and effectiveness of health interventions.

The United Nations International Children's Emergency Fund as a United Nations affiliate does extensive development work for people of all ages throughout the world. Its annual report on the health of children should be required reading for all those doing international humanitarian work.

The United Nations High Commissioner for Refugees is responsible for assisting refugees and internally displaced people all over the world. The World Food Program and the Food and Agriculture Organization help develop new forms of food and assist in distributing it in disasters, while the Office of the Coordinator of Humanitarian Affairs works to assist in collaboration of United Nations agencies and nongovernmental organizations in disaster relief and assists in appeals for funds.

6.2.5 Global Professional Associations

In the field of orthopedic surgery, global professional associations including the AO and the SICOT are involved in facilitation of international disaster relief effort worldwide. Though primarily professional societies focusing on academic and research work, both expanded their scope of activities into that of disaster relief surgery in recent years.

Société Internationale de Chirurgie Orthopédique et de Traumatologie, or SICOT, is an international nonprofit association incorporated under Belgian law with the aim to promote the advancement of the science and art of orthopedics and traumatology at international level in particular for the improvement of patient care and to foster and develop teaching, research, and education. In the aftermath of the 2004 Indian Ocean tsunami, 2005 Pakistan Earthquake, and 2010 Haitian earthquake, SICOT started a collaboration with the international medical humanitarian organization MSF, aiming at the improvement of surgical/orthopedic care in emergency situations, thus taking advantage of SICOT's network of highly qualified orthopedic surgeons and traumatologists and MSF's experience and knowledge of emergency medical care, in providing surgical teams for such challenging work.

Arbeitsgemeinschaft für Osteosynthesefragen, or AO, is a medically guided nonprofit organization led by an international group of surgeons specialized in the treatment of trauma and disorders of the musculoskeletal system. Founded in 1958 by Swiss surgeons, AO today fosters an extensive network of surgeons, operating room personnel, and scientists in over 100 countries, with the aim to expand their network of healthcare professionals in education, research, development, and clinical investigation to achieve more effective patient care worldwide. In 2010, they set up a Disaster Relief Task Force that aimed at facilitating fast, effective, and sustainable aid under catastrophic/disaster conditions through their network and other necessary partners. The group advocates updating of existing crisis management procedures as part of a new disaster relief alarm and action plan globally. A global disaster relief surgery seminar was held in Davos in 2011, and an Asia-Pacific seminar was held in 2012 in Hong Kong, working toward these goals.

6.2.6 Nongovernmental Organizations

There is no generally agreed legal definition for nongovernmental organizations (NGOs). In general, it refers to a legally constituted organization created by natural or legal people that operates independently from any government. It is a term usually used by governments to refer to entities that have no governmental status, or so-called non-state actors. The term originated from the United Nations and normally refers to organizations that are not a part of a government and are not conventional for-profit businesses. According to the World Bank definition, they are private organizations that pursue activities to relieve suffering, promote the interests of the poor, protect the environment, provide basic social services, or undertake community development [5]. The typology the World Bank uses divides them into operational and advocacy or campaigning. Operational NGOs seek to achieve small-scale change directly through projects, while advocacy or campaigning NGOs seek to achieve large-scale change promoted indirectly through influence of the political system. It is not uncommon for NGOs to make use of both activities. For instance, operational NGOs will use campaigning techniques if they continually face the same issues in the field that could be remedied through policy changes. There are, however, controversies regarding these definitions. In our context of disaster relief surgery, they refer to any civic or public advocacy organization, which generates, transfers, or administers humanitarian and other aid (development/relief) to an area struck by disaster. NGOs are usually organized as nonprofit corporations (charities). They can be local or international (INGOs), and they may work with or be entirely independent of governments. Generally, they do not include professional associations, businesses, and foundations. It is important to realize that organizations may relate to definitions other than that prescribed for NGOs. Adding to this confusion, there are related acronyms like CBO (Community-Based Organization), CSO (Civil Society Organization), DONGO (Donor-Organized Non-Governmental Organization), GONGO (Government-Organized Non-Governmental Organization), IO (International Organization), BINGO ('Business-friendly International NGO' or 'Big International NGO'), TANGO ('Technical Assistance NGO'), NGDO (Non-Governmental Development Organization), PDO (Private Development Organization), PSO (Public Service Organization), PVO (Private Voluntary Organization), QUANGO (Quasi-Autonomous Non-Governmental Organization), and VO (Voluntary Organization) (Fig. 6.4). NGOs vary greatly. The structure of NGOs is often similar to that of a business, and they usually demonstrate considerable flexibility in responding to disasters. NGOs may have international structures as well as local or regional structures, which can assist in their timely response. NGOs providing aid in disasters usually have the core values of neutrality, impartiality, and independence. Such core values may contrast or conflict with the core values of other groups involved with disaster health response.

Another classification of NGOs is dependent upon whether their composition is based on religious or other sectarian/partisan lines. There are many religious groups or faith-based organizations that work in disaster relief, such as Catholic Relief Services, World Vision, Christian Medical and Dental Society, and the Islamic Relief [7]. RNGOs are defined as nongovernmental organizations whose identity and mission are self-consciously derived from the teachings of one or more religious or spiritual traditions and which operates on a nonprofit, independent, voluntary basis to promote and realize collectively articulated ideas about the public good at the national or international level. Although RNGOs operate within the same legal and political frameworks of secular civil society, their mission and operations are guided by a concept of the divine and a recognition of the sacred nature of human life. In contrast with the rights-based approach of many secular NGOs, the starting point for RNGOs is the duty-oriented language of religion characterized by obligations toward the divine and toward others, by a belief in transformative capacities, and a concern for justice and reconciliation. Claiming religious affiliations may render RNGOs sectarian and irrational to some, but it also enables these organizations to make use of "cultural power" – cultural resources such as such as symbols, ideologies, and moral authority – to achieve their goals. Some examples of RNGOs can be found in Toolbox 6.1 and includes the Salvation Army, World Vision, World Muslim Congress, Islamic Relief, and Catholic Relief Services. It must be emphasized that most of these religious or faith-based NGOs do not select their beneficiaries along religious lines [17–19].

For secular NGOs, some have clear-cut long-term directives, whereas others may change their specific goals depending on the source of funding from their donors for a particular crisis. For the NGOs with a focus on medical activities, many have developed their own working principles and special field-based skill sets. Medecins Sans Frontieres (MSF), or Doctors Without Borders,

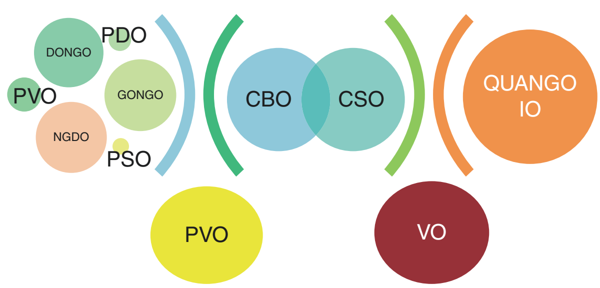

Fig. 6.4 Alphabet soup of NGOs

Toolbox 6.1

Baha'i
- Baha'i International Community

Buddhist
- International Buddhist Foundation
- Soka Gakkai International

Christian
- Baptist World Alliance
- Catholic Relief Services
- Commission of the Churches on International Affairs of the World
- Council of Churches
- Congregations of St. Joseph
- Friends World Committee for Consultation (Quakers)
- Habitat for Humanity International
- Lutheran World Federation
- Order of St. Augustine
- World Vision International

Jewish
- Americans for Peace Now
- B'nai B'rith
- Hadassah, The Women's Zionist Organization of America, Inc.
- World Jewish Congress

Muslim
- Africa Muslims Agency
- Islamic Relief
- Muslim World League
- World Islamic Call Society

Multi-Religious
- International Association for Religious Freedom
- World Conference on Religion and Peace

Spiritual
- Brahma Kumaris World Spiritual University
- International Fellowship of Reconciliation

sends overseas medical teams frequently to areas of natural and man-made disasters, as does Medecins du Monde (Doctors of the World). Both are international medical humanitarian organizations that originated in France, but have evolved into a global movement. International Medical Corps also sends medical staff to many conflict and disaster zones.

NGOs are usually proficient in both operational capability and advocacy. Advocacy is important for fundraising and working with various groups and organizations involved in disaster health response, often with the help of the mass media. Those NGOs with local branches are usually well connected at the local level, which can assist greatly with timely response. Many are willing to work in high-risk areas, and they consider themselves not constrained by state sovereignty. They are fully integrated with the local population before the disaster and therefore are well positioned for disaster response once it happens. Usually, they can mobilize quickly and can fill gaps – especially in terms of specialized skills and capacity.

6.2.6.1 The Main Issue with NGO Activities in Disaster

NGOs can work beyond their means and capability, which is sometimes expedient in times of disasters, but this may not lead to an optimal outcome. The extent to which an NGO can contribute to any disaster relief operation is often dictated by the context. The context in turn may enhance or inhibit optimal and timely response in times of disasters. The mainstream culture among NGOs is to be independent from each other and from governments. Usually, they have decentralized authority, relying heavily on information directly obtained from the field. As a result, they often develop a range of field guidelines of their own, e.g., MSF and the Red Cross.

Many agree that a long-term perspective needs to be developed. The Sphere Project is one example of these efforts. It was launched in 1997 by several humanitarian NGOs and related organizations, including the Red Cross and Red Crescent. There are three elements: a common handbook, collaboration effort, and an expression of commitment to quality and accountability in humanitarian relief. The project includes a Humanitarian Charter and minimum standards in disaster response. It serves as an example of a widely agreed standard to aspire toward, and to be measured against. Otherwise, there is little formal external monitoring of NGOs, although several NGOs and related organizations involved in disaster health response have developed their own standards and codes of practice, such as the Red Cross Code of Conduct and the InterAction Professional Volunteer Organization (PVO) Standards.

It is also important that NGOs coordinate with other agencies in the field so that they do not duplicate services in the field. The host government ministries or relevant authorities should take a leading role in this, as well as other government agencies. On an international level, United Nations Coordination Entities (like UNHCR, WFP, UNDP, UNICEF, OCHA, Special Humanitarian Coordinator, etc.) may mediate too. Moreover, there are usually NGO-Only Coordination Bodies or coordination meetings in the field. Their culture makes them reluctant to communicate with Civil-Military Cooperation or Operation Centers, but in areas with ongoing armed conflict, this may be necessary.

6.2.6.2 Government: NGO Collaboration

Successful disaster relief effort requires careful planning to combine knowledge, technology, expertise, institutional capacities, management skills, and practical experience for generating optimum results, which would not be possible without proper collaboration between the two key players: the state and the civil society.

The host government should perform an honest and accurate assessment of the medical facilities and resources available for relieving the crisis, including the hospital infrastructures and surgical personnel expertise. Specific shortfalls (such as renal dialysis, plastic, and reconstructive surgeons) need to be highlighted, and a call for foreign medical teams should be initiated if the national medical capability is exceeded by the scale of the disaster. An estimate of the number of casualty and victims should be provided, as well as those uninjured and coping.

For the countries sending foreign medical teams, their governments must ensure that they come on invitation and with the consent of the host government. They should also work out an achievable plan and assess the security situation for their team to work safely. Taking into account the limit of personnel being overwhelmed and exhausted, a rotation roster may be necessary for a sustainable overseas relief effort.

More often than not, foreign medical teams come from nongovernmental organizations experienced in and prepared for international disaster relief. In the host country, there may be local specialized civil groups (e.g., local NGOs) which possess a preexisting network that can help with the relief effort.

Coordination of host government, foreign stakeholders, and NGO sectors during disaster will help to secure the basics that all humans require to maintain health, and determining the current and likely health threats to the affected community, given the local environment and the community's resources, knowledge, and behavior. It is recognized that successful disaster relief relies on careful efforts in combining and matching knowledge, technology, expertise, institutional capacities, management skills, as well as practical experience in order to achieve vital and optimum results. This process will not be possible without proper connection and partnership between the state and the civil society (Behera 2002).

The government can effectively link up knowledge, technology, skills, resources, and expertise offered by specialist institutions with grassroot experience, organizational capacity, participatory management skills, and community-based initiatives of NGOs for disaster reduction. NGOs are usually more innovative, rooted to the ground, and participatory in their approach, while governments can replicate best practices for larger impact.

The role of NGOs assumes significance in view of their wider engagement in civic and development initiatives. Factors such as disillusionment with centralized structures, emphasis on pluralism, expanded civic engagement, and collaboration among multiple actors explain this change in perception. The growing importance of NGOs can also be attributed to the realization that neither the state nor the market can fully address the enormous problems facing the world today. Over the last few decades, NGOs have become important players in the development process across the globe, engaged in wide-ranging activities starting with community development to training, policy research, and advocacy. Their organizational flexibility, informal work style, and close engagement with grassroot communities enable them to deliver services to people at lower costs. They supplement government initiatives by acting as a conduit between development programs and beneficiaries, informing people about their rights and entitlements. Their ability to mobilize people and understand people's concerns enables them to better articulate problems encountered by the people.

Today, NGOs play an important role in disaster response and mitigation in different regions. Many international NGOs specifically focus on providing humanitarian aid to disaster victims. Therefore, stronger GO-NGO coordination and collaboration is desirable for disaster relief operations. For instance, the community-focused approach of NGOs can be expanded for wider impact through continuous dialogue and engagement between the state and NGOs. This dialogue would create greater understanding among them and facilitate policy changes for replication of microlevel projects. In countries where resources and logistic and infrastructure facilities are limited, optimal use of available financial and human resources, organizational energies, and support systems is necessary for timely disaster response and effective disaster reduction measures, which cannot be achieved without effective GO-NGO partnership. Timely response to natural disasters remains a difficult task in low-income countries, where a majority of people live in dispersed rural settlements with inadequate communication facilities. Involvement of multiple actors, especially NGOs, makes it possible to reach humanitarian aid to marooned victims and initiating restoration work in cutoff zones. However, without coordination, such engagement of multiple actors could result in duplication, overlapping, and confusion. Adequate coordination of efforts made by government and NGOs can ensure proper sharing of responsibility in the disaster response process [11–13]. While the state follows a universalistic approach in supporting victims, NGOs could adopt a community-oriented approach and cater to the needs of vulnerable groups who otherwise find it hard to cope with the impact of disasters.

Poverty and lack of awareness in low-income nations explain higher human casualty and deeper adverse impact of disasters. Techno-intensive solutions for disaster response and reduction are hard to adopt in view of higher economic costs and uncertainties surrounding their adaptability to local sociocultural situations. Success of disaster preparedness in such contexts depends more on effective community-based approaches to risk reduction and management, in which NGOs have a bigger role to play.

In brief, without proper coordination between government and NGOs, initiatives in disaster response, mitigation, and reduction will bear little fruit. There is always a strong co-relationship between successful project implementation and effective GO-NGO collaboration. Advocacy for better GO-NGO collaboration for disaster response should put the issue in a broader perspective.

From the side of NGOs, however, this concept of GO-NGO collaboration or even integration is strongly rejected by some organizations. They argue that even the UN's impartiality is of variable geometry, depending on the political interests of the members of the Security Council, and this somehow compromises humanitarian impartiality. As this impartiality is vital to continue providing medical assistance to vulnerable populations in need, they consciously choose to defend their independence of action from governmental entities. While acknowledging that the coexistence of independent actors is the best option for populations in danger to have a chance to obtain needed care and assistance, they refuse to allow humanitarian relief to be transformed into a system in which government and humanitarian action is intermingled. In their opinion, the involvement of humanitarian actors in such matters as conflict resolution initiatives risks diluting the primary responsibility of humanitarian aid to alleviate suffering [15]. Moreover, it will further shift the responsibility for the resolution of conflicts and the respect of international legal conventions from accountable political institutions to the private sphere. While accepting the need to communicate on the field, they are reluctant to collaborate or allow themselves to be integrated. They maintain that their decision and action are purely dependent on the needs of the affected population as assessed by themselves on the ground. To them, the blurred division line between humanitarian actors and military groups in man-made disasters where there is ongoing armed conflict, such as Iraq and Afghanistan, is an unwelcomed change in the humanitarian landscape. Toolbox 6.2 summarizes the key issues NGOs should clarify before initiating their disaster relief response.

Toolbox 6.2: Key Issues to Examine for NGO Involvement in Disaster Settings

A. Situation analysis of the disaster
- How robust or resilient the local community is.
- Who are there?
- Are NGOs recognized players?
- What is the platform or framework in place on the ground for NGOs to operate?
- Are the roles clarified?
- What voice does the NGO have?
- What is their respective capacity?
- Are their tensions between players?
- Are there coordination plans in place?
- Are they recognized by other NGOs? How are they funded?

B. Although the effectiveness of NGOs' response to disasters in the field is largely in their own hands, it is also determined in part by the extent to which they can collaborate and coordinate with other agencies. The capacity of an NGO to contribute to disaster response depends on their own ability to define their role within the broad context of disaster health management, effectively communicate that role, and ensure that they add value. Key questions to examine regarding NGOs activities include:
- What are their operational mandates?
- What have they chosen to do in the context?
- Do they add value to the field situation?
- Are there duplication efforts?
- Are the actions accountable and being properly evaluated?

6.2.7 Hybrid Organizations

The major distinction between governments and NGOs is whether they are state (or interstate) actors or non-state (private) actors. However, there exists in between a hybrid form of organization, of which the Red Cross and Red Crescent movement are the most involved in disaster relief. Virtually unique among international bodies, it brings together institutions born out of private initiative and the States parties to the Geneva Conventions. This hybrid composition derives from the organization's objectives. As Henry Dunant and the other founders of the Red Cross saw it, the intention was not to establish new public agencies but to set up voluntary relief societies that would be based on private initiative and would rely on private support. However, in order to be able to provide relief for the wounded on the battlefield, the new societies had to establish a strong relationship with the civil and military authorities already in peacetime [6]. That relationship was to be maintained at two levels. At the national level, each National Society was to "get in touch with the Government of its country, so that its services may be accepted" in case of war. At the international level, the relationship was upheld by virtue of the states participating in the International Conference of the Red Cross. While the International Red Cross and Red Crescent Movement are essentially a nongovernmental international association, the participation of government representatives at the International

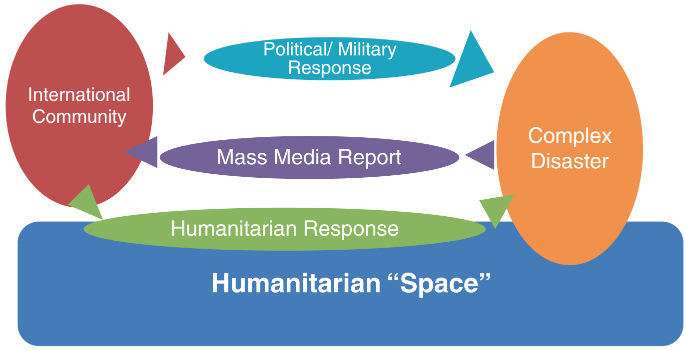

Fig. 6.5 How the international community gets involved in a "local" disaster

Conference gives the meeting a hybrid status, both private and public. By this unique position, they are capable of clarifying the coordination of humanitarian action by the components of the movement and those carried out by the states during disaster relief, especially for man-made disasters where political and military forces are involved.

6.2.8 The Mass Media

Not officially a direct actor in disaster relief, the media, particularly those with international mass appeal, can influence the effectiveness and intensity of attention and support from the international community and can sometimes even make or break a sustained response, altering the "humanitarian space" (Fig. 6.5). Media coverage of a disaster can generate attention and sympathy toward the suffering of the victims, which is one of the most powerful triggers for initiating support from foreign governments and international NGOs. Once the relief operation has started, continued coverage of the performance of the governments and NGOs, as well as the plight of the victims, may determine whether there will be a sustained reaction from the international community, who are the donors behind the INGOs and the electorates behind these foreign governments. The mass media plays a crucial role in the advocacy function of many international NGOs.

Conclusion

There are a number of different actors in any major disaster relief operations, including governments and NGOs. Each of them should get familiar with the expected and actual roles of one another. In the ideal situation, they should be complementary to each other. To achieve this goal, platforms should be built for regular communication and joint planning among the NGO sectors, governments, and other stakeholders in disaster response.

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7 Civilian Hospital Role in Mass Casualty Event (MCE)

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7.1 Introduction

The potential for MCEs to occur at any time and any place necessitates the need for medical systems to develop and have the capabilities to withstand such an event. In this respect an MCE can be compared with an "ambush" as they can strike when least expected and are difficult to prepare for. Thus, a response system should be similar to that of a trained soldier – automatic and based on preestablished and drilled practices. Hence, there is a crucial need for continued preparedness, including standing orders and repeated exercises [1].

Civilian mass causality terror attacks are on the steady rise in recent years due to various geopolitical reasons [2]. Each week news headlines from around the world announce another disaster. Scores of people are killed or injured in occurrences ranging from floods or earthquakes to man-made catastrophes, such as train derailments or airplane crashes. Some of these tragedies can be characterized as mass casualty incidents when number of injured and killed exceeds the capacity of existing medical resources. Today, we are being called on to address new mass casualty threats posed by terrorists using conventional weapons, such as bombs, and unconventional weapons, such as "dirty bombs," small nuclear devices, and chemical and biological agents. These "weapons of mass destruction" pose new challenges to the medical community in preparing to and potentially caring for the injured. Medical providers must care for the victims of such agents while protecting themselves from these same hazards. Emergency response planning becomes even more essential to mitigate the effects of unconventional terrorist acts on the lives of all those involved [3].

Mass casualty incidents in urban areas are an increasing concern justified by the terrorist bombings in Bombay, India, in July, 2006; New York, on September 11, 2001; and London, in July 2005. These attacks all occurred in crowded areas at the busiest times of the day. All these incidents imposed an enormous challenge on civilian medical services that were unaccustomed to dealing with events of that kind and the resulting injuries [4].

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_7

Despite the daunting threat of chemical and biological warfare, conventional terrorism is still the most common form of attack resulting in high causality events [5]. This is augmented by the easiness of obtaining high-quality explosives and the relative high degree of associated damage caused by them. Examples from the early 2000s are the London attacks in 2005 [4] and the Madrid train attacks in 2004 [6], as well as the succession of suicide bombing during the Palestinian uprising in 2000–2005 [7, 8]. Recently in low- and middle-income countries such as Pakistan and Iraq, there has been an extreme rise in terrorism [9].

The typical pattern of the resultant injuries is distinct both in magnitude and severity when compared to the more "traditional" blunt trauma injuries [10, 11].

The extent of civilian terror attacks, as well as the unpredictability of the events, poses a significant challenge to healthcare facilities, exhausting the capacity of even large level 1 trauma centers in certain instances [12–15]. Terror attack victims, in general, sustain a higher proportion of life-threatening injuries than those commonly seen in other trauma mechanisms [11, 14, 16].

Mass casualty events preparedness should dictate the tactics for triage, physical exam, imaging, and eventually treatment, including the general patient management and the specifics of damage control orthopedic surgery [17].

The Israeli experience in MCEs is immense. Through years of experience, Israel as a nation developed a coordinated organized response system. All hospitals in Israel are able within minutes to change their mode of operation in response to an MCE.

This chapter describes general principles of civilian hospital role in mass casualty event (MCE) and provides more details from the Orthopedic Trauma Service at Hadassah Hebrew University Medical Center. It touches upon prehospital-level preparedness, emergency department management, triage, management in other hospital departments and/or resources, and finally the surgical treatment of injuries, including orthopedic surgery.

7.2 General Principles

7.2.1 Hospital Readiness and Preparedness

At the national level, the Emergency and Disaster Management Department (EDMD) of the Ministry of Health, in coordination with the Home Front Command (HFC) and Medical Corps, develops materials to facilitate training for various scenarios and conducts annual nationwide evaluations of emergency preparedness. Periodically, regional drills are conducted with an emphasis on the coordination and synchrony of teamwork at the interface among all participants in a complex system [18]. External officials monitor the hospital's performance according to a Ministry of Health (MOH)-standardized evaluation statement of emergency readiness. This standardized checklist serves as a guideline for the process of emergency preparedness [19].

At the hospital level, a preparedness program for the hospital's staff is developed and implemented. The preparedness program is planned on a yearly basis and includes different scenarios and training of all the hospital personnel: doctors, nurses, paramedic staff, administrators, security staff, social workers, management personal, etc. One needs to realize that coping successfully with an MCE needs multidisciplinary team effort.

A variety of methods have been adapted to educate, implement, and maintain knowledge and skills. Among them are theoretical learning of hospital organization, theoretical learning of treatment principles, using video and computer simulation, active hands-on simulation, self-drills, and national drills.

Implementation of training plans is challenging. Considering limitations in resources, the training should be goal oriented and not too time consuming. A vital aspect for success is the hospital management's commitment to providing leadership and support. The process of preparedness is no less crucial than the drill itself. It gives the organization the opportunity for self-evaluation and improvement in order to be prepared to respond to an actual MCE [18].

7.2.2 Management at the Hospital Level

Hospitals need to establish a steering committee that is responsible for preparing and organizing emergency events and for developing the organizational plan based on national government doctrine. The steering committee discusses manpower, equipment, procedures, and logistics problems.

In addition one needs to pay heed to the "Ten Commandments for Emergency Preparedness Deployment a Basis for Quality Model" in the organization:

- Creating a clear management policy.
- Assigning highly proficient, qualified key persons to be in the lead of the organization.
- Creating a multidisciplinary management team: physician, nurse, and administrator, with the notion that there is only one manager.
- Emergency activities are similar as possible to routine level.
- Using a division of tasks for treating casualties, for example, one physician and two nurses.
- Using clear and elaborated checklists as the basis for emergency activities.
- Trainings and drills are a solid basis for knowledge.
- Maintaining high materials, infrastructure, and stocks availability.
- Providing accessible communication channels.
- Using debriefing as the basis for organizational learning and quality improvement.

To properly deal with MCE and provide injured patients with the highest level of care possible, we created a flowchart that begins with triage, which divides the injuries to 3 sites – critical site, immediate site, and delayed and stress reaction site. All sites have their directors (doctor, nurse, and administrator), checklist, personnel position, equipment, and relationship chart. In specific scenarios, for instance, non-conventional events, a decontamination site will need to be added to the flowcharts. In a mega event, the hospital becomes a triage hospital; therefore a pretransfer site to treat and transfer the injured will need to be opened as soon as possible according to the ministry of health decisions. In every event, an information center needs to be opened to give information and to help relatives find their loved ones. A special hospital headquarters integrates all the information from the field and from the hospital and makes decisions about the managements and activities of the hospital and reports to the MOH and the MFD.

When an event occurs, the hospital has to obtain updated information from the field about the event and try to confirm the information. This is extremely important for making the right decision about the type of event (conventional or nonconventional) and which sites to open (dependent on the number of injured). Simultaneously, the emergency department and all the sites at the hospital (critical, immediate and delayed area, information center, and decontamination area) receive their orders and start to act according to their checklists. In addition, the hospital headquarters for the management of the hospital and an Emergency Public Information Site (EPIS) are opened.

7.2.3 Step-by-Step Management of Emergency Events at the Hospital Level

The management of emergency events can be divided into three separate and consecutive phases:

Phase 1 – Preadmission preparedness.
This phase begins with the notification of an emergency event and ends when the first injured person arrives.
Phase 2 – Managing the emergency event.
This phase begins when the first injured person arrives at the emergency room (ER) and ends with the formal declaration to end the event.
Phase 3 – Debriefing and lessons learned.
This phase includes a process of returning the hospital to routine work and going through a

process of debriefing and drawing conclusions. Nurses' roles and distinctive contributions in emergency events will be highlighted in each phase.

7.2.3.1 Phase 1: Preadmission Preparedness

The type and scope of the event are determined by a process of notification, validation, and decision-making.

Notification, Validation, and Decision-Making

Notification Once the hospital is notified about an MCE, the first step is to open the standard operating procedures (SOPs) folder and follow the checklist. Upon announcement that an MCE has occurred, several basic questions must be answered regarding the injured: the number of wounded, types of injuries, clinical status, age range, and estimated time of arrival. Since the initial message of the MCE can be short, confusing, and stressful, the precise facts should be written down to provide concise information.

Validation The information must be validated with the relevant external organizations. This could include the police, IRC, fire department, and the army's HFC.

Decision-Making Several crucial decisions need to be made on an ongoing basis during the course of the emergency event. A written checklist helps the director of the event identify problems before they become obstacles.

This checklist must take into account:

- The appropriate time to start in-hospital staff mobilization
- The need for out-of-hospital staff recruitment according to a prepared EAN list
- The need for secondary evacuation (referring injured individuals to other health facilities)
- The need for opening new treatment sites
- The need for stopping routine hospital work
- Prioritizing operating room (OR) use (operations, facilities, staff) (Fig. 7.1)
- The need to open a public information center
- Critical upcoming shortages (staff, equipment, supplies)

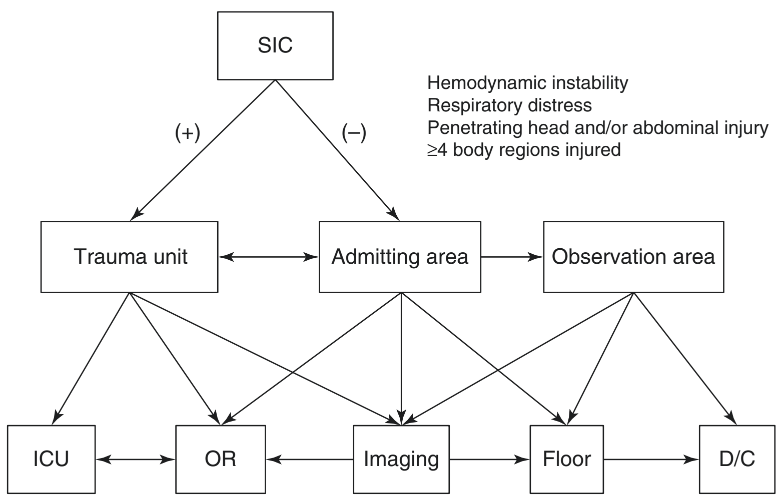

Fig. 7.1 Algorithm for the triage and initial management of victims of suicide bombing attacks. The presence of external signs of trauma is a considerable adjunct to triage. Flow of patients from the trauma room and admitting area is unidirectional. Lightly injured victims are transferred to an observation area and are examined once chaos subsides. Solid lines, primary pathways; dotted lines, secondary pathways; *D/C*, discharge home, *OR* operating room, *SIC*, surgeon in charge (Reproduced with permission from Almogy et al. [10])

After the decision is made regarding the type and scope of the event, the relevant staff is notified and called to action according to the pertinent SOP [19].

Role Assignment

Role assignment helps personnel address shortages of time, staff, equipment, and supplies. Assignment of the following roles within the ER is of top priority: triage officer, medical director, and five nurses (each one for a different assignment). It is important that healthcare personnel follow the SOP specific to their role and be familiar with the functions of their colleagues during an MCE. The nurses' role within the healthcare team is significant: leading the management and treatment teams at different emergency sites and taking responsibility for quality assurance, continuity of care, information gathering and reporting, and supporting the injured and their families.

Triage Officer A senior surgeon or intensive care specialist should stand at the ER entrance. The triage officer in the initial period of the MCE should be the best available because casualties arrive to the medical facility in three waves: people who are mobile and have mostly minor injuries, people who have moderate to severe injuries that needed EMS to transport, and those with stress response and other mild injuries. If a triage officer is not assigned immediately, the medical facility might be overwhelmed by the first wave, and non-urgent casualties will block treatment capabilities. The triage officer must use his experience to make decisions within seconds; he or she must decide the severity of the casualties of the incoming patients.

Medical Director An experienced physician is needed who can supervise the staff and ensure the appropriate flow of patients. He or she is officially the supreme authority to decide whether a patient has received adequate treatment and is ready to be released from the ER [20].

Medical Staff Three healthcare personnel staff to each treatment bay: a surgical specialist doctor, an ER nurse, and a recruited ward nurse. The ER nurse takes charge of direct care and, together with the surgical ward doctor, coordinates the overall treatment and oversees the recruited nurses.

Delegating roles to nurses ensures that tasks are performed simultaneously and not sequentially. Nurses should be assigned five tasks: evacuation of the ER patients, personnel recruitment, organization of emergency equipment, opening necessary sites, and quality assurance.

Nurse number 1: ER patient evacuation. Nurse number 1 is responsible for evacuating patients from the ER. The number of beds needed is determined in accordance with the type of event and the hospital's policy. Nurse number 1 and the medical director should decide quickly about hospitalization or discharge. ER patients who must be hospitalized should be admitted without delay. All ambulatory patients should be sent home.

Nurse number 2: personnel recruitment. Nurse number 2 is responsible for the organization and guidance of the recruited personnel. Staff members meet at the ER at preestablished meeting points, where they receive basic instructions and orientation (basic Mass Casualty Advanced Trauma Life Support [MC-ATLS] guidelines and task assignments). Another aid is a review card handed to the personnel prior to arrival of the injured.

Brief instructions and orientation are important to relay during the high-alert situation, when they will best be remembered. These precious minutes should be used effectively. After the brief orientation, personnel are assigned to specific treatment bays.

Nurse number 3: organization of the emergency equipment. Nurse number 3 brings all the necessary equipment from the storage room and allocates it for use by every two to four beds. The equipment is stored on trolleys in a nearby accessible storage room. Each trolley is organized in the same manner. The contents of the cart and expiratory data are monitored via a computerized program.

Nurse number 4: opening necessary sites. The role of nurse number 4 depends on the type of event.

Most major trauma events require two additional sites of treatment: one for patients who do not need immediate treatment (delayed treatment site) and the second for people with trauma stress reactions (acute stress reaction site).

Nurse number 5: quality assurance rotating ER nurse. Nurse number 5 is responsible for the supervision of quality and continuous care and assists the caregivers at the treatment bays as needed. Moreover, he or she helps in managing administration of medications, especially pain relief medications, light sedatives, and rapid sequence drugs.

Other Nursing Roles Several other nursing roles are important in the preparedness for patient arrival: ER head nurse, trauma coordinator nurse, and recruited ward nurses. If those nurses assigned are not available, there is a plan for substitutes to fill their roles. The ER head nurse has a crucial role in the organization of the ER, according to familiar protocols. He or she mobilizes personnel according to local needs, helps the five ER nurses with their specific roles, communicates with families of injured persons, coordinates the rapid transfer of patients from the ER to the hospital wards, and, together with the ER medical director, is responsible for the MCE debriefing as well as emotional support for the healthcare teams. The trauma coordinator nurse, together with the medical director, is responsible for the overall quality assurance of treatment during the MCE. He or she helps treat severely injured patients, orders medical consultations, and supervises the use of imaging services, OR priorities, and intensive care unit (ICU) admissions. When the delayed treatment site opens, the trauma coordinator nurse moves out of the ER and supervises the additional treatment site. In addition, he or she updates the hospital's emergency headquarters regarding the number and severity of casualties, as well as immediate shortages and needs. The recruited ward nurses are assigned to reinforce all emergency sites outside their ward: ER, delayed treatment site, acute stress reaction treatment site, and public information center. Nurses have an important role during the preadmission preparedness phase. They are the largest sector available 24 h at the hospital and best prepared for managing an MCE.

7.2.3.2 Phase 2: Management of the Emergency Event

Early preparedness ensures that from arrival of the first injured person, the staff members know their roles and act according to the SOPs. No standing order can replace the common sense of human judgment based on the real dynamics of the scenario. Therefore, strategies must be developed to ensure optimal lifesaving and to prevent complications. The key strategic issues include the following:

Identification and Documentation Next to the triage officer should stand two administrative personnel: one for records placement and the second to serve as a photographer. Upon arrival to the ER entrance, every patient receives a special pre-numbered (iron number) chart and a corresponding wrist tag. This is the patient's identification for as long as the MCE lasts. Unconscious patients are photographed and these pictures are sent to the public information center for identification. All hospital information centers and morgues in Israel are connected to a Web-based program. Basic characteristics described by worried family members, together with presentation of the appropriate photos by social workers, facilitate identification of the injured and preclude the need for relatives to seek their loved ones at other hospitals. This way the confidentiality and dignity of the injured and dead are preserved.

Triaging the Casualties Before Entering the Hospital By an experienced physician into one of three groups:

- Critical – beyond treatment. These patients have an immediate life-threatening injury, and their chance of survival would be poor even in a routine situation.

- Severe – immediate treatment. They suffer from injuries that if not treated immediately may cause death or loss of a limb.
- Moderate – delayed treatment. Their injuries may tolerate postponed treatment, even for several hours, without endangering life or limbs.
- The injured in each of these three groups are treated in separate locations to ensure that the majority of personnel are devoted to treating those who will benefit most from the use of limited resources.

Imaging Quickly available ultrasonography (US) is the method of choice for detecting whether bleeding is present in the abdominal cavity, thus minimizing the need for computed tomography (CT) during an MCE. No mobile radiography is used, as this is time consuming, creates a hazard to medical staff safety, and can be substituted by clinical judgment.

Diagnosis and Treatment of Life-Threatening Injuries This is limited to the admitting area. Additional injuries are diagnosed and treated on the ward after the MCE subsides.

Documentation This is limited to the basic diagnosis and time of treatments. Every effort is made to plan and educate teams for using short forms and concise writing.

One-Way Casualties Flow Once the injured leave the ER, they will never return. Once the medical director is informed of the injured status, he or she decides where the patient should go: imaging, OR, ICU, or surgical ward.

Access to the Hospital A plan to secure and maintain proper access to and from the hospital should be arranged together with the assistance of external agencies (e.g., police, army, and security).

Secondary Triage Measures Plans should be made for the transfer of treated, stabilized patients to facilities outside the region.

Emergency Public Information Site (EPIS) During an MCE, the public converges at the hospital. The EPIS, headed by the social work department, is opened to relay information to the public. Services included are a telephonic information center, an area for incoming families requiring information, site for identification of anonymous injured, police, and social service representatives. Social workers posted at the ER or OR relay information about anonymous injured. At the EPIS, social workers respond to inquiries by phone or in person and, together with nurses, if needed, accompany family members to the sites of the injured. Using the Web-based program, the EPIS personnel can help family members locate their loved ones outside the respective hospital.

Media and VIPs The director of the hospital and the spokesperson for the hospital are delegated to deal with the media and VIPs. A special location is designated and equipped with facilities for journalists and reporters [19].

Ending the MCE The emergency event does not end until an official announcement is made. In the case of a local MCE, the director of the hospital is authorized to make this decision after consulting with the IRC and police. In the case of a large- or mega-scale MCE, the HFC is responsible for the declaration based on the information gathered from the organizations and hospitals involved. After the official declaration of the end of the event, a number of activities continue at the hospital level. For example, the recruited personnel gradually return to their wards after all injured are treated, and an immediate debriefing process is held. The public information center remains open to help families locate their loved ones and to offer continuing emotional and physical support.

7.2.3.3 Phase 3: Debriefing and Lessons Learned

The debriefing is a learning process based on a systematic review of what has occurred. It should follow a standardized and structured process and include measurable indicators of the phases and outcomes. The goal of the debriefing process is to improve the quality of care of the injured and increase the preparedness for future emergency events, both in clinical and organizational aspects. Local and national plans are prepared and updated according to lessons learned from the debriefings [20]. The debriefing should be objective, open minded, nonjudgmental, and with full transparency. The management and treatment of the event is described in detail and compared with the standing orders. Problems and obstacles should be presented, as should acceptable conduct. Lessons learned should be operative and aimed at the managerial level. Immediately at the end of a drill or a real MCE, a two-phase process of debriefing starts. First, the manager of each treatment site debriefs all personnel who were active at the site. The purpose of this initial debriefing is to gather as much information as possible and afford an opportunity for emotional ventilation [20].

The local debriefing process relates to four main domains: medical treatment, logistics, staffing, and management.

The second phase in the debriefing process should take place as early as possible following the initial debriefing. The hospital's emergency steering committee convenes at all sites to analyze aspects of medical care, managerial decision-making, logistical implications, and inter- and intraorganizational communication. Each system (prehospital, hospital, and other emergency services) needs to evaluate its performance according to national or local guidelines and protocols. The conclusions are relayed to the EDMD, which is responsible for sharing the knowledge and experiences gathered from all involved organizations and creating a final national report for nationwide distribution. The improvement process on all levels and follow-up are obligatory and enforced by the director of the hospital and the EDMD [20].

The debriefing procedure is a powerful tool for the organization's ongoing learning process, quality assurance, and improvement. It facilitates the sharing of experiences on the local managerial level, as well as the national level, and turns each drill or real event into a valuable opportunity for upgrading and pursuing excellence.

7.2.3.4 Evaluation of the Model

Evaluation of healthcare organizations is challenging in today's reality, given the pressure to reduce costs, improve the quality of care, and meet rigorous guidelines. The Israeli medical emergency doctrine was historically developed by the IDF in cooperation with the MOH. Thus, the emergency doctrine relies heavily on the military philosophy of effective performance under stress in times of crisis. The Israeli emergency model is characterized by a defined hierarchical structure, clear chain of command, standardized operational procedures, strict training, minimal changes from routine structures and roles, debriefing processes, quality control measurement, drawing conclusions, and ongoing implementation of changes. This model has proven to be effective based on the vast national and local experience of Israel and its hospitals, including written evaluation reports after real emergency events and drills. In Israel, a national trauma registry is measuring health outcomes of the treatment of casualties such as survival rates, morbidity, complications, and mortality rates. A comparison between the Rambam trauma center and five other level I trauma centers in Israel has shown that throughout the years, the mortality rate of severely and fatally injured has been significantly lower at Rambam Hospital. The average length of stay of wounded in the ER at Rambam Hospital is shorter in comparison with other trauma centers (2.1 h vs. 3.5 h) [21]. Comprehensive evaluation of a complex healthcare system, especially in emergencies, is crucial in order to save lives and improve quality of care in the reality of limited resources.

7.2.4 Training International Teams for Mass Casualty Situations

Rambam Health Care Campus leads a unique trauma system in northern Israel, covering prehospital and hospital facilities. The Teaching Center for Trauma, Emergency, and Mass Casualty Situations (MCS) was established in 1999. Its mission is to share the knowledge accumulated at Rambam Health Care Campus and in Israel on building a trauma system and preparing for MCS.

The various educational programs are aimed at all who are involved in the organization and treatment of trauma and mass casualty victims: prehospital forces, hospital physicians, nurses, and administrators. Physicians and nurses attend the programs together.

The educational programs can be tailored to the needs of every hospital and district. It can be followed by a team of experts who will advise on the implementation of the guidelines to the specific needs of developing a working system that will serve your medical community in the next mass casualty situation.

All the programs can be conducted in Israel or abroad, depending on the needs of each organization.

7.2.4.1 Topics of Courses and Workshops

Organizing a Trauma System

- Structure of a national trauma system
- Structure of a local trauma system
- Injury prevention and control: importance and protocols
- Prehospital system: treatment, triage, transport, communication, quality assurance
- Treatment in the trauma center:
  (a) Acute phase: admitting area, operating room
  (b) Subacute phase: intensive care units – general, neurosurgery, pediatrics
  (c) Long-term phase: surgical departments – general, maxillofacial, orthopedic, neurosurgery, plastic surgery
- Trauma coordination – the pillar of the system
- Teamwork in trauma
- Steps in developing a specific national trauma system
- Interconnections in trauma systems: prehospital; hospital; intrahospital; interhospital; government
- Quality assurance
- Research
- The place of the Medical Corps of the Israel Defense Forces in the trauma system in Israel

Mass Casualty Situations (MCS)

– Definition and general guidelines
– Biological, chemical, and toxicological MCS
– Training of personnel for MCS
– Hospital headquarters in MCS
– Information center and debriefing
– Lessons learned from terror attacks in Israel
– Guidelines and protocol: initial assessment and treatment of a single patient
– Medical management and treatment of mass casualty patients, special injuries

Participants complete the courses and workshops with a working plan consisting of clear ideas for the implementation of a Trauma System/Mass Casualty Situation Organization and a method for building of such organization in their own countries. Participants' exposure to the Israeli system and their personal efforts help to develop or upgrade trauma systems and improve the treatment of patients in their countries.

7.2.5 Summary and Conclusion

We have described the Israeli emergency model in all its levels, phases, and roles. In this model, a central national organization, the SHA, is responsible for the emergency policy, management, coordination, quality control, and ongoing improvement. The national leadership is characterized by a unique cooperation between a civilian organization (MOH) and a military organization (IDF Medical Corps). There is no better way to be ready for managing a real MCE than practicing ongoing preparedness activities (i.e., theory, simulations, drills) with multidisciplinary staff and all involved emergency services at the local and national level.

This chapter addressed the management of MCEs at the hospital level with emphasis on structure, roles, and step-by-step management. Throughout the chapter we highlighted the unique contribution of nurses on all levels and in all phases of managing MCEs in Israel. Nurses play significant roles both clinically and managerially in leading and organizing emergency events. Lessons gained from the presented model, particularly regarding unique nursing roles, may be considered for applicability in other countries.

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7.3.1 Rationale

The mainstay of terror related injury is blast. Blast injury is a multiorgan "disease" similar to blunt trauma, although specific site injuries tend to be more severe in nature, somewhat similar to high-energy multiple site-penetrating trauma [10].

Studies performed in Israel, comparing terror-related injury (TRI) to "conventional" trauma, have demonstrated a distinctive pattern of injury, characterized by multi-system involvement, high morbidity and mortality, high requirement for acute surgery, and prolonged ICU stay [22, 23]. The mortality pattern itself is different from the "classic" one observed in blunt trauma – including a higher in-field and in-hospital immediate mortality [8].

The blast injury mechanism has been classified to the primary blast effect and the accompanying effects that follow it and increase the extent of injury [24, 25]. Although this classification has been mentioned in numerous instances, it is worth mentioning briefly due to its implications on the diagnosis and treatment of the resultant injuries.

7.3.1.1 Primary Blast Effect

The primary blast effect is related to the rapid pressure wave created during the detonation of an explosive [26]. The scene location and type of explosive used have a direct effect on the severity of injuries. Blast wave energy tends to decrease rapidly in space and dissipate [27]. When blast occurs in a closed or confined space such in a bus or in a room, the blast waves are reverberated from the walls instead of dissipating [25, 27, 28], thus inflicting more damage on human victims. In a series of suicide bombing in Israel occurring in buses during the years 1995–1996, a threefold increase in primary blast injuries was observed when compared to open-space explosions, exemplifying this phenomenon [28].

Organs with air-fluid interface such as the lung are badly injured probably due to the pressure differences, causing parenchymal haemorrhage, pulmonary contusion, pneumothorax, hemothorax, pneumomediastinum, and subcutaneous emphysema [29].

The second most common type of primary blast injury is to hollow viscera. The intestines, most usually the colon, are affected by the detonation wave. Mesenteric ischemia or infarct can cause delayed rupture of the large or the small intestine; these injuries are difficult to detect initially. Rupture, infarction, ischemia, and hemorrhage of solid organs such as the liver, spleen, and kidney are generally associated with very high blast forces or proximity of the patient to the blast center [30].

Tympanic membrane injury has been extensively discussed in the literature dealing with terror attacks. It is the most common nonlethal injury caused by relatively low-pressure blast waves. Traditionally the presence of tympanic membrane injury was used to predict severe primary blast injuries (such as the lung or bowel); however this remains questionable and unreliable [31]. This will be further discussed in the triage section.

Limb injuries due to terror attack are usually not caused by the primary blast effect. Blast usually affects air-fluid interfaces and therefore limbs are probably less affected than the lungs or intestines. Hull and Cooper studied primary blast effects on the extremities resulting in traumatic amputations in Northern Ireland [32]. Only 9 of 52 victims with traumatic amputation survived, demonstrating the high level of energy needed to avulse a limb. In all 52 patients, the lower extremity amputation was at the level of the tibial tuberosity, and the limb was avulsed through the fracture site rather than through the joint. The coaxial forces produced the fracture, and dynamic forces (i.e., blast wind) caused the avulsion of the fractured limb [33].

7.3.1.2 Secondary Blast Effect

Secondary blast effects comprise the core of the orthopedic injuries observed in the 2000s Middle Eastern experience [23, 34, 35]. Secondary blast effects are related to penetrating injuries caused by fragments ejected from the explosives or the foreign bodies impregnated within it. The extent of this effect depends on the subject's distance from the detonation center, the shape and size of the fragments, and the number of foreign bodies implanted or created by the explosive. In contrast to most warfare injuries, the improvised explosives used by terrorists have multiple added fragments including screws, bolts, nails, and other objects that may increase the damage caused by penetrating injuries [36]. Open fractures, severe soft tissue injuries, and multiorgan penetrating injury are the more common pattern seen in the severely injured victim [36, 37] .

7.3.1.3 Tertiary Blast Effect

Tertiary blast injury refers to the blunt trauma component of the explosion. Flying or falling objects can cause additional traumatic elements in addition to the injuries occurring due to the primary and secondary blast effects [7]. Reports from other parts of the world, where structural collapse occurred, such as the one originating from the Oklahoma City explosion, state this as the primary mechanism of the injury [38], with devastating results.

7.3.1.4 Quaternary Blast Effect

The quaternary blast effect includes the thermal and chemical damage caused by fire and noxious substances occurring at the vicinity of the explosion. Confined-space explosions significantly increase these types of injuries [28].

The last effect originates from the fact that more and more suicide bombers are involved in modern terrorism, which may increase the risk of biological contamination of the victims with tissues originating from the terrorists themselves such as bone fragments [39]. The concerns of blood-borne infections such as hepatitis B/C and HIV should be born in mind when dealing with suicide bombers [40].

7.3.2 Preparedness

Mass casualty events are not simply large emergencies and they are very different from routine, daily emergencies [41–43]. They pose unique problems that require different strategies and are often characterized by initial disorder and chaos [44, 45].. The difference is more than just one of size as these situations cannot be adequately managed simply by mobilizing more equipment, personnel, and supplies [43, 46].

7.3.2.1 Surge Capacity

Creating a surge capacity may include the cancellation of hospital activities such as elective surgeries or redesigning the current inpatient space to accommodate more beds when needed [47, 48]. Patients may also receive treatment in nontraditional places within and outside the hospital [49], and treatment protocols may be changed so that patients may be discharged, who under normal circumstances would not (also known as reverse triage) [48].

Two other issues related to surge capacity include staffing and supplies. Lack of available and appropriately trained staff may be an issue during public health crises. Staff may be off duty due to illness caused by infectious diseases, as happened during the severe acute respiratory [50] syndrome (SARS) outbreak [47] and 2009 H1N1. Hospitals also store limited supplies on site. This "just-in-time" inventory creates a significant threat to a successful disaster response as many hospitals now do not have adequate supplies on site [50–52] as was evident during the 2009 H1N1 pandemic when supplies of personnel protective equipment (PPE) were in short supply or had run out. The provision of the "normal" standards of care may be difficult under disaster circumstances [53–56] and this raises ethical concerns which require further work and discussion [49, 57, 58].

7.3.2.2 Triage

Disaster triage is the process of allocating treatment and evacuation priorities to patients based on the severity of their injuries [4, 59–63]. This course of action is usually outside the normal daily experience of most emergency healthcare providers [43] and can be very difficult [64]. Patients may present with injuries different from normal emergency department presentations [42, 44]. Additionally, patients may present from different age groups (such as pediatric patients) [65] and emergency healthcare professionals may have limited experience in triaging children [66]. Special expertise will also be required in triaging those patients who have been exposed to chemical, biological, radiological or nuclear insults [54, 67]. Compared to routine practice, triage principles during a disaster require an entirely different approach to evaluation and care and often run counter to training and ethical values [68–70]. Due to potential resource limitations [41, 70], mass casualty triage is aimed at ensuring that medical resources are directed at achieving the greatest good for the greatest number of people [45, 49, 61–63, 68, 71–74], in an attempt to reduce mortality and morbidity [43, 60, 68, 70].

Patients requiring triage are sorted into four categories: immediate, delayed, ambulatory, and expectant. Immediate patients are deemed to be critically injured and require immediate intervention. Delayed patients are those who are injured but not expected to die within the first hour of care if not treated. Ambulatory patients can walk and are presumed not to be critically injured. Lastly, expectant patients are those patients who are presumed deceased or have catastrophic injuries and survival is not expected [55, 63]. When resources are inadequate, triage undergoes the process of rationing in which scarce resources are distributed in a prioritized manner to the neediest [62]. In a mass casualty event, many people with clinical conditions that are survivable under usual healthcare system conditions may have to forego life-sustaining interventions owing to scarce resources [68, 75]. Triage of scarce resources is an extreme option; therefore, training and familiarity with the triage and allocation process is vital. This requires advanced consideration and is best accomplished prior to any mass casualty event [75].

7.3.2.3 Damage Control Strategy

Since the majority of terror attacks in civilian populations occur in crowded areas, the number of victims exceeds the treatment capacity allocated routinely in all levels. Therefore, "damage control" strategy is the most appropriate one in this stage and correct allocation of resources will ideally minimize under-triage, resulting in less missed fatal injuries, and at the same time can avoid over-triage that would cause exhaustion of the system when minor injuries are overtreated [76] . One of the core concepts of disaster preparedness is to have straightforward plans and protocols that staff are familiar with and can automatically follow [77, 78]. These plans should be consistent with normal arrangements wherever possible to minimize confusion and maximize compliance.

Here are some principles and recommendations following the damage control strategy.

On-Site Level Reading the memoirs of one of our anesthesiology faculty members recalling their impressions upon encountering a scene will demonstrate some of the difficulties in the field level [79]: "I did not know what to do. Should I choose one survivor, giving him or her the best treatment I could, and abandon the others? My first-aid kit seemed ridiculous among the multiple casualties." Besides the frustration there are some other considerations to be taken: (1) The existence of broken glass, sharp objects, and noxious materials may be dangerous for both the victims and the treating team on the scene. (2) Many terrorists employ a "second wave" delayed bombing intended to kill and injure the rescue team as well as other population gathered around the scene, creating an unsecured zone. (3) In an urban setting the distance from the hospital is usually short and the number of available vehicles is usually sufficient for immediate evacuation of victims. (4) Availability of a level I trauma center in most of the targets of terrorism attacks (major cities) rarely requires prolonged patients transport. Therefore, all efforts should be concentrated on rapid evacuation of victims without any delay. Victims with amputated body parts who are not showing signs of movement and those who are pulseless with dilated pupils are considered dead *(expectant patients*). Attention is directed to evacuate the remaining victims. The rationale is to limit the number of interventions on scene to secure airway, major external bleeding control, and tension pneumothorax decompression; all other things can be done en route [9, 79].

In the progress of such an event, to minimize chaos and maximize control, the first team in the field takes responsibility at the scene level after the arrival of additional teams. The responsibility is redirected according to the pre-planned strategy.

Evacuation Unlike isolated events when EMS services should be instructed to evacuate patients to the nearest level I trauma center, this policy has not been implemented at all times when mass causalities have occurred [80]. Therefore, due to the very rapid evacuation (average 5–10 min), the nearest hospitals and not the nearest level I trauma center have received the major mass of patients. These hospitals are actually converted from treating facilities into triage stations receiving the bulk of patients and then act as referring centers for more critically ill patients [80]. This "damage control" evacuation scheme requires initial triage is done in the field, due to the imminent danger of a "stay and play" policy, and further triage is performed at the *nearest hospital* and en route by the EMS services, in order to funnel the patients to the correct treatment facilities.

Emergency Department Level Unlike the events on September 11 2001, Oklahoma city building, the Madrid and London events, when analysis demonstrated that emergency departments were theoretically readily capable of handling the number of critically ill patients [81], our experience proves that this was not the case in many of the attacks in Israel, and a scenario of an overcrowded and understaffed emergency room was possible. There are several explanations to these differences: First, the distance from the hospitals as well as the training of the EMS services might add to the speed at which patients arrive in the OR; while in London the critically ill patients were received in the level I trauma center within 1–2 h [4], in Hadassah hospital in Jerusalem, on one occasion, 18 critically ill patients were evacuated within 6 min after the onset of the event [10], with a maximal time of 43 min to arrival [13] . Second, the mechanism of injury dictates different on-scene mortality and morbidity. While structural collapse occurs, such as the World Trade Center event in 2001, the total number of critically ill (ISS >15) patients admitted to the two nearest level I centers was 20 [82], while in an average suicide bombing explosion in Israel during 2000–2003, 26 % of patients were critically ill [14] averaging about 4–8 per event that is 90-fold less in magnitude – thus paradoxically, higher mortality due to a higher-energy mechanism might lead to less load on the ED.

Despite the above, the majority of patients in these causalities are "walking wounded" and not critically injured [14]. Critically injured patients can be missed while attention is being given to the latter [83].

Logistics of ED management have a major impact on triage. The non-critical, non-terror-related patients should temporarily be evacuated to the hospital floors while the seriously ill patients can be treated in designated areas. The trauma bays are then dedicated only to resuscitative efforts done on critically ill patients and the rest of the ED is divided into an admitting area for the rest of the patients. Each area is designated with a surgeon in charge of the other members of the treating team (surgical and orthopedic residents, nurses, medical students, etc.). The surgeon in charge acts in critical moments [10]: Triage at the initial admitting phase and in treating cycles whether directed to the OR, admitting floors, or diagnostics are constantly done until the general chaos is reduced. Of course these logistics are specific for each hospital based on its setting and should be ready for use when the right time arrives [22, 81, 84, 85]. Over-triage should be encouraged, provided that the personnel and space for doing so are allocated, therefore not interfering with the care of the more critically wounded patients [12]. Despite that, over-triage can exhaust hospital resources such as blood banks and imaging facilities [86–88].

A system in which the surgeon in chief of the event is gathering information in repeated rounds of triage and then delegates the team surgeons, the diagnostics and treatment, until the next rounds allows better control and allocation of resources. This was termed the "accordion method" [12] and was utilized successfully in numerous events in our hospital (Fig. 7.2).

7.3.2.4 Information Centers

Mass casualty events invariably trigger a state of urgency, instability, and unrest among the general public, disrupting the lives and daily routines of the families involved. The state of crisis produced by a mass casualty event is particularly acute because news of terror attacks tends to reach hospitals and the general public almost simultaneously. Immediate implementation of effective communication between the families of victims and the hospital is therefore critical. Although all hospital units dispensing medical care to trauma victims are organized according to specific "mass casualty" protocols and checklists, the family/public information center (FIC) is deployed to respond to the immediate needs of families affected by the mass casualty event. These families are primarily concerned with locating relatives who may have been hurt or killed in the attack [89].

7.3.3 Diagnostics and Management

Some important and unique triage and physical and diagnostic efforts have been taking place in recent years, giving us a better perspective on the management of multiple casualty events. Since the number of patients may exceed the diagnostic capacity of the facility, these should be prioritized. The CT scanner is well known to be the "bottleneck" [85] in these scenarios and many recommend restriction of its use solely for head injuries [4, 88].

Early predictive signs: In two studies originating from Jerusalem [30, 86], physical signs such

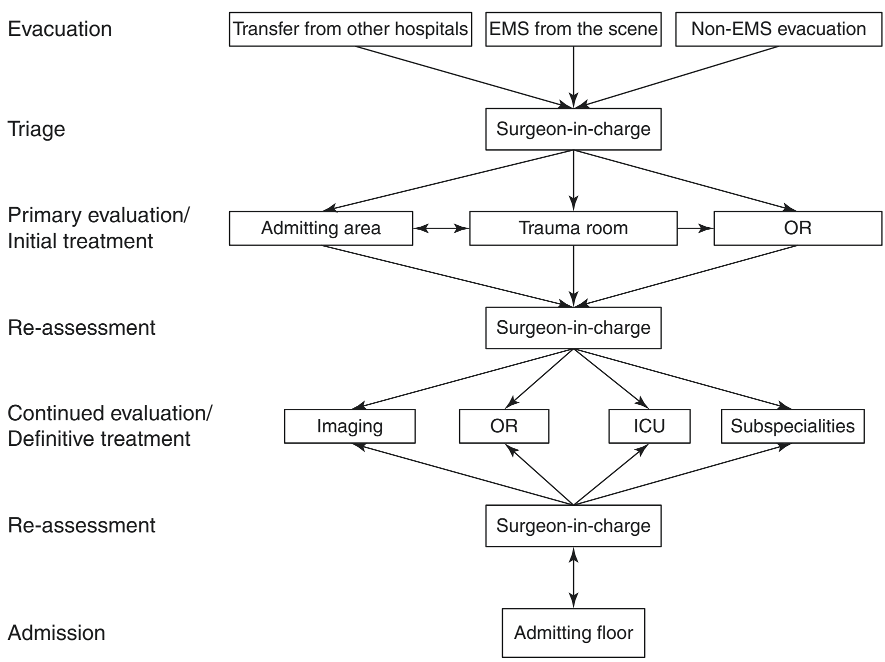

Fig. 7.2 The triage method in our institution depicts the role of the "surgeon in charge" in mass casualty events – with converging and diverging decision points, similar to an accordion

as penetrating injury to the head and penetrating injury to four or more sites were highly predictive of blast lung injuries. It should be mentioned that since many of the victims in suicide bombing are facing away from the detonation, examination of the back is crucial [10].

Penetrating torso injury as well as penetrating injury to four or more sites was highly predictive of intra-abdominal injury. At the London attack [4], CT was used only for the evaluation of head injuries, while laparotomies were performed only on the basis of ultrasound examination. Hypotension as a result of penetrating injury was also used as a guideline for laparotomy in an abbreviated "damage control" strategy [10]. However, when the number of critically injured patient is small, normal diagnostic efforts can safely take place [90].

In a work [91] comparing gunshot injuries to blast injuries, the existence of a long bone fracture was indicative of a more severe ISS, morbidity, and mortality. Therefore a long bone fracture may alert the surgeon that life-threatening injuries are imminent in this subgroup of patients.

The patient flow out of the trauma bay should be directed in a "one-way" system, moving the patients after their diagnostics if needed either to the operating room or to the ICU, never to return back to the ED or the trauma unit [10, 92]. Availability of multiple ORs simultaneously during such an event is a key factor, since up to 50 % of admitted patients will need some form of a surgical intervention [11]. Although in a single event like the Madrid and London bombings a single time effort of having multiple ORs was feasible [4, 93], repetitive events may exhaust the system as experienced in Israel [12].

Despite that, some events may result in a limited number of critically ill patients. In that case, a more systematic approach should be used, allowing a more liberal use of diagnostic studies and utilization of resources. These events were recently termed as "limited multi-casualty events" [90]. Care should be taken, however, to recognize a true mass casualty event and damage control strategies judiciously to avoid unnecessary delays in triage and treatment.

The next bottleneck usually encountered in terror attacks is the intensive care unit; since blast-injured patients have significantly more critical injuries than the "traditional" blunt trauma victims [11], ICU admittance is very predictable from our experience, ranging from 4 to 8 patients per an average event and usually comprising of 50 % of admissions [7], the very same proportion that was seen in the Madrid and WTC data [93]. Provisional ICU beds such as in the PACU or other surgical care units should be available while evacuating the general or trauma ICU. In case ICU vacancy becomes an issue, the event workflow can be seriously disrupted [7]. Special ventilation considerations should be given to blast-injured patients, and the reader is referred to the literature regarding the current recommendation on this matter [7]. A suggested workflow demonstrating the surgeon in charge (SIC) and the different working area is presented in Fig. 7.2.

7.3.3.1 The Morning After

As the case is with blunt trauma, the percentage of missed injuries can exceed 10–20 % [94, 95]; many of them (over 50 %) are musculoskeletal injuries. Thus, secondary and tertiary surveys are essential, since the orthopedic injuries are the ones commonly missed. The orthopedic trauma team had adopted, in our center, "morning after" rounds where records from the ED admitting area were used to allocate patients in the entire hospital. After a vigilant physical examination, all penetrating injuries were documented both literally and graphically, using the burn-unit diagram to describe the skeletal injuries distribution. More than once, fractures and foreign bodies requiring removal were found during that process. Most commonly, a general surgeon and a trauma nurse attended the "morning after" rounds in order to document and locate these injuries.

A thorough control of the entire population of inpatients is crucial not only at the acute phase of the trauma but also for later stages in order to plan late reconstructive procedures, cooperation with other disciplines, and control over the OR and the ICU.

7.3.4 The Role of Orthopedic Surgery in Mass Casualty Events

Blast injuries to the extremities are highly unpredictable and diverse. This is due to the fact that the amount of foreign bodies impregnated in the explosive is erratic as well as the distance of the victim from the detonation center. In a close proximity, the velocity of a fragment can be up to 1800 m/s but decreases very rapidly because of a lack of streamlining [17].

Blast injury to the extremities is different from the more familiar one caused by gunshot wound (GSW). The latter can be characterized by a fracture accompanied by a variable degree of soft tissue damage, depending on the energy and velocity of the bullet [96]. These are usually successfully treated according to standard protocols, including modern treatments such as intramedullary nailing [97]. In a study conducted by us [91], we looked into the patients' statistics as well as management of long bone fracture caused either by blast injury or GSW. The blast injury group had significantly more multiple fracture involvement, higher ISS, and mortality, while the GSW had more severe localized tissue damage such as high-grade (IIIB and C) open fractures and compartment syndromes. The national trauma registry statistics in Israel of patients with terror-related orthopedic injuries was published. Again, besides significantly more open fractures and amputations in terror victims as compared to blunt trauma patients, a higher ISS, mortality, and a higher requirement for surgery were found in the former [98]. Also, when comparing gunshots and blast injuries, the former, again statistically, involved more systems, had higher ISS and length of stay (including ICU), and were considered more "polytrauma" than the latter [99].

The surgical principles advocated for damage control orthopedics are more than appropriate in treating a critically ill patient with a terror-related injury with a long bone fracture [100, 101] – the average ISS of patients with long bone injuries caused by blast is 20 with 75 % associated injuries [91]. Besides the traditional markers, using the modified protocol of predicting blast lung injuries [30] can be helpful in determining the risk for a "second hit." Although we did not experience extensive morbidity attributed solely to an "early total care" approach that was widespread in our institution at that time, this may be masked by the severity of the accompanying injuries. A good illustrative case demonstrating the need for the adoption of the "damage control orthopedics" policy is presented. After a suicide bombing in Jerusalem, 2001, a 14-year-old girl sustained multiple fragment wounds to her lower extremities with extensive soft tissue damage. Her injuries included bilateral open fractures of the femora and tibiae, with bilateral obstruction of the posterior tibial artery. Following the injury the patient was taken to the OR and had all her fractures nailed in a 4 h procedure by multiple teams. Following that, she developed hypothermia and coagulopathy, the vascular injuries were not repaired, and she was transferred to the ICU. She continued to bleed profusely from multiple entry sites and received 57 units of red blood cells, 39 units of FFP, 14 units of platelets, and 19 units of cryoprecipitate. Twenty-two hours after admission, she received 100 mcg/kg of recombinant factor VIIa with an immediate improvement of her INR from 2.11 to 0.64. Patient was complicated with ARDS although initially her injuries were isolated to the lower extremities. The patient eventually recovered functionally – but the question of early total care in extreme situations should be raised, despite the availability of OR and multiple surgical teams during these events.

Based on our experience and the current literature recommendations to what we judge as appropriate clinical guidelines for damage control orthopedics when long bone fractures are encountered with blast injuries (Table 7.1).

It should be stressed that the direct evidence for the use of this policy in a specific subset of patients is still lacking. We can logically presume that what may be the treatment of choice in blunt trauma may apply to these unique circumstances. The fact that the patients in question are generally more critically ill may even strengthen these assumptions. More data and evidence including objective measures such as platelet counts, temperature, coagulation studies, and finally inflammatory profiles still need to be studied.

7.3.5 Benefits and Risks

As described earlier, there are some controversial issues when dealing with mass casuality events. Our suggested protocols and experience are a bit different from those described elsewhere. We would like to touch on a few of the unsettled points mentioned above:

1. Prehospital care: although increasing evidence supports the “scoop and run” [102] policies for general trauma care, at the face of a dangerous working zone that might be trapped with a timed second explosive or sharp objects, the minimum should be done on the scene. The personal risk associated with over-resuscitation is too high and outweighs the risk of under-resuscitation at the unsafe scene.
2. Evacuation to a trauma center or to the nearest hospital: reality demonstrates that sometimes the nearest hospital might serve as an outpost triage hospital [13]. This unsettled question of the desired evacuation pattern is still to be answered with the risks and benefits of each approach.
3. Implementing abbreviated diagnostic measures: use of external signs for determining the severity of injury, relying heavily on US, and avoiding the unnecessary use of the CT scanner – at that setting, usually false-positive surgery (so far on a minor amount of cases [10]) a risk that far outweighs over delaying treatment and creating bottlenecks.
4. Damage control orthopedic surgery: the risks of immediate intramedullary nailing of certain critically ill patients had been repeatedly demonstrated [103, 104]. There is no doubt that critically ill terror attack victims are usually “sicker” than their counterpart blunt trauma patients [11] even when controlling for the same skeletal injuries [98]. The open nature of these procedures usually mandates repeat debridement in any case. Therefore, safe conversion to internal fixation can easily take place. It has been shown that performing it in a reasonable time basis will only add a minimal risk of infection [105].

Table 7.1 Guidelines and recommendations for damage control orthopedics in blast injuries

Damage control orthopedics
Either one of the following: penetrating injuries to > 4 body areas with foreign bodies, penetrating head injuries
Multiple long bone injuries (>1 long bone fracture) due to blast regardless of other injuries
ISS > 20
Blast lung injury

7.3.6 Summary

Terrorism is the modern war for the human race. It achieves chaos and mass hysteria and the occasional overwhelming of medical care systems and other municipal public services. The battlefield is no longer remote [2]. Preparedness, drills, and implementing damage control strategies are crucial to minimize mortality and morbidity of a significant proportion of critically injured victims of this dreadful era.

Damage control does not apply only to the hospital scene – it is a way of treating the victims at the immediate scene, using only airway-saving procedures, and evacuating the patients to the nearest hospital as an outfield triage post. Using convergent and divergent control pathways allows for overcoming the chaos at a mass casualty event and educated decision-making by the most senior authority [106]. Control must be maintained at all times using our suggested scheme. Limitation of resources such as imaging, blood products, and the resuscitation bay at the trauma units requires dynamic and fast management of patients, without delaying necessary emergency procedures. Using the proper diagnostic studies and the judicious use of CT scan with priority to head-injured patients is necessary.

Patients suffering from long bone fractures due to blast are more critically injured than their counterpart blunt trauma or gunshot patients due to the high energy absorbed. Damage control orthopedic principles should be liberally used in this subset of patient population. Following the acute event, re-rounding and locating all the patients using a tracking list and meticulous documentation minimize the risk of missed injuries.

Mass casualty events are not simply large emergencies and they are very different from routine, daily emergencies. They pose unique problems that require different strategies and are often characterized by initial disorder and chaos. One of the core concepts of disaster preparedness is to have straightforward plans and protocols that staff are familiar with and can automatically follow. These plans should be consistent with normal arrangements wherever possible to minimize confusion and maximize compliance.

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8 Individual Preparedness in Disaster Response

Wilson Li and Anthony Redmond

8.1 Introduction

Sudden-onset disasters continue to cause extremely high numbers of casualties in the new millennium (Table 8.1). Having overwhelmed the local and national medical facilities, many countries have called upon international medical teams to provide surgical support as many of those rescued had suffered life-threatening injuries that required emergency surgery (Table 8.2). After earthquakes in particular, many survivors have incurred severe musculoskeletal injuries that necessitate repeated operations (Fig. 8.1).

The international response to sudden-onset disasters has been highly variable in terms of skill, experience and accountability, particularly with regard to the standard of practices in the delivery of emergency medical humanitarian assistance and surgical intervention [4]. Once the acute phase with its accompanying intense media attention has passed, many teams failed to provide sustained and coordinated follow-up action. Many who responded were well meaning and enthusiastic but were ill prepared for the challenges they would face.

There has been a wider move in recent years to improve humanitarian intervention standards and preparedness. Specific concerns have centred on needs assessments, clinical competency,

Table 8.1 Ten worst natural disasters of the twenty-first century

1. 2010 Haiti earthquake	Death toll: 316,000
2. 2004 Indian Ocean tsunami	Death toll: 230,000
3. 2008 Cyclone Nargis	Death toll: 146,000
4. 2005 Kashmir earthquake	Death toll: 86,000
5. 2008 Sichuan earthquake	Death toll: 69,197
6. 2010 Russian heat wave	Death toll: 56,000
7. 2003 Iran earthquake	Death toll: 43,000
8. 2003 European heat wave	Death toll: 40,000
9. 2011 Tōhoku earthquake and tsunami	Death toll: 18,400
10. 2001 Gujarat earthquake	Death toll: 19,727

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_8

Table 8.2 Earthquake deaths and injuries

Year	Location	Deaths	Crush syndrome cases	Dialysis cases
1988	Spitak, Armenia	25,000	600	225–385
1990	Northern Iran	>40,000	Not reported	156
1995	Kobe, Japan	5,000	372	123
1999	Marmara Region, Turkey	>17,000	639	477
1999	Chi-Chi, Taiwan	2,405	52	32
2001	Gujarat, India	20,023	35	33
2003	Boumerdes, Algeria	2,266	20?	15?
2003	Bam, Iran	26,000	124	96
2005	Kashmir, Pakistan	>80,000	118	65
Total		>217,000	>1,900	>1,200

Source: Adapted from Sever et al. [9]

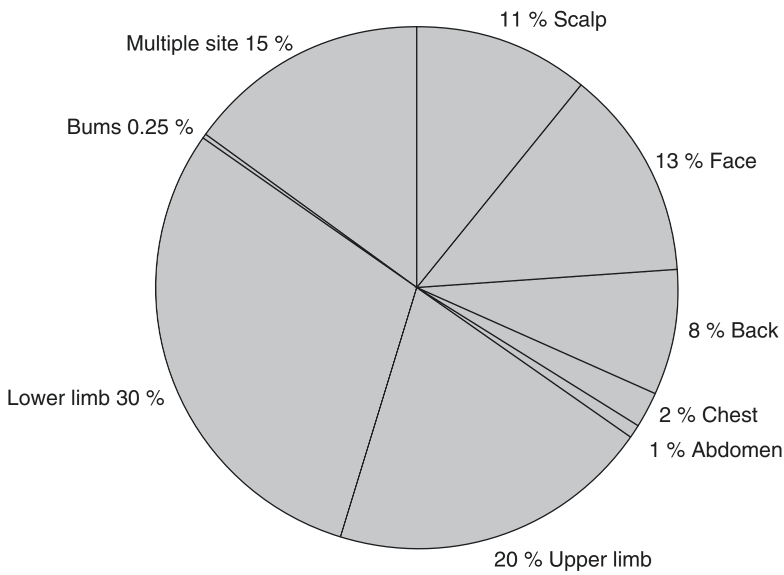


Fig. 8.1 Typical profile of injuries arising from earthquakes

record-keeping and patient follow-up. Accountability, quality control, coordination and reporting are beginning to be addressed by the international community. In this chapter, we will deal with preparedness of the individual medical worker in a disaster relief setting, with special reference to surgical activity and in particular orthopaedic surgery. Existing practice in different parts of the world will be drawn upon as examples.

Anyone planning to provide surgical services to foreign countries in a sudden-onset disaster must prepare themselves well and have acquired a set of core ('hard skills') and psychosocial ('soft skills') competencies.

8.2 Core Competencies

Training for core competencies includes both clinical and non-clinical skills. The healthcare provider should already possess an expert level of surgical or nursing skill in the management of major trauma and be flexible enough to adapt them to an austere environment, with limited diagnostic, and at times therapeutic, resources. Triage skills are a core component of disaster management as the number of casualties will inevitably at least for some time exceed the medical capability. Those who respond must understand that true epidemics do not usually follow earthquakes and that the unburied dead in a sudden-onset disaster poses little health risk to the living but that the movement of survivors into inadequate shelter with poor water and sanitation facilities will increase the risk and spread of infectious and usually diarrhoeal diseases. In addition to the consequences of natural phenomena such as earthquakes and tsunami, awareness of other environmental hazards (e.g. chemical, biological and radiation) is essential. The 2011 Tohoku earthquake and tsunami with the subsequent nuclear plant leak was an example at hand.

Updates in the practice of clinical medicine and surgery in a resource-limited setting should be incorporated into the training of the individual. The STAE (surgical training for austere environments) course at the Royal College of Surgeons of England in the United Kingdom is an example. The impact of disasters is further increased when they hit remote rural areas where pre-existing medical facilities were already scarce. The affected community might not understand or accept 'outside' international assistance, so negotiation may be required to achieve compliance. Diagnostic aids, such as laboratory or radiological support, may be lacking locally, so it is important to have already done a needs assessment or negotiated with the local authorities to determine what diagnostic equipment the foreign team needs to take into the area. In particular, the supply of electricity may be erratic, and hand-powered surgical instrument should always be included in the team's equipment.

Non-clinical skills might prove as important as the clinical skills in a disaster setting. The healthcare worker must familiarize themselves with the logistics chain of the medical supplies. Forward planning is essential as shipment of reinforcement supply might take weeks or months. Besides the medical supplies, team members must have knowledge of the supply of basic needs such as water, food, sanitation, safety and security.

Teams that deploy must be equipped with and be able to use radios and satellite phones as landline-based telephones are often down in the early stages after the disaster and it can take some time to re-establish Internet connection. Pre-deployment training must include drills to practise the use of GPS and communication equipment; this might prove life-saving in times of need. As part of the pre-deployment training and deployment briefing, each team member must be familiar with the emergency rescue evacuation protocols.

8.3 Psychosocial Competencies

Mental preparation is as important as clinical skills. Involvement in disaster relief can be highly stressful, with long and erratic working hours, personal security and safety concerns, a seemingly overwhelming number of casualties and their relatives and sometimes suboptimal treatment outcomes. The psychological stress is not limited to the time of the deployment, but may extend beyond the time the worker returns to the original situation. Predeparture health screening to exclude from deployment those who already have a significant psychological or mental health issue is required. Syndrome has been reported among aid workers [14]. Flashbacks and déjà vu, and a sense of guilt due to departure, were among the reported symptoms. Good psychological preparartion may be helpful for individuals going to the field [13].

Good psychological preparation is necessary for individuals going to the field. This may include stress relief techniques, counselling or even mental training. The formation of peer support groups (buddy systems) is an additional mechanism that might help to limit the impact of stress upon fieldworkers. Post-mission debriefing procedures should raise awareness of potential psychological issues rather than immediate automatic critical psychosocial debriefing.

A disaster relief mission does not affect only the individual worker but impacts greatly on family and colleagues. Mundane day-to-day activities at home will still require attending to and must be part of predeparture preparation, particularly for overseas deployment that may extend for a prolonged period.

8.4 New Challenges

Today, medical relief workers are facing new sets of challenges due to a rapidly changing environment. There are multiple actors in the international humanitarian relief response, including both governmental and increasingly nongovernmental organisations. New roles emerge for the military, who are often the first forces mobilized to the disaster zone. There are also new and evolving standards and guidelines on medical practice in disaster relief [10].

New equipment and products also come out at an unprecedented pace, making it essential that teams use equipment with which they are very familiar and that is appropriate to the context in which they work. It is essential that equipment taken into another country is compatible with that used by the host medical facilities. Incoming teams must demonstrate the ability to provide relevant, timely and well-targeted interventions, and countries only deploy trained and prepared teams.

It is becoming increasingly appreciated that incoming foreign medical teams must have the ability to rapidly adapt to a different culture, language, professional practice and working and living condition and understand the need to coordinate, build and work in teams, to interact with communities across sectors (health, water, sanitation, shelter, nutrition, security, gender, the environment) and to understand how these links impact upon the overall health and wellbeing of the disaster victims. In short, they need to develop the capability to communicate effectively with many stakeholders in the field. There has been attempts in establishing training and accreditation standards for individual preparedness for disaster relief in different parts of the world in recent years [7].

8.5 The Americas

In North America, the United States has disaster training courses for both civilian and military surgeons. The American College of Surgeons Committee on Trauma developed the Disaster Management and Emergency Preparedness (DMEP) course to help surgeons interested in disaster relief develop the necessary skills, understand the language and appreciate the structural transformation for effective response to mass casualties in disasters [1]. This programme aims at getting the individual ready for the common surgical emergencies that may accompany a disaster, as well as the special skills of operating in an austere environment. The American Academy of Orthopaedic Surgeons (AAOS) and the Orthopaedic Trauma Association (OTA) run a Disaster Preparedness and Response Course which has been developed by the Society of Military Orthopaedic Surgeons (SOMOS) [2]. This training course is designed specifically to help prepare orthopaedic surgeons for the unique patient care requirements and personal challenges presented by the austere environments of disaster. Orthopaedic care techniques critical to disaster-inflicted injuries and treating the wounded in austere environments are taught in a full day of lectures and a half day in a cadaveric skills laboratory, covering topics like clinical orthopaedic skills needed in austere environments, personal and team preparation, cultural sensitivity, medical ethics in disaster medicine, lessons learned in previous disasters and an overview of disaster response structures (governments and NGOs). Supplemental training under the Core Disaster Life Support (CDLS) Course introduces participants to common background knowledge in disaster-related medicine and public health that can be reinforced and expanded in the Basic Disaster Life Support™ (BDLS®) and Advanced Disaster Life Support™ (ADLS®) Courses. From the military side, the SOMOS represents a broad spectrum of active duty, retired and reserve military orthopaedic surgeons, who take the lead in many fields of orthopaedic surgery in disaster areas such as Haiti and in austere environments across the globe [11].

The International Medical-Surgical Response Team (IMSuRT) is a US-based mobile civilian medical and surgical unit staffed by professionals from medical and bioengineering fields, with the ability to rapidly mobilize appropriate manpower and equipment to a mass casualty site domestically or overseas. IMSuRT works in cooperation with local authorities at the mass casualty site to provide rapid assessment and medical stabilization of injured persons. When the mass casualty is overseas, rapid evacuation of casualties is accomplished by the responding US military air evacuation service. InterAction, on the other hand, is the largest coalition of US-based international nongovernmental organizations (NGOs) working to focus US development and humanitarian assistance on improving the conditions of the world's poor and most vulnerable. InterAction members have responded to numerous natural disasters and complex emergencies around the globe, providing direct relief and support to affected populations. InterAction serves as a hub for its members by assisting them to educate the public, coordinate with one another and engage with and do advocacy work on the issue.

On the other hand, the Surgeons OverSeas (SOS) programmes concentrate on emergency and essential surgical care – basic and life-saving procedures that can easily be undertaken and taught in resource-limited environments. SOS also provides a forum for surgeons and residents in developed countries to more easily connect with colleagues in developing countries. Their philosophy is to empower local surgeons and physicians to safely provide the surgical care that is needed for disaster relief. The aim is not to provide a 'Western' standard of care, but to develop local solutions within the constraints of each local situation.

8.6 Europe

The United Kingdom has established an international emergency trauma register (UKIETR). This is focused on a surgical response to sudden-onset disaster, particularly in regard to limb salvage surgery. Surgeons and other healthcare workers who wish to consider volunteering for a national overseas disaster response are invited to join the register. Pre-deployment and deployment training is provided along with overseas experience working alongside in country NGOs. Anaesthetists take the well-established Anaesthesia in Developing Countries course run by the University of Oxford, and surgeons are directed towards the STAE course of the Royal College of Surgeons of England. This combines training in the management of both crush and ballistic injuries and training by the Royal College of Obstetricians and Gynaecologists in the management of obstetric emergencies.

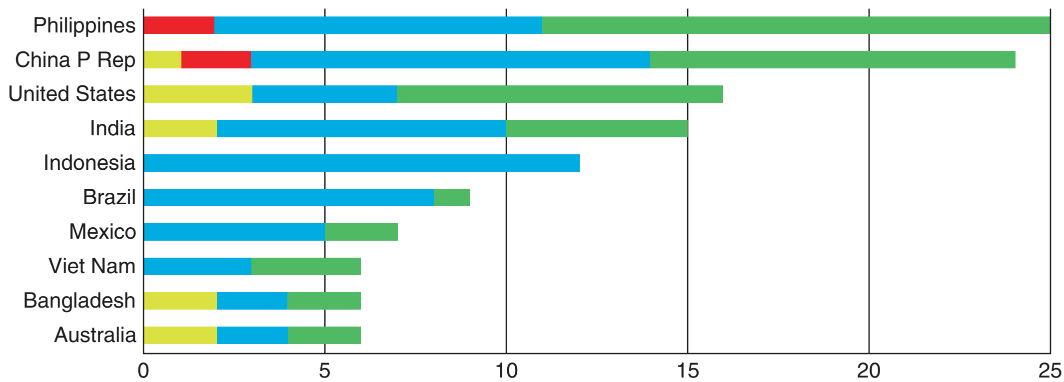
There was an attempt by the European Commission to establish a disaster training curriculum programme with the stated aim of developing a standardised, strong, comprehensive and efficient EU wide approach to crises and disasters. Whilst the DITAC programme was not completed, the EU continues to look to the possibility of a European wide disaster response.

8.7 Asia-Pacific

Situated in the 'Ring of Fire', Asia-Pacific is the most geophysical disaster-prone region in the world. The incidence of climate-induced disasters is also high compared to other regions [5]. Indeed seven of the top ten countries that reported the highest number of natural disasters are situated in this region (Fig. 8.2). Past disaster trends suggest that high-density population in Asian cities increases the mortality and the number of affected people in a typical disaster event, which in turn also results in increasing economic losses in the region (Fig. 8.3). Unfortunately, this is also the region with the largest number of countries with critical shortage in healthcare providers, after Africa (Fig. 8.4).

The Asian Urban Disaster Mitigation Program (AUDMP) implemented by the Asian Disaster Preparedness Center (ADPC) has contributed substantially to the present recognition in the countries of the region of the importance of disaster mitigation to the process of sustainable development and economic growth and stability. AUDMP established strong networks of regional and national disaster mitigation professionals and experts who can continue to help replicate disaster mitigation models unique to the Asian context throughout the region. The programme built the capacity of ADPC to be able to support regional disaster mitigation initiatives in Asia through these networks of institutions and professionals both technically and at policy decision-making at the highest levels of government [3].

In Asia, the Japanese Government had initiated the process of establishing a disaster management centre. In the Philippines, there was an attempt to establish a centre based on the ADPC model, resulting in the formation of the Health Emergency Management Staff (HEMS) under the Department of Health, which is managing emergencies and disasters in the health sector. It actively represents the department to the National Disaster Risk Reduction and Management Council (NDRRMC) in the country and advises on disaster preparedness for medical workers. A new disaster mitigation programme was also initiated with Japanese



	Philippines	China P Rep	United States	India	Indonesia	Brazil	Mexico	Australia	Bangladesh	Viet Nam	Total
Climatological	0	1	3	2	0	0	0	2	2	0	10
Geophysical	2	2	0	0	5	0	0	0	0	0	9
Hydrological	9	11	4	8	7	8	5	2	2	3	59
Meteorological	14	10	9	5	0	1	2	2	2	3	48
Total	25	24	16	15	12	9	7	6	6	6	126

Fig. 8.2 Top ten countries by number of reported events, CRED 2009 (Source: EM-DAT: The OFDA/CRED International Disaster Database www.emdat.be – Université Catholique de Louvain – Brussels – Belgium) [8]

Country	Disaster distribution	No. of deaths	Country	Disaster distribution	Deaths per 100,000
India		1,806	Samoa		81.5
Indonesia		1,407	American Samoa		51.4
Philippines		1,334	Tonga		8.7
Taiwan		630	El Salvador		4.5
China P Rep		591	Namibia		4.4
Australia		535	Solomon Is		4.1
Peru		419	Bhutan		3.3
Viet Nam		356	Taiwan		2.7
Italy		335	Australia		2.5
El Salvador		275	Sierra Leone		1.9

Climatological Geophysical Hydrological Meteorological

Fig. 8.3 Top ten countries stricken by sudden-onset disasters by total number of deaths (*left*) and by proportion of deaths per 100,000 population(*right*)

Fig. 8.4 Countries with a critical shortage of health service providers (doctors, nurses and midwives)

and UN funding, called the RADIUS that was designed around similar principles as the AUDMP, and resulted in the implementation and documentation of demonstration projects but focused on earthquake mitigation.

On individual preparedness for surgeons and nurses, the Tan Tock Seng Hospital Trauma Training Centre in Singapore and the Queen Mary Hospital Surgical Skills Training Centre in Hong Kong are the regional trauma training hubs. Both centres run several regional trauma courses such as the Definitive Surgical Trauma Care (DSTC) Course, the Advanced Trauma Life Support (ATLS) Course and the Definitive Perioperative Nurses Trauma Care (DPNTC) Course. The DSTC course is developed under the auspices of the International Association for Trauma Surgery and Intensive Care (IATSIC) and is designed to teach qualified surgeons and advanced surgical trainees strategic thinking and decision-making in the management of the severely injured patients and provide them with practical surgical skills to manage major organ injuries. The teaching format included didactic talks, discussion groups and practical skills workshops on animal models.

In Australia, the National Critical Care & Trauma Response Centre (NCCTRC) was established as a result of the national response to the Bali bombings in 2002 and 2005. Its aim is to enhance surge capacity and provide clinical and academic leadership in disaster and trauma care. It is responsible for the training and deployment of Australian Medical Assistant Teams (AusMATs) for international disaster response. These multidisciplinary health teams incorporate doctors, nurses, paramedics, firefighters, logisticians and allied health staff and are designed to be self-sufficient, experienced teams that can rapidly respond to a disaster zone to provide life-saving treatment to casualties, in support of the local health response.

AusMAT's courses are at two levels: The basic team member courses which are considered the entry level one before a candidate is considered ready to be deployed on an AusMAT mission. Other mandatory requirements include registration on the NCCTRC database, vaccine programme, medical and fitness checks and ongoing training/exercises, foreign language classes, etc. The more advanced specialist courses are offered for registered team members aiming at specialist role training, in particular surgeons, anaesthetists, team leaders, needs assessment specialists and medical logisticians.

8.8 International NGOs

It is useful for potential volunteers and all those aspiring to work in international disaster relief surgery to familiarize themselves with the many acronyms of the range of organizations they will come across. Agencies can be divided into United Nations agencies, international organizations and nongovernmental organizations, including faith based and secular. The number of nongovernmental organizations involved in international medical work increases almost every day, each group having its own special skills, remit and mission statement. Some are faith based, although many others pride themselves on being very secular. In terms of nonsectarian organisations, Médecins Sans Frontieres (MSF), or 'Doctors Without Borders', is a medical humanitarian organisation that provides emergency medical humanitarian assistance including emergency and elective surgical services in both sudden-onset disasters and conflict zones, in some of the most austere environment in the world. MSF runs 'Surgical Week' training regularly to equip recruited workers with the capacity to assume their role as a truly general/trauma surgeon, gynaecologist or anaesthesiologist for MSF-specific setting within a MSF surgical mission. The aim is to enable new recruits to understand their role in the range of surgical activities that MSF performs and to understand surgical activities (gynaeco-obstetrics, anaesthesia, surgery) as part of a broader comprehensive medical care, each with its own task divisions and/or responsibilities. Participants come to understand the different kinds of infrastructures that they can potentially meet in the field and learn to deal with stress that might appear during their mission. The minimum prerequisites (preconditions) to start surgical activities are also defined, as well as the surgical protocols and guidelines. Preparedness planning to deal with cases of mass casualty due to emergency and disaster scenarios is discussed and practised in simulation workshops. Their additional role and responsibilities as Human Resources Manager as well as the supervisor, evaluator and trainer of the surgical team are explained.

8.9 Red Cross and Red Crescent Movement

The International Red Cross and Red Crescent Movement is the largest humanitarian network in the world. Its mission is to alleviate human suffering, protect life and health and uphold human dignity, especially during armed conflicts and other emergencies. The group is a unique international system consisting of three parts: The International Committee of the Red Cross, the International Federation of Red Cross and Red Crescent Societies and the National Red Cross and Red Crescent Societies. The International Committee of the Red Cross is a private Swiss corporation and is an independent and neutral organisation that promulgates an international mandate, the Geneva Convention. Individuals can volunteer for the International Committee of the Red Cross medical positions through their national societies. The federation has a membership performed from the national societies. Being a multinational organisation, it tends to be less involved in armed conflict and more in natural disasters. The International Committee of the Red Cross (ICRC) recruits staff, trains them and develops their skills, so that the organisation can call on a sufficient number of qualified personnel to support and conduct its operations. The International Mobilization and Preparation for Action (IMPACT) course is the basic individual preparedness training for humanitarian relief teams, while more specialised surgical and nursing trainings are provided for these workers before their departure for mission.

8.10 Format of Training

In the past, much disaster relief training has taken the form of classroom-based didactic lectures or discussion groups, coupled with role-playing and table-top simulation exercises. The background of many participants (highly specialised, lacking cross-cultural experience and effective communication skills, lacking practice in community entrance techniques and basic household interview skills) can leave them overwhelmed and without training, barely able to cope in real deployments to a disaster zone. Completing a classroom training course does not necessarily qualify all fully prepared people for complex humanitarian operations. In recent years, the International Federation of Red Cross and Red Crescent Societies (IFRC) developed a field-based training model focusing on humanitarian response in disasters. Five Field Schools were conducted (in Kenya in July 2007 and November 2009, Belize in May 2008, Cambodia in December 2008 and Fiji in June 2009) in this new format.

The settings selected for the field training missions were all remote rural communities with high rates of morbidity and mortality resulting from poverty and chronic disasters.

The thematic focus throughout the training has been on public health in emergencies, using a comprehensive approach encompassing water, sanitation, emergency shelter, nutrition and psychosocial support. The Field School is a new format of training, consisting of total immersion in a mission environment. The Field School emphasises 'learning by doing', while participants are mentored by experienced facilitators on a 24-h, 7-days-a-week basis.

The mission places participants in conditions of physical and psychological stress similar to those they are likely to experience in the early stages of deployment to major disasters. These participants are chosen against specific selection criteria and are required to complete a pre-course paper outlining their expectations, aims and objectives. They are also required to complete pre-course reading aimed at providing theoretical knowledge across response sectors.

Field School facilitators have extensive humanitarian field experience, as well as the proven ability to coach, mentor and support personnel in working environments. The facilitators promote continuous active learning and demonstration, coupled with a culture and ethic of true community participation.

Facilitators are constantly challenged to sharpen their own pedagogical skills and to be flexible, responsive and creative in meeting the learning objectives of participants.

Learning objectives are articulated in a defined but flexible curriculum. Participants are divided into small teams of five to seven people and are required to engage with communities in a 'real' disaster response. No classroom presentations are used.

The participants assess, plan, train local volunteers and implement short-term interventions, which have included disease prevention and health awareness activities. This work takes place in close partnership with local branches, volunteers and communities, thus simultaneously building local capacity. Improving communication skills and learning how to build trust with local counterparts are integral components of the curriculum. The Field School offers a unique chance to coach participants and practice communications with a variety of counterparts, often through interpreters and under stressful conditions. While engaged in the mission, the field teams manage budgets and work to tight deadlines. They also use existing disaster response tools, guidelines, manuals and templates, including communicating with simulated task forces and the media. Security awareness and simulations are also included in the curriculum. Where possible, the Field School links with ongoing activities in the area managed by the authorities, local Red Cross branches, the Ministry of Health and NGOs. These have included food or relief item distributions, health services and coordination meetings. Active coordination with other actors in a community is key to a successful intervention and one of the hardest tasks for teams under time pressures and stress. An additional component has been the field-testing of various relief and medical products, including rapid malaria tests, inflatable rafts, solar cells, rapid set-up latrines, shower tents and water purification systems. This component is seen as a vetting process to enable better decision-making in selecting the appropriate technology for the field.

Humanitarian aid continues to evolve from ad hoc assistance into a science that requires skilled and specialised personnel. Those engaged in the delivery of disaster relief surgery need not accept that they can only learn the skills they require during actual operations, possibly at the expense of delivering suboptimal services to stricken communities. Some recent external reviews confirmed the benefits of the Field School concept. The Field School has demonstrated that it can build upon classroom-based training, adding a practical layer through total immersion in disaster operations, representing a form of internship for humanitarian workers. In a real-life situation, participants learn to apply combined theory and skills, use appropriate tools and communicate effectively with communities and among themselves. This holistic multidisciplinary approach is uniquely possible in the type of mission environment the Field School provides.

The new format can be applied to other sector trainings as well, through the development and adaptation of existing classroom-based training modules and coaching by facilitators. The modular curricula can be modified to address longer-term community-based disaster preparedness and development.

The Field School concept could expand and become more effective through partnerships with other humanitarian organisations, applied research groups and academic institutions. It can also be used to field-test new concepts, devices, products and approaches before deploying them in actual emergencies.

The Field School has shown to be an appropriate and successful training format for developing the field skills of disaster response workers to an adequate and effective level. An improved response to disasters requires more coordination and collaboration among humanitarian organisations and academic institutions to further validate such approaches and gather further evidence. Mainstream tools can then be developed and adopted to improve disaster relief surgery outcomes overall. While the Field School model has addressed many of the gaps in the humanitarian working environment by focusing on developing the skill sets of humanitarian aid workers, a commitment is needed to the parallel development of policies, standards, guidelines and equipment for disaster response.

8.11 United Nations Affiliates

The earthquake in Armenia some 25 years ago probably marked the time when the current trend towards the dispatch of many foreign medical teams to sudden-onset disasters began. In an attempt to address the uncoordinated dispatch of teams of varying quality, two UN-affiliated organisations were established. The international search and rescue advisory group INSARAG was established in 1991, following initiatives of international SAR teams that responded to the 1988 Armenia earthquake. The United Nations was chosen as the INSARAG secretariat to facilitate international participation and coordination. The Field Coordination Support Section (FCSS), located within OCHA Geneva's Emergency Services Branch (ESB), functions as the INSARAG secretariat. INSARAG's principal functions are registration, classification, accreditation, training and retraining.

The United Nations disaster assessment and coordination team UNDAC was formed to allow a small team of experts across a range of specialties to be immediately dispatched to the disaster at the request of the host government in order to carry out an immediate needs assessment, publish this widely and then encourage donors to respond to specific requests and identified needs rather than a blanket uncoordinated untargeted influx of aid. In spite of UNDAC being in existence for a similar period as INSARAG, there remains an uncontrolled influx of humanitarian teams into disasters and usually including medical teams of unknown capability. The lack of classification and registration of the medical teams sits in sharp contrast to the mechanism that is now in place for the search and rescue teams. This contrast is put into even bolder relief when one acknowledges that the majority of those rescued in a sudden-onset disaster are rescued by their fellow survivors and very few indeed are rescued by foreign teams. The humanitarian emergency response review of the UK government analysed the cost-effectiveness of the dispatch of its search and rescue facility to the earthquake in Haiti alongside its dispatch of medical teams. Its conclusion was that medical teams are at least 100 times more cost-effective in terms of life saved than search and rescue teams.

However, the uncoordinated dispatch of medical teams is not always a good thing. An analysis of the surgical response to Haiti revealed unacceptable practices including lack of accountability to the patient of the host Ministry of Health, with poor or no record-keeping and no follow-up. To address these concerns, the Pan American Health Organization (PAHO) called a meeting of experts in Cuba in December 2010 to update its guidelines on the use of foreign field hospitals in the aftermath of sudden impact disasters. At this meeting, it was agreed that there were shared concerns internationally about lack of accountability, quality control, coordination and reporting and specific concerns about clinical competency, record-keeping and follow-up. It was recommended that a foreign medical team working group be established jointly between WHO and the Global Health Cluster and hosted by WHO in Geneva. The aim of the group was to oversee international registration of foreign medical teams (FMT). Terms of reference were agreed that confirmed WHO as the host agency, with membership drawn from representatives of the Global Health Cluster, selected main global providers of FMT, two designated NGOs, bilateral agencies supporting actively this initiative, two countries having been affected by the most recent mass casualty sudden-onset disasters, academic institutions engaged in this field, the World Association for Disaster and Emergency Medicine (WADEM) and individual experts from other organisations or institutions invited on a case-by-case basis [6]. The group was looking for a commitment to an adherence to a minimal set of professional and ethical standards and working in support of the national response. Teams were to ensure they were fostering onsite coordination with, and accountability to, local health service framework and demonstrating operational coordination, cooperation and record-keeping, data collection, data sharing and appropriate reporting. Of particular importance is the commitment to working only to the competencies for which individuals are recognised in their own country. As part of their remit, teams must see the need to support the development of a uniform reporting system to facilitate later analysis and to secure an organised exit strategy agreed with local health providers. In the future, providers of teams should be formally registered internationally to promote accountability and a level of training, equipment and preparedness that meets an agreed international professional and ethical standard [12]. In summary, registration of FMTs is to be seen as the first step on the road to quality assurance with each country establishing a national register and only deploying and receiving registered teams. In recognition of the need to build capacity in disaster-prone areas and reduce the travel time for foreign medical teams, there will be a concerted effort to establish regionally based teams and for the ongoing process of development to be guided by the experience of disaster-prone countries. The goal was to develop a set of functional criteria for classification and minimal standards for FMT required for such registration, as wells as a minimum set of information and reporting to the recipient health authorities. The classification and standards established by the FMG working group were applied successfully for the first time during Typhoon Hayaan in the Philippines in 2013 and again during the response to the earthquake in Nepal in 2015. The impact of foreign medical teams was further established during the response to the Ebola outbreak in West Africa.

WHO has now established an Emergency Medical Teams secretariat in Geneva in support of a Global Health Emergency workforce and online registration of teams has begun with a mentoring programme in place to support the development of national teams and to review their training programmes and equipment.

8.12 Telemedicine

In the modern age of telecommunications, one must now start asking serious questions about the need for expertise to be physically flown into a country when it can be provided virtually. Telemedicine links in the field can bring experienced clinical advice directly into the operating room much quicker than it can take for that person to make the journey in person. The experience of Haiti showed that GPS phones can also be used to track the movement of the population and thereby target where aid should be focused. Satellite and Internet facilities can be established in the remotest area as soon as the first help arrives, and in the near future, we should look to a much greater application of smart technology in the response to sudden-onset disaster.

Conclusion

At the root of the preparation for dispatch of a medical team to a disaster overseas must be the same principles and practice that guide everyday good medical practice. Medical teams must be appropriately trained and qualified and not be an ad hoc arrangement put together for a single incident. These teams should prepare planned protocols and practise regularly in drill scenarios. They need to be self-sufficient not just in terms of clinical competency, but also in terms of logistics support, including food, water, safety, and shelter. Teams should be registered nationally and respond to a specific request for help from the stricken country. Uninvited teams can only place a burden on an already struggling country that now has to host the uninvited incoming team and divert attention from their own response to the disaster. In order for affected countries to choose the teams they really need, those teams must have registered their capabilities with national and international authorities. Such invited teams must sign up to working with the local authorities and alongside UN affiliates and other colleagues in a cooperative and not competitive spirit. Most importantly, medical and surgical teams must recognise that, as in their own country, they must be authorised to practise medicine in the country where they now find themselves. Teams who are part of a recognised national response will gain such authority by intergovernment agreement, and other invited teams must seek such authority from the local Ministry of Health as it is they who are ultimately overall in charge of the medical/surgical response.

For the sake of the victims of these disasters, we must all work to ensure that the medical and surgical response is professional and that those who respond have the necessary specialist experience and expertise to bring optimal medical care to those in most needs and in the most difficult of circumstances.

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9 Orthopedic Equipment Needs in Disaster Setting

Punto Dewo, Nikolaj Wolfson, and Brendon Drew

9.1 Introduction

In mass-casualty events, such as natural disasters, surgical assets and resources could be damaged or become unavailable; hence, they need to be delivered by a disaster relief team. Disaster relief team should work with the goals according to the time of intervention and based on the attainment of reliable information regarding what is required [1].

In the initial phase, all efforts are made to save lives of as many people as possible. Following initial triage, resuscitation measures are taken according to ATLS protocol. Orthopedic care is based on the principles of damage control surgery. Any open fractures should be irrigated, realigned, and splinted or can be put on traction, either cutaneous or skeletal. Fast and easy applied external fixation systems can be used to facilitate more adequate fracture reduction and stabilization. Mangled extremity can be either amputated or salvaged. The choice and decision made are based on multiple factors. It depends upon condition of the damaged extremity, patient's general health condition, expertise of the treating team, resources available, and magnitude of the mass casualty event and other factors.

The window of opportunity, i.e., day 5 to day 10, can be used to perform redebridement, fracture reduction, and external fixation for open fractures or internal fixation for closed and/or intra-articular fractures. Later in the reconstructive phase (starting in the third week), further definitive surgery can be initiated. This can be in the form of exchange plating or nailing from provisional external fixation or more complex surgery, for example, arthroplasty for proximal femur fracture or soft tissue coverage (flap, skin grafting) for soft tissue loss. Correction of deformities, reconstruction of bone defects, or nonunions take place in the later stages of the patient's care. When patient's presentation is delayed, surgical approach is adjusted to accomodate patient's general health condition and bone and soft tissue compliance of the affected extremity.

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_9

9.2 General Equipment Needs for Initial Response Team

9.2.1 Portable Power Generator

In the austere environment after disaster, electricity is hardly available and may not in the area for the work of the relief team. Portable electric power generator is therefore very useful as the source of electricity in the field to power up lightings, sterilizator, patient monitoring systems, electrocauter device, and electric suction device.

9.2.2 Portable Sterilizator

The universal principles of sterility in treating musculoskeletal injury should by all means be followed as part of the rule of "first do no (more) harm" according to Salter [2]. All instruments even for damage control surgery must be sterilized properly prior to any surgical procedure. Portable autoclave or dry heat sterilizator should be considered as one of the first priority equipment for disaster relief team.

9.2.3 Electrocauter Device

In the catastrophe condition with a very large number of victims, initial response team needs quick handling and hemorrhage control. Electrocauter device is needed to reduce initial blood loss and blood loss during operation and reduce the need for transfusion. In the disaster zones, this device should be portable, handheld, and reusable.

9.2.4 Tourniquets and Topical Hemostatic Agents

Uncontrolled hemorrhage remains the leading cause of potentially preventable death in combat casualties. In the modern military conflicts, one-third of these deaths occurred as a result of extremity injuries with compressible injuries [3]. Ability of the bleeding from the large blood vessels to stop spontaneously is diminished due to the amount of the tissue trauma and often due to acute coagulopathy.

9.2.4.1 Tourniquets

Use of tourniquet goes back to 199 BCE–500 CE when Romans used it to control bleeding during amputations. The first reported use of stop extremity hemorrhage was back in 1674 during the siege of Besancon [4]. Controlling bleeding from the wounded extremities saved many lives during military conflicts [5, 6]. It has been shown that exsanguination from extremity wounds was the leading cause of preventable death among American casualties in Vietnam and accounted for 7.8 % of preventable deaths in the first 5 years of the conflicts in Iraq and Afghanistan [3].

There are two main types of tourniquets:

1. The traditional, noninflatable tourniquet that constructed of rubber or elasticized cloth
2. Pneumatic tourniquets that have cuffs and are inflated by compressed gas

Although pneumatic tourniquets are preferred and common in orthopedic surgery, tourniquets that have been used by the US military have proven more effective at hemorrhage control [6].

In the recent years, other types of tourniquet had been developed [7] (Fig. 9.1).

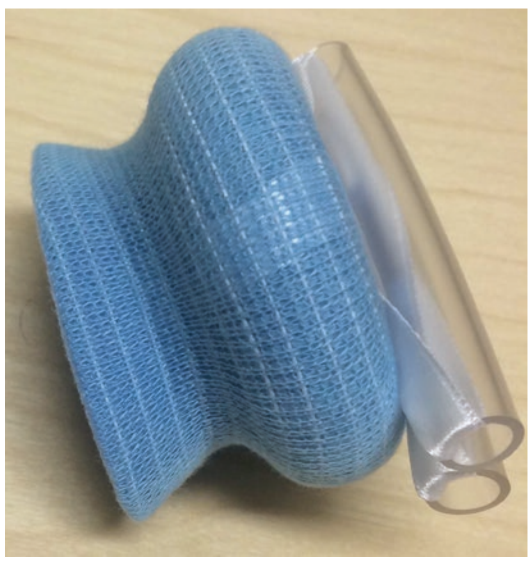

Fig. 9.1 One of newly developed tourniquets

There are no conclusive studies delineating a safe upper limit of tourniquet time; no documented cases of permanent injury have been reported from the appropriate use of field tourniquets. Keeping tourniquet inflated up to 2 h seems to be safe upper limit.

Tourniquet use before shock onset saves more lives than after shock; use them before extraction or transport.

The following recommendations can be utilized [6]:

- If possible use scientifically designed, laboratory tested, and clinically validated tourniquets.
- Use improvised windlass tourniquets when scientifically designed tourniquets are unavailable.
- The goal of emergency tourniquet use is *to stop bleeding* and stop the distal pulse.
- Avoid tourniquet use over Hunter's canal near the knee as it risks ineffectiveness.
- Side-by-side use is useful to rid distal pulses and stop bleeding if one tourniquet is ineffective.
- Tourniquets work well proximal to the wound even on the forearm or leg and need not only be on the thigh or arm as sometimes recommended.
- Remove all clothing about a tourniquet at the first opportunity to detect all wounds. Remove materials under a tourniquet at the first opportunity to avoid looseness.
- Record and mark clearly and accurately the date and time of the tourniquet application.

9.2.4.2 Hemostatic Agents

Blood-clotting capacity in case of severe bleeding can be substantially compromised as a result of extensive soft tissue trauma, hemorrhagic shock, hypothermia, and other factors. In the past 15 years, several hemostatic products have been developed for treatment of compressible hemorrhage.

While majority of these products are based on accelerating and strengthening of the blood clotting (gauze), others physically adhere to the damaged tissue and seal bleeding blood vessels (chitosan dressing). Some products, such as WoundStat (TraumaCure, Bethesda, MD), have very high hemostasis efficacy and are acting in both ways. Combat Gauze is the first mineral-based hemostatic dressing. These products have been developed for the military use [8].

Ideal hemostatic dressing should:

- Stop arterial bleeding within 2 min or less
- Be nontoxic
- Cause neither pain nor thermal damage
- Be light, durable, and easy to apply
- Be flexible for application on complex wounds and be easily removable
- Have long shelf life (>2 years)
- Be inexpensive
- Be bioabsorbable [9]

9.2.5 Suction Device

The use of a suction system is mandatory in most orthopedic procedures to remove blood from operative field, tissues (including bones), gases, or bodily fluids of the patient. Contamination of the system must be avoided to prevent deep wound infection which jeopardizes the operation [10]. In disaster setting, when there is no warranty for electrical power, reusable and washable manual foot-operated surgical suction device can be prepared (Fig. 9.2).

9.2.6 Antibiotics, Analgesics, Tetanus Toxoids and/or Tetanus Immunoglobulins, and Irrigation Solution

Initial treatment of disaster casualties with open extremity injury including open fracture should include administration of proper antibiotics, analgesics, and prophylactic treatment to prevent tetanus, together with wound irrigation and debridement and reduction and stabilization of the fractures. Broad-spectrum antibiotics are commonly used with the addition of aminoglycosides for severely contaminated wounds.

Fig. 9.2 Foot-operated surgical suction device

Initial point of care antibiotics are ertapenem or cefotetan, with definitive infection control being provided through surgical debridement. Continuation of broad-spectrum antibiotics after initial care and debridement results in complex, multidrug-resistant bacterial and invasive fungal infections.

Meticulous debridement must be done with irrigation of the wound and removal of foreign materials. Irrigation serves to reduce bacterial count, float out remaining debris, and cleanse the wound of hematoma.

All wounds in a disaster setting with unimmunized populations may be considered as tetanus-prone wounds and therefore need tetanus immunoglobulins. The current dose of immunoglobulin is from 75 U for patients <5 years of age, 125 U for those 5–10 years old, and 250 U for those >10 years old. The dose for toxoid is 0.5 mL regardless of age [11].

Multimodal analgesic regiment may be used, i.e., a combinations of narcotics, acetaminophen, tramadol, COX-2 inhibitors, and local anesthetics [12].

Oral transmucosal fentanyl citrate (Actiq) at strength of 800 μg has been shown to be safe in the prehospital setting. An additional measure to prevent too much analgesic delivery is to tape the device to the patient's finger. As the patient becomes sleepy from opiate administration, the weight of the arm removes the device from the patient's mouth. In addition to transmucosal fentanyl, intranasal administration of medications such as ketamine, fentanyl, midazolam, naloxone, and flumazenil can be used.

In the disaster setting, starting intravenous lines may take a considerable amount of time and resources away from personnel who need to concentrate on triage and patient movement.

9.2.7 Plaster of Paris (PoP) Cast, Padding, Elastic Bandage, and Cast Cutter

The use of PoP cast in disaster setting is as provisional stabilization or temporary external support of fractures in the initial phase waiting for the definitive treatment or as definitive treatment for some fractures such as minimally displaced long bone fractures, fractures around wrist joint, fractures of the hand and foot, and most pediatric fractures.

Plaster of Paris rolls with the range of from 3 to 8 in. are needed. Other materials needed for casting are paddings, gauze rolls, tape, elastic bandages, and disposable rubber gloves. Baby powders are useful for dusting the skin, to reduce the risk of skin inflammation.

Cast cutter either in the form of electric cast saw or manual cast cutter must be available for cast revision and/or cast removal in the case of impending compartment syndrome.

9.3 Wound Dressings Including Negative-Pressure Wound Therapy (Wound VAC System)

Standard wound management consists of initial surgical debridement then either wet to moist gauze dressings or Opsite dressings which need to be changed routinely every day. The application of topical negative pressure with vacuum-assisted closure may promote faster wound healing with fewer painful dressing changes. It removes blood and serous fluid, reduces infection rates, and increases localized blood flow, thereby supplying the wound with oxygen and nutrition to promote accelerated healing [13]. Either branded VAC (Classic VAC® system (KCI, San Antonio, TX)) or handmade modified VAC could be used. The ideal pressure setting is 125 mmHg. In the recent years there is a development of devices controlled and generated by a computerized program through predetermined mode settings. This negative pressure-assisted wound therapy (RNMP) is very promissing and can also be supplemented by oxygen, having synergistic effect on treatment, both prevention of anaerobic wound infection and promotion of the wound healing [14].

Handmade modified VAC could be built using transfusion set, 50 mL syringe as pump, three-way stopcock, 500 mL glass bottle, adhesive drape, sterile gauze, or if available polyurethane ether foam (stimulation of granulation) and polyvinylalcohol foam (restricted formation of granulation) (Fig. 9.3).

9.4 Skeletal Traction

During damage control surgery, femur fracture and/or tibia-fibula fracture can be promptly provisionally stabilized using skeletal traction. Steinmann pin can be introduced by using either hand drill or power drill. This procedure can save time and prevent later telescoping or shortening of the fracture fragments. Steinmann pins with

Fig. 9.3 Handmade modified VAC applied to patient with open fracture of the middle third of the right tibia

the diameter of 5.5 mm for the femur and 4.5 mm for the tibia and/or calcaneal traction with metal stirrup is usually needed for this purpose. If metal stirrup is not available, rope or roll gauze can be used to connect the pin to the weight at the end of the bed (Fig. 9.4).

9.5 Skin Traction

Skin traction kit is useful for temporary immobilization, for example, for pediatric patients with femur fracture waiting for later spica cast or adult patient with proximal femur fracture which does not need heavy traction, waiting for subsequent definitive treatment (Fig. 9.5).

9.6 Basic Surgery Set, Suture Materials, Gigli Saw

The needs of basic surgical set are essential in disaster setting. Basic surgical instrument sets include the basic instruments needed for any surgical procedure. A general instrument set is required for the incision and exposure and for closure. Scalpel handle, scissors (mayo and metzenbaum), needle holder, hemostatic forceps (mosquito, Crile, and Kocher), tissue forceps, towel clam forceps, Volkmann retractor, Langenbeck retractor, and suction tube are among the basic surgical sets.

Mangled extremity in disaster setting often requires immediate amputation [1]. This can be done during the damage control surgery. Staged amputation is recommended although some consider it as inappropriate disaster care [15].

Suture materials from 5/0 for tendons up to 0 or 1 for fascia are needed either monofilament or multifilament, braided or nonbraided, and dissolvable or nondissolvable.

9.7 Arm Sling

In disaster setting, arm sling is needed for all closed fractures of the upper extremity which do not need operative management. These include

Fig. 9.4 Skeletal traction

Fig. 9.5 Skin traction

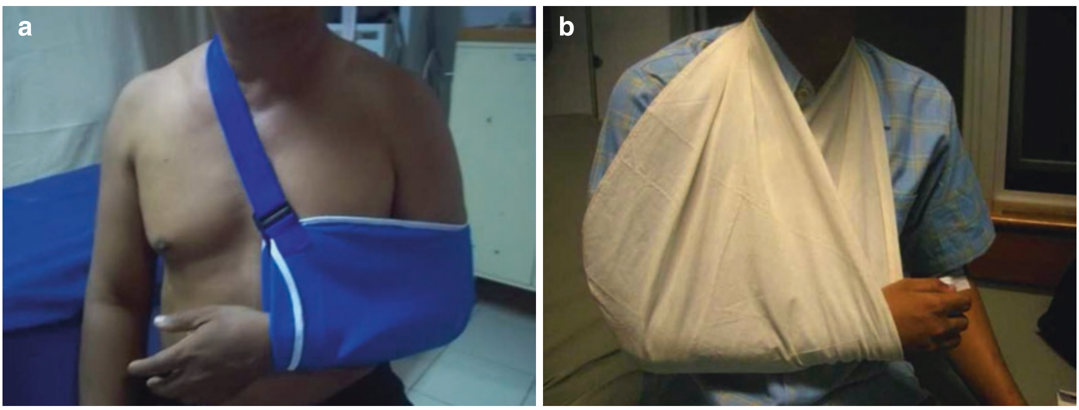

Fig. 9.6 (**a**, **b**) Arm sling

closed fractures around shoulder girdle, humerus, and forearm (Fig. 9.6).

9.8 Orthopedic Equipment Needs for Secondary Response Team

9.8.1 External Fixation Set

The external fixator should provide stability, allowing emergency stabilization of the fracture and the limb, and be able to accomodate a wide variety of fractures and wounds [16]. Sterile prepackaged external fixator is preferable for practicality where available [17], or external fixation set containing full range of pins, bars, and clamps including the tray ready for sterilization can be provided. If not, Schanz screws of 2.5 mm, 4.5 mm, and 5.5 mm diameter for the forearm, tibia, and femur respectively can be provided together with bar and clamp constructs accordingly. If bars and clamps are limited, bars can be replaced with simple aluminum bars from construction store or stainless steel wires, and PMMA can be used instead of clamps, to fix the construct (Fig. 9.7a, b). This external fixation, although in normal condition should only be for temporary stabilization, in disaster setting, to some extent can be considered as definitive

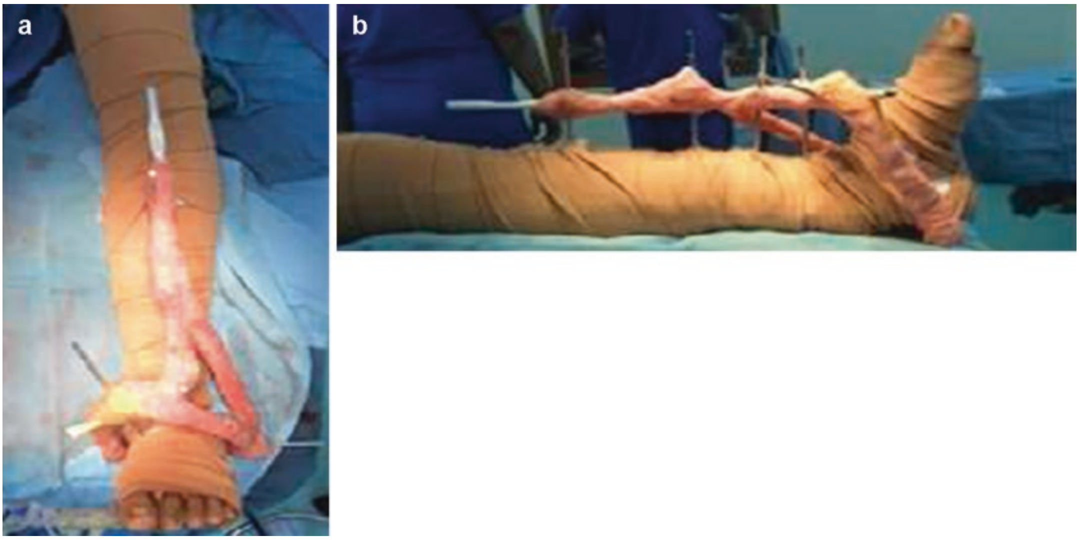

Fig. 9.7 (**a**, **b**) Improvised aluminum bar – PMMA external fixation

treatment considering the principle of "leave behind as little as possible" [18].

Commercially available uniplanar external fixators have been developed and used in situation when fast and easy application is required (Fig. 9.8).

9.8.2 Basic Orthopedic Instrument Set, Small and Large Fragment, Instrument Set for Nailing

These instruments are needed for definitive treatment of fractures from day 5 to day 10 and after the third week.

To perform effective, safe, and rapid surgery, the instrument must be complete and functioning well. Consider bringing more than one orthopedic instrument set for the team to handle more victims simultaneously. The must-have orthopedic instrument were basic orthopedic instrument set, small and large instrument set, and orthopedic set for nailing. More specific instruments, such as for periarticular femur fracture and for hip arthroplasty, and accessory orthopedic instruments, such as periosteal elevators, chisels and osteotomes, gouges, mallets, rongeurs, may also be needed in the later phase.

Fig. 9.8 Commercially available external fixation

9.8.3 Battery-Operated or Electric Power Drill

Autoclavable either battery-operated or electric power drill must be provided. If for some situation that these are not available, small

Fig. 9.9 Mechanical dermatome

construction/industrial power drill still can be used with sterile linen covering [19].

9.8.4 Orthopedic Implants

All range of orthopedic implants which include K-wires, nails, and small and large fragment implants are to be provided along with the trays/containers ready for sterilization. Specialized implants such as for periarticular fractures or in the case of osteoporotic bones can also be provided if possible.

9.8.5 Dermatome

Skin grafting is often required to cover wounds that cannot be closed or are not amenable for healing by secondary intention. In an ideal situation electrical dermatome will be most helpful. In conditions where electrical power is not easily available, mechanical dermatome can be used (Fig. 9.9).

9.8.6 Assistive Device

Assistive devices are to be provided after definitive care and/or after reconstructive phase to assist mobilization of the victims with injured lower extremity. These are in the range from canes, crutches, walkers, to wheelchairs. These devices can be brought by relief team and/or can be made locally with available materials such as wood or bamboo to meet the physical needs of those with disabilities within their environment and economic situation (Fig. 9.10) [20].

Fig. 9.10 Handmade wooden crutches

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Part II

General Overview of Disaster and Mass Casualties Management: Orthopedic Injuries of Specific Event Types

Traumatic Injuries During Earthquakes

10

William Henry Boyce, S.A. Saravanan, and Nikolaj Wolfson

10.1 Earthquakes

Natural disasters (e.g., earthquakes, cyclones, floods, etc.) and human-derived crises (e.g., conflict, terrorist attacks, chemical emergencies, etc.) result in an acute debilitation of regional infrastructure, profound decreases in healthcare capacity, and broad population injury and death [1, 2]. The diminished faculty of local resources augments the vulnerability of affected populations and often necessitates a national or global humanitarian response. Analysis of previous disasters highlights the importance of a coordinated preparedness and the preemptive training of medical professionals [3].

The original version of this chapter was revised. An erratum to this chapter can be found at DOI 10.1007/978-3-662-48950-5_46

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Earthquakes result from the sudden release of stored elastic strain energy accumulated primarily by stress created from plate tectonic forces. Faults, planar rock fractures within the Earth's crust, move diametrically and aseismically until asperities on the rock's surface create sufficient friction resistance to locally halt shearing. Rock elasticity in the ductile lower crust and mantle aggregates potential strain energy up to a slip threshold. The precipitous release of energy, propagating from a deeper hypocenter (or the focus) to the surface epicenter, causes seismic waves, heat, and fracture of the brittle oceanic and continental crusts. This is referred to as a "stick-slip process" and is part of the elastic dislocation theory [4–7].

There are three basic types of earthquakes. A *strike-slip* fault is the result of horizontal motion from pulling or tension causing the blocks to move past one another laterally. *Normal and thrust faults* are the combination of vertical and horizontal tangents. *Normal faults* are produced by the stretching of the Earth's crust and moving the block down the fault's plane, while *thrust faults* are formed by compressing potencies and moving the block upward. Megathrust earthquakes (the cause of the ten largest earthquakes) are up-dip thrust faults occurring when one tectonic plate is subducted (forced beneath) by an adjacent plate, dipping into the Earth's mantle, while the other plate is driven upward [6, 8].

The accurate measurement of energy released by earthquakes began around 1900 as the seismometer incrementally developed. Charles

N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_10

Richter, using the Wood-Anderson seismograph first built in 1922, stratified this quantity of energy to invent the Richter Magnitude scale (promptly improved to become the Richter-Gutenberg scale). The Richter used a base-10 logarithmic scale where an earthquake of 5.0 on the Richter scale causes ten times the ground movement as a 4.0 and releases 36 times the energy. The Richter scale also coincidentally relates to an earthquake's annual frequency. For example, typically ten thousand to fifteen thousand 4.0–4.9 magnitude earthquakes happen per year, and that one thousand to one thousand five hundred 5.0–5.9 magnitude earthquakes will occur per year, displaying a factor of 10 increases in the frequency for each magnitude of earthquake on the Richter scale. This logarithmic ratio continues at each level of the scale so that we can estimate that an earthquake with a magnitude of 8.0–8.9 will strike once per year. In 1979, the Moment Magnitude Scale (MMS) supplanted the Richter-Gutenberg Magnitude scale as a more accurate estimation of earthquakes. Fortunately, the MMS retained the Richter's 1–10 magnitude values for the sake of continuity and familiarity [9–11].

Eyewitness, empirical data is used to calculate the strength of impact made by an earthquake using the Mercalli Intensity scale that ranges from I to XII after the event has occurred. A level of II is the lowest experienced by an individual possibly at the top of a building, whereas a level of XII would describe seeing waves of earth rolling over the ground, objects being thrown upward, and distortions of the horizon's level plane [12, 13].

During the time period of seismological recording, beginning around 1900, eighteen major earthquakes (7.0–7.9) and one great earthquake (8.0 or higher) have been documented per year. This frequency remains consistent giving a total of nineteen 7.0 or greater earthquakes per year [14]. From 2004 to 2014, the earth experienced an unusual surge in great earthquakes, bearing eighteen earthquakes with a magnitude of 8.0 or higher, approximately 1.8 per year. Eleven out of the eighteen earthquakes were megathrust faults, further emphasizing the devastating possibilities of this form of seismic event. The 2004–2014 collection of severe activity is scientifically noteworthy as it coincides with the placement of new geophysical instrumentation, allowing for unprecedented detail of elucidation. The primary branches for earthquake evaluation are satellite imaging with the LandSAT and InSAR (Interferometric Synthetic Aperture Radar), GOCE (Gravity Field and Steady-State Ocean Circulation Explorer), and GRACE (Gravity Recovery And Climate Experiment) using gravity gradiometer and interferometry, GPS, and global broadband seismic recording networks [15]. The combination of the 2004–2014 density of seismic activity and the current proficiency in studying the precursory, coseismic, and post-seismic progression of earthquakes has been a humbling reinforcement of our inability to predict such events, as this surge of disasters has transpired predominantly without warning [16].

The human impact of an earthquake is not just a factor of the energy released. Probabilistically, the deadly earthquakes will be megathrust, shallow focus (above 70 km of depth into the earth's crust) great earthquakes (8.0 or above) along the circum-Pacific belt (U-shaped ring of tectonic and volcanic activity rimming the Pacific Ocean; 81 % of the largest recorded earthquakes) near a densely populated, poorly regulated urban area in a low-income country or in the ocean [6, 16, 17]. Earthquakes may be the impetus for direct or secondary devastation. An immediate consequence of seismic energy is the shaking and rock fracture that lead to structural failure and collapse (Haiti earthquake of 2010). Rock fractures can be several meters wide and are of particular danger to large infrastructural constructions like dams, nuclear power plants, and bridges leading to ancillary emergencies such as flooding or air/land contamination [18]. Secondary consequences of earthquakes can be equally devastating in the form of tsunamis, landslides, earth liquefaction, flooding, and fires.

Most tsunamis result from 7.5 or higher magnitude earthquakes, while lower magnitudes rarely produce impactful tsunamis. Tsunamis can travel at 300–500 miles per hour at times causing destruction of hundreds of miles away without warning. Tsunamis arrive not as a "V" shaped, surfable wave, but as a tidal surge. The seafloor displacement on the fault plane causes a *leading positive-wave* (initial tsunami wave) leading to *inundation* (a horizontal measurement of the path of the tsunami) and *run-up* ("amount of water that a tsunami pushes onto the shore above the regular sea level"…measured as "the maximum vertical height onshore above sea level reached by a tsunami"). The run-up height and the run-up distance describe tsunami on land and the affected area. The tidal surge of a tsunami leads to the same injury types as found in tropical cyclones [6, 16, 19, 20].

Landslides and liquefaction may result in areas of ground instability and saturation, and the danger of occurrence may persist long after the earthquake has passed (El Salvador earthquake of 2001) [21]. A secondary manifestation may deliver even more damage and mortality than the earthquake itself by instigating fire and impeding a response through broken water pipes and other emergency infrastructure as in the San Francisco fire of 1906 [22]. This disruption of infrastructure is often a significant hindrance to medical earthquake response efforts [1].

Earthquakes are reported in a standardized fashion that contains its moment magnitude, date and time of manifestation, geographic coordinates, epicentral region, tectonic setting, seismic hazard, MMI, type of earthquake, tsunami risk, speed and direction of tectonic movements, potential for damage, population exposure, distances to population centers, brief history of regional seismic events, and a unique identification. Understanding the geophysical dynamics and earthquake categorization will aid medical responders in the interpretation of earthquake reports and the impacts on human lives and national capacities. As health professionals prepare for and implement medical care in such chaotic environments, it is important to remember that earthquakes are cyclical, natural events, as well as the cause of seemingly insurmountable loss and harm.

10.1.1 Surgical Care in Natural Disasters

The vital role of surgical care and postoperative rehabilitation brings these faculties to the forefront of essential needs during a disaster [1]. The complex and multidisciplined nature of operative treatments for trauma-related injuries underlines the necessity for robust systems of coordination between search and rescue, medical management, and rehabilitative support and the requirement for well-integrated standardization. Although local systems may be reduced, the support and amplification of local capabilities is a vital component of an effective relief effort [1, 23].

The variability of injury within the different types of natural disasters stems from the dominant mechanical forces inflicted upon the victims. Much has been learned about the impact of each form of disaster. Disaster events which cause a tidal surge such as tsunamis and hurricanes result in significant more death than injury, many victims may drown but fewer are usually injured [24]. Whereas an earthquake would have a higher ratio (3:1) of injured to dead [24] (see Table 10.1).

10.1.2 Surgical Care in Earthquakes

Earthquakes cannot be accurately predicated or stopped and produce devastation most prominently in densely occupied, urban populations, with poor seismic architectural preparedness [25]. They destroy medical facilities, disrupt supply chains, and create a large population of patients in demand of complex medical and surgical treatment. Earthquakes are related to the collapse of buildings and structures, fires, tsunamis, and epidemic situations. The size and structure of the irretrievable loss and health of the population during earthquakes can be determined by the magnitude of the earthquake, types and conditions of the buildings, and structures in which the population is located at the time of shock, and the structure of traumatic injuries depends on the location and position of the body at the moment of shock.

Table 10.1 Health-related impact of different disaster types [24]

Effect	Earthquakes	Strong winds	Tsunamis and flash floods	Ordinary floods	Landslides	Volcanic and lava activity
Loss of lives	High	Low	High	Low	High	High
Severe injuries requiring complex treatment	High	Moderate	Low	Low	Low	Low
Major risk of communicable diseases	Potential risk following all significant phenomena (likelihood increases with crowding and the degradation of sanitary conditions)					
Damage to health facilities	Severe (structure and equipment)	Severe	Severe but localized	Severe (equipment only)	Severe but localized	Severe (structure and equipment)

It is assumed that in the case of earthquakes, 45 % of injuries occur from falling buildings and structures, and 55 % from wrong behavior (inability to hide, panic, and falls from a height). Skeletal multiple and combined injury, polytrauma, combined lesion, and compression injury are the life-threatening injuries in earthquakes. Low-income groups and countries are at risk for higher incidences of morbidity as they are more likely to have worse architectural stability and less emergency response infrastructure and personnel (see Table 10.2).

Table 10.2 Comparison of population vulnerability and economic status [26]

Country income category	Number of disasters	Killed in disasters
High income	1476	75,425
Low income	1533	907,810

Income status is but one variable within a complex array of factors that affect the severity and type of injury. For example, there is a diurnal characteristic to injury where nighttime earthquakes, hence sleeping victims, have higher mortality and injuries (proximal femur and humerus fractures) specific to this time frame [26, 27]. Earthquakes have caused almost 60 % of the 780,000 disaster-related deaths over the past decade and have impacted the lives of two billion [26, 28]. As the increase in urbanization marches forward, so will the need for curative surgical and medical capacity in the setting of earthquakes [28].

The two most devastating earthquakes of the past decade have individually caused 222,557 deaths (Haiti earthquake, 2010) and over 300 billion US dollars in damages (Tohoku earthquake, 2011) [29]. An earthquake generally has three waves of fatalities. The immediate impact of falling buildings results primarily in trauma to the central nervous system at both the brain and spine. Within hours of the incident, lacerations of the spleen and liver, subdural hematomas, and pelvic fractures make up the next wave. The final period, covering days to weeks, is the result of sepsis, disseminated intravascular coagulation, and multisystem organ failure [30]. Crush syndrome that leads to secondary diseases, especially acute renal failure, plays a significant part in these deaths [31]. Although the period of highest need for health care is the first 7 days, the acute phase may continue for 3 weeks [26].

10.1.3 Orthopedic Care in Earthquakes

Earthquakes are distinct in their requisite need for orthopedic care [30, 32, 33]. The orthopedic treatments in most demand immediately following the event are external fixation, amputation, and debridement. Often the equipment and amenities to perform more sophisticated procedures such as internal fixation are unavailable and overall injuries are often complex, involving multiple systems [25].

Much of the knowledge about orthopedics in the context of disasters and more specifically earthquakes is derived from the bridging of civilian, military, and humanitarian research [1, 2, 34]. The *Best Practice Guidelines on Surgical Response in Disasters and Humanitarian Emergencies: Report of the 2011 Humanitarian Action Summit Working Group on Surgical Issues within the Humanitarian Space* is an excellent example of what can be achieved through cross-sector and cross-discipline collaboration [1]. Wound prevalence data on musculoskeletal injuries, amputations, crush injuries, and infection rates are as vital as insights into logistics, response teams, and the lessons learned from working in austere environments. For example, Clover et al. found that the presence of a plastic surgeon in their orthopedic surgical response team during the 2010 Haiti earthquake greatly improved limb salvage and that many procedures were orthoplastic in nature, yet anecdotally they describe seeing very few plastic surgeons in the relief efforts in Haiti, 2010 [2].

Secondary diseases following orthopedic care are primarily the sequelae of crush injury and infection to open wounds. Many of the patients with open wounds present days to weeks after the initial injury as they waited for search and rescue extraction [35]. Multi-organ failure from sepsis is the most common cause of delayed mortality, and the mortality of acute renal failure following earthquakes can be 14–48 % [36, 37]. The often ad hoc surgical theaters following an earthquake can lead to an increased risk of infection with postsurgical infection rates being as high as 14.8 [38] to 19 % [39]. Infections following intramedullary (IM) nail insertion for a closed femoral fracture have been reported at around 5 %, similar to the internal fixation infection rates reported by an extensive analysis by the US military field hospitals in low- and middle-resource countries [33, 38, 40].

10.1.4 Ethical Considerations

Not many surgeons have the knowledge or experiential basis for traumatology in a disaster context which brings unique technical and ethical considerations [41]. In mass casualty situations, physicians become the stewards and dispensers of life-saving resources in the face of overwhelming demands. Maintaining principles of "doing no harm" and saving the most lives with considerations for the long-term life impact on patients means prioritizing who will receive care and who will not. Decisions must be made at each stage of management: triage – who is admitted or denied services; surgical and intensive care – the use of limited resources with high demand; and rehabilitation, discharge, and the ultimate life consequences of treatment [41].

Ethical guidelines are developed within the confines of a specific situation and must undergo revisions as the disease types and local health systems evolve. For example, Merin et al. during the Haiti earthquake of 2010 used a triage system based on three questions: "How urgent is this patient's condition? Do we have adequate resources to meet this patient's needs? Can the patient's life be saved?" [41].

Specialists in earthquakes are often confronted with novel limitations to their training and the situation. Orthopedists encounter demanding wounds such as pelvic fractures, spinal cord injuries, and crush injury sequelae without appropriate resources which could save more lives. Lower limb crush syndrome is common in earthquakes and presents a challenging dilemma in the prioritization of care [12, 16]. These injuries present in a wide variety of ways and come with uncertain outcomes [42]. Those that proceed to rhabdomyolysis and renal impairment have high mortality rates especially if the capacity for dialysis is not present. The development of ethical committees has been recommended to reduce the burden of responsibility on any one individual in making such decisions to prioritize resources. Such committees can then assess the urgency and severity of clinical conditions, the availability of beds, staff, and equipment and the survivability of patients with a shared system of principles and accountability [3, 41, 43, 44].

10.1.5 Cultural Factors

The culture of the country where a disaster strikes has major influences on some of the most important aspects healthcare delivery. The decision to save or to amputate an affected extremity is a tough one to make. An amputation that will save the patient's life may be more evident when it happens in patients with mangled extremities or crush syndrome that can lead to renal insufficiency, cardiac arrhythmia, sepsis, and death. However, when the dilemma of salvage versus amputation is not revealed by an indisputable mortal condition, the decision-making process should be conducted in a very organized fashion and be based on the consideration of multiple factors. Young amputees in many third-world countries may not have the opportunity to be fitted with a well-functioning prosthesis nor benefit from a necessary rehabilitation program. He or she may be sentenced to a very difficult nonproductive life, without the ability to neither sustain their family.

The triage and the decision to amputate should ideally be done by medical practitioners with experience in multiple casualty events, and with the environment's confines, and the patient's life prospects in mind. Time should be found to discuss a patient's status and have, if possible, involvement of the medical providers from the local community, the patient's family members, and, if the situation permits, informed consent from the victim, the victim's family, or members of the community.

Whether it is a nongovernmental organization (NGO) or any national or international disaster relief organization, appropriate documentation, preferably in a local national language, should be available to explain, record, and educate treated patients and their families. This will allow needed information to pass to the next team of healthcare providers; to be available to the patient and their families; and to accurately document the patient's medical history, diagnosis, and treatments for the organization's research and quality improvement goals. Proper documentation may help to alleviate a transferred patient's feelings of frustration and confusion.

10.2 The Main Types of Damage Caused by Earthquakes

10.2.1 Fractures

Fractures represent 20 % of earthquake musculoskeletal injuries [32]. The majority of fractures occur in the lower extremities (83.3 %). Open fractures vary from 11 [45] to 54 % [46]. The largest number of patients seen has closed femur fractures, while the largest number of open fractures is in the distal tibia and fibula bones. A third of patients have multiple breaks and 6 % of injuries have neurovascular complications [47]. Overall, the most common fractures are of the major long bones, i.e., the humerus, radius, femur, and tibia (77 %) [33].

Wounds necessitating tertiary orthopedic care are compartment syndrome, crush injuries, gangrene, long-bone fractures, and pelvic fractures (especially lateral compression pelvic fractures) [27]. With respect to orthopedic procedures, just over a third of interventions in an earthquake are external fixations. Amputation, nailing, and traction range between 14 and 16 %, while plating is around 10 % [33].

10.2.2 Amputation

Amputation is a life-saving decision when acute trauma or infection has denied all other limb-salvaging options [33, 48]. Amputation rates following an earthquake range from 1.6 to 3 % for all patients treated and 6.2–10 % for those with extremity injuries [49–51]. Within the first 16 days after the event, nearly two third of the total amputations will have been done with 15 % of them being secondary interventions [52]. Amputations are associated with mortality in earthquakes with an odds ratio of 2.81 ($p = 0.01$) [53].

There is a paucity of research on quality of life following amputation in low-resource countries. When the infrastructure has been tremendously debilitated by the disaster factors such as the healthcare facility, postoperative follow-up, rehabilitation options, and prosthetic care need to be considered [48]. The main body of work on amputation recovery and livelihood comes from developed countries where rehabilitation, prosthetics, work, and ambulation amenities for the disabled can be managed [48, 54]. When the prosthesis costs $1000 to fit and produce and the roads are made of earth rather than asphalt, the procurement and life impact of prosthetics carry higher risks [57]. Amputees in economically depressed environments often cannot purchase the prosthetics nor may they have access to the parts and tools for maintaining their functionality; therefore, the decision to amputate should be considered with these factors in mind [56, 57]. Under these conditions, the reasons for limb salvage become stronger. The rise in quality of limb stabilization and vascular reconstruction has augmented the situations where limb salvage is possible [58]. As severe extremity wounds are common in victims of earthquakes, integrating a plastic surgeon into response teams may provide the resources for improved limb salvage [59–62].

The primary indications for amputations are irreversible vascular injury and completion of a partial amputation, as a last resort in order to remove a trapped victim in the field and overwhelming sepsis. Crush injury, although not a distinct indication for amputations should be considered with regard to the possibility of decompensating renal functioning [48]. Factoring in the risk for the blood loss, the category of the crush injury, and the contamination of the wound can aid in the evaluation for amputation [48].

10.2.3 Crush Injuries, Crush Syndrome, and Compartment Syndrome

Crush is a typical mechanism of injury during earthquakes. It is also one of the most common causes of mortality, after severe head injury and asphyxiation, among earthquake victims. Among patients with crush injuries that reach a hospital, about 50 % recover while the other 50 % develop crush syndrome [51].

It is of major importance that the difference between crush injury, crush syndrome, and compartment syndrome be recognized and understood.

Crush injury (extremity) is an injury caused by direct pressure to the extremity. The damage is to the soft tissues: skin, muscles, nerve, and blood vessels.

Crush injuries may lead to compartment syndrome with or without associated skeletal injury [55]. By definition, a *compartmental syndrome* is produced when the tissue pressure within a confined space rises to the point where the circulation and the function of the tissues within that space are compromised [56].

Treatment of compartment syndrome injuries when presented acutely, up to 6 h, can lead to reversal of ischemic changes. The release of compartment pressure via fasciotomy can have a satisfactory outcome.

When an injured extremity is exposed to substantial crushing force for a prolonged period of time and the volume of the compressed, crushed tissue is substantial, irreversible changes can take place, including muscle cell death and systemic manifestations.

The *crush syndrome*, sometimes called *rhabdomyolysis*, was first described in the English literature after the battle of London in 1941 by Bywaters and Beal [51] in patients who after being extracted from the collapsed buildings, later died from acute renal failure. Crush syndrome may develop after 1 h in a severe crush situation, but usually requires 4–6 h of compression for the systemic manifestations to occur. At the early stages, there are very few local changes. Clinically detectable vascular compromise may develop at the advanced stage of injury. Rhabdomyolysis may occur due to ischemic changes in the affected muscles, which lead to muscle cell death. More pronounced swelling, skin redness or pallor, pain with passive movement, paresthesia, and motor deficit may become apparent. If and when circulation to the affected limb is restored, the toxic byproducts of rhabdomyolysis can cause myoglobinuria with resultant renal failure, and hyperkalemia, which may cause fatal dysrhythmias. Versus compartment syndrome, where treatment is more at the level of affected extremity, in crush syndrome it is primarily focused on preservation of the patient's cardiac, renal, metabolic, and circulatory functions.

Fasciotomy is used as the main treatment in patients with acute compartment syndrome and in patients with crush syndrome whose peripheral circulation is significantly compromised.

There is well-reported evidence from different disaster zones showing high rates of infection and associated amputations when fasciotomies were performed in the presence of crush syndrome [57–65]. In hypoxic tissues, mechanisms of infection control and healing are impaired so that the risk of infection and wound healing are distinctly higher than after other kinds of injuries. When damage to the extremity is significant and risk of reperfusion-related systemic changes is high, amputation can be performed to save patient's life.

There is some experimental evidence that the severity of crush syndrome is proportional to the amount of damaged muscle and the time of the compression [53]. This has not been supported by the data from the actual disasters [54]. Kidney damage, which occurs as a result of myoglobinuria, has not correlated with the degree of muscle damage [52]. Thus, the correlation between severity of clinical manifestations and duration of the compressed extremity has not been well defined.

A large body of evidence suggests that fasciotomy should not be performed in patients with compartment or crush syndrome if more than 12 h has elapsed since the patient was extracted. The main risk is a high rate of complications, especially infection, which is the most common cause of death after crush syndrome.

For more comprehensive coverage on the subject of crush injuries, please refer to Chap. 22.

10.2.4 Polytrauma and Multiple Trauma

Polytrauma or multiple trauma is a medical term describing the condition of a person who has been subjected to multiple traumatic injuries, such as a serious head injury in addition to a serious burn. This is a complex pathological process causing damage to several anatomical regions or segments of limbs with severe manifestations, which involves the simultaneous onset and progression of several pathological conditions and is characterized by profound disturbances of all kinds of metabolic changes in the central nervous system, cardiovascular system, and respiratory system.

During earthquakes, a massive increase in multiple injuries is inevitable. At the zone of destruction, the doctor faces two main challenges in the prehospital period.

1. To identify the most serious damage, dominantly affecting the overall condition of the victim
2. To conduct an immediate antishock treatment and resuscitation

Virtually, all patients with multiple injuries develop general or local complications that determine the choice of treatment. Lack of timely and accurate diagnosis will lead to magnification of the severity of the injury and the formation of multiple organ failure. In the early period of polytrauma (from the time of injury up to 24 h), a series of pathophysiological changes will define the prognosis. These changes are firstly dependent upon location and size of the damaged organ and, secondly, unconsciousness of the victim.

Acute hemorrhage and traumatic shock are observed in the majority of patients with multiple injuries. The latter is a direct cause of death and accounts for 80 % of deaths, particularly in the prehospital period. Clinical manifestations of acute blood loss depend on its volume, which depends on the caliber and quantity of initially damaged blood vessels, blood pressure, and time elapsed since the injury.

Blood loss is classified by the rate of blood flow.

1. Profuse (over 50 ml/min)
2. Strong (less than 50 ml/min but not exceeding 30 ml/min)
3. Moderate (less than 30 ml/min)
4. Small (10–12 ml/min)

Profuse bleeding leads to death within minutes and is almost impossible to stop. The main causes are damage to the aorta, or the vena cava or their branches, or the large vessels of the abdomen. In theory, the victim with heavy bleeding can survive with the aid of surgical hemostasis. This typically is impossible as the time to treatment is greater than 2 h during which the victim can lose more than 40 % of circulating blood, which is usually fatal.

Classic traumatic shock has been observed in victims with moderate and low bleeding. It is prevalent in more than half of patients with multiple injuries, with concomitant injury of the musculoskeletal system, and combined and multiple internal injuries. It is well known that traumatic shock is the most severe complication of these injuries. Naturally, the severity and rate of development of shock circulatory disorders are directly dependent on the severity of the injuries. Polytrauma predominates during earthquakes thereby determining the rapid formation of irreversible shock and circulatory disorders and the attendant high mortality.

10.2.5 Circulatory Shock

Circulatory shock commonly known simply as "shock" is a life-threatening medical condition that occurs due to an inadequate substrate for aerobic cellular respiration. In the early stages, this is generally an inadequate tissue level of oxygen.

The typical signs of shock are low blood pressure, a rapid heartbeat, and signs of poor end-organ perfusion or "decompensation/peripheral shutdown" (such as low urine output, confusion, or loss of consciousness). There are times that a person's blood pressure may remain stable, but may still be in circulatory shock, so it is not always a reliable sign. The shock index (SI), defined as heart rate divided by systolic blood pressure, is a more accurate measure of shock than hypotension and tachycardia in isolation.

The final result of this process is the formation of acute cardiovascular failure and death. Normally, rescue teams arrive to the zone of destruction 2–4 h after the onset of earthquake, and medical units are deployed between 4 and 8 h.

10.2.6 Concomitant Injury to the Brain

Intracranial hematomas, third-degree contusions of the brain (intracerebral hematoma), including bleeding in the brain ventricles and severe subarachnoid hemorrhage, are the life-threatening brain injuries observed during earthquakes. Other injuries are not having fatal character and manifesting in the form of skeletal fractures (60 %) and soft tissue injuries (15 %).

Disruption of the brain in the form of cerebral coma of varying severity determines the clinical picture. Shock in the form of moderate hypotension (SBP 90 mmHg) is relatively rare (10–15 % of survivors). In the absence of obvious clinical signs, low blood pressure is more dependent on the destruction of the brain stem, not from hypovolemia.

10.2.7 Combined Spinal Cord Injury

Spinal cord injury is an injury to the spinal cord resulting in a change, either temporary or permanent, in the cord's normal motor, sensory, or autonomic function. Spinal fracture dislocations and fractures have been reported at 33 % and 36 %, respectively. Burst fractures are the most commonly cited injuries ranging from 49 [63] to 55 % [63]. Compression fractures comprise around 30 % of fractures [65]. Spinal cord injury in the form of para- and quadriplegia or deep paresis is the most serious. These injuries are always a consequence of unstable fractures of the bodies and vertebral arches in the cervical, thoracic, or lumbar spine.

Depending on where the spinal cord and nerve roots are damaged, the symptoms can vary widely, from pain to paralysis to incontinence. Spinal cord injuries are described at various levels of "incomplete," which can vary from having no effect on the patient to a "complete" injury, which is a total loss of function.

The majority of spinal injuries following earthquakes are thoracolumbar [65, 66], with the lumbar spine primarily affected [65, 67]. Numerous reports have observed that multilevel injuries are common (22–29.5 %) [64, 65].

10.2.8 Combined Chest Trauma

Chest injuries account for 25 % of all deaths from traumatic injury. Common injuries observed after an earthquake are large hemothorax (single or double), tense pneumothorax (single or double), and a floating chest. Internal rupture of lung with pulmonary hemorrhage and esophageal tears is rarely observed. Unilateral or bilateral rib fractures are common in all victims after the disaster.

Most blunt injuries are managed with relatively simple interventions like tracheal intubation, mechanical ventilation, and chest tube insertion. Diagnosis of blunt injuries may be more difficult and require additional investigations such as CT scanning. Penetrating injuries often require surgery, and complex investigations are usually not needed to come to a diagnosis. Patients with penetrating trauma may deteriorate rapidly, but may also recover much faster than patients with blunt injury.

Acute respiratory failure is the main cause of death in most cases during earthquake. Chest compression (traumatic asphyxia and superior vena cava syndrome) is needed to be mentioned. Its symptoms can be very similar to the head injury or fat embolism. Chest compression occurs due to a sudden and relatively prolonged compression of the thorax. This is one of the main types of traumatic injuries during mass lesions – earthquakes, landslides in the mines, the panic in the crowd, and others.

10.2.9 Combined Abdominal Trauma

Abdominal trauma can be life threatening because abdominal organs, especially those in the retroperitoneal space, can bleed profusely, and the space can hold a great deal of blood. Solid abdominal organs, such as the liver and kidneys, bleed profusely when cut or torn, as do major blood vessels such as the aorta and vena cava. Hollow organs such as the stomach, while not as likely to result in shock from profuse bleeding, present a serious risk of infection, especially if such an injury is not treated promptly. Gastrointestinal organs such as the bowel can spill their contents into the abdominal cavity. Hemorrhage and systemic infection are the main causes of deaths that result from abdominal trauma.

One or more of the intra-abdominal organs may be injured in abdominal trauma. The characteristics of the injury are determined in part by which organ or organs are injured. The injury may be blunt or penetrating and may involve damage to the abdominal organs. Signs and symptoms include abdominal pain, tenderness, rigidity, and bruising of the external abdomen. Abdominal trauma presents a risk of severe blood loss and infection. Diagnosis may involve ultrasonography, computed tomography, and peritoneal lavage, and treatment may involve surgery.

10.2.10 Concomitant Injury of the Musculoskeletal System

More than half of victims experience unstable fracture of pelvis, multiple fractures of large segments, traumatic amputation, and compression injury of extremities during earthquake. Mild head injury, rib fractures, and retroperitoneal hematoma are often presented as mild injuries. Acute renal failure will be the life-threatening cause during these types of major injuries.

10.2.11 Combined Injury of Two or More Cavities

This is the most difficult group to identify during disasters. Statistically, more than 80 % of victims died at the scene before the arrival of ambulance or on the way to the hospital. Patients with these types of injuries are unconscious (from cerebral coma or shock III-IV degree) and may present with severe hypotension (shock, blood loss, or destruction of the brain stem) or respiratory distress due to chest injury, brain stem lesions, and asphyxia.

10.3 Discussion

The mortality after an earthquake directly depends on the availability of prehospital medical care. Only 45–60 % of victims are alive at the time of transfer to a medical care center. In the intensive care unit, another 20 % of deaths are added to the mortality count which had occurred in the prehospital period. The prehospital period determines the immediate outcome of polytrauma. The casualty's condition may worsen at any time, but competent medical assistance can quickly stabilize it.

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Tsunami and Flood

11

Taikoh Dohjima and Katsuji Shimizu

11.1 Introduction

The earthquake occurred at 2:46 pm on 11 March 2011. The magnitude was 9. It was the Great Eastern Japan Earthquake. Thirty minutes after the earthquake, a tsunami occurred; the tsunami struck the northeast coast of Japan. At least 15,854 people died. There were more than 340,000 refugees, and 3155 people are still missing 1 year later.

Tsunami is a Japanese word meaning "harbor wave," which makes sense when you consider the fact that we have suffered the terrible effects of tsunami from ancient times. The northeast coast of Japan was savaged by a tsunami in May 869 and more recently in June 1869 [1]. Previous generations left an important warning: "After the big earthquake, a tsunami came."

In 2011, the Japanese people had a horrific experience: a huge earthquake, followed by a tsunami, and unexpected radiation pollution. We must document the facts since we have a responsibility to leave a message for the next generation.

In Eastern Japan, most of the damages and destruction were caused by the tsunami, not by the earthquake or fire. In the case of the tsunami, most people either managed to survive or drowned.

A previous study showed that sea water from a tsunami is not safe and contains virulent microorganisms. It can cause sepsis, serious lung infection, and severely contaminated wounds [2, 3]. Skin and soft tissues were the most commonly involved, especially the lower extremities [4]. The aims in the early stages of wound and fracture management are to diagnose the injuries, debride wounds, and immobilize fractures [5].

The Gustilo and Anderson's classification is often used for open fractures [6]. These wounds should be provided adequate initial treatments. Immediate stabilization of bone fractures with effective traction or splints is a basic principle of orthopedic care until definitive surgery in the second week [7].

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_11

11.2 Type of Orthopedic Injury by Tsunami

There were 475 orthopedic-related patients on 11–20 March 2011, at Kesennuma Public Hospital in Japan. Laceration, contusion, and sprain were 209 (44 %). Fracture and dislocation were 48 (10 %) and lumbago 123 (26 %). Rheumatism and arthritis were 90 (19%). Tetanus toxoid (15 were stocked) was exhausted on that day (11 March 2011) [8] (Table 11.1).

In Thailand, data from three hospitals are involved with the tsunami incident on 26–31 December 2004 [5]. There were totally 2311 patients. Approximately 40 % (946 patients) suffered from salt water aspiration and orthopedic-related injury 61.4 % (1461 patients). Most common orthopedic injuries were minor [559 patients (24 %)] and major wounds [586 (25 %)]. Around 7 % sustained fracture dislocation. Minor wound was defined as abrasion, scratch, or small lacerations where there was no need for debridement. Major wounds were lacerated and included with or without skin loss, infected tissue, necrotic fasciitis, and open fracture. Two of eight necrotizing fasciitis cases had sepsis and died from puncture wounds [5] (Table 11.2).

Table 11.1 Orthopedic-related patients on 11-20th March 2011 at Kesennuma public hospital in Japan

Injury	Patients *n* (%)
Laceration	100 (21)
Contusion	95 (20)
Fracture	43 (9)
Dislocation	5 (1)
Sprain	14 (3)
Arthritis	43 (9)
Rheumatism	47 (10)
Lumbago	123 (26)

Table 11.2 Orthopedic-related patients on 26-31th December 2004 at three hospitals in Thailand

Injury	Patients *n* (%)
Minor wound	559 (23.7)
Major wound	586 (24.8)
Fracture	133 (5.7)
Dislocation	12 (0.5)
Spine injury	13 (0.6)
Necrotizing fasciitis	10 (0.4)

11.3 The Infections and Treatment of Wounds

Wound infection was the second most common health problem among the survivors of tsunami. Wounds occurred just after the tsunami and became infected within 72 h. Infections were more likely to occur in open wounds than in abrasion, contusion, or ecchymosis. Data was collected from 26 December 2004 to 31 January 2005 at four public hospitals in Thailand [9]. Wounds were contaminated with mud, sand, debris, and sea water and had an infection rate of 674/1013 (66.5 %). Most wounds (45 %) had polymicrobial infection with gram-negative rods such as Escherichia coli, Klebsiella pneumonia, Proteus, and Pseudomonas species (Table 11.3). Early treatment with antibiotics was protective for post-tsunami patients with wounds. Patients should be given broad-spectrum antibiotics targeted for gram-negative bacteria, polymicrobial infections, and with human tetanus immunoglobulin.

The risk of wound infection increased with size and presence of an open fracture. However, wound with small penetrating entrance should be considered dangerous and should not be underestimated by first triage. Case reports presented patients who walked in with a minor wound but died within 24–48 h as pathogens penetrated the skin and destroyed the underlying structure rapidly [10]. It caused widespread necrotizing fasciitis. In the later stages, multiorgan failure from sepsis occurred [11]. Late-stage infections may result in gangrene, necrotizing fasciitis, systemic illness, and sepsis. Treatment is with antibiotics (doxycycline and third-generation cephalosporin) or fluoroquinolone [12].

Table 11.3 The type of bacteria cultured from wound from 26th December 2004 to 31st January 2005 at four public hospitals in Thailand

Bacteria cultured from wound	Frequency *n* (%)
Escherichia coli	26 (16.8)
Klebsiella pneumonia	19 (12.3)
Staphylococcus aureus	18 (11.6)
Proteus vulgaris	14 (9)
Pseudomonas aeruginosa	14 (9)
Proteus mirabilis	9 (5.8)

The high rate of infection was related to resource-limited situation, despite most of the patients (94.9 %) received antibiotics. Sand embedded in the tissues can be removed by a toothbrush. In case of unavailable sterile saline, bottle water or tap water should be an acceptable substitute [13]. The wounds should be left open, using ample absorbent gauze dressings, or covered temporarily with a vacuum-assisted closure (VAC) system [14]. The wounds should be re-explored and re-debrided 24–48 h after initial procedures. Excluding the risk of infections, delayed primary closure of wounds is recommended approximately 5 days later.

Choice of limb salvage or amputation should be carefully judged. Discrepancy in the treatment modalities may be related to surgeons' experience and judgment. Surgeons need to be familiar with a wide range of injuries and advanced techniques in soft tissue and bone management. Although there is not sufficient evidence, reconstruction should be considered as soon as possible once the wound bed is clean [15].

11.4 Communications and Cooperation

We went to the disaster area as a Disaster Medical Assistance Team (DMAT) on 11 March 2011 the same day that the earthquake struck. The first DMAT in Japan was established after reflection on the lessons of the Kobe earthquake of 1995. It was realized that such teams could have saved many lives immediately after such a large earthquake. A DMAT is a specially trained team that conducts rescue work and provides emergency medical treatment and transportation of seriously injured victims within 48 h after a disaster. The DMAT brings medical supplies and personnel to the disaster area and airlifts victims out of the area, because the roads are often blocked.

In the Kobe earthquake, many buildings and roads collapsed as a result of earthquake tremors or were destroyed by fire. Many people were injured. In the case of earthquake accompanied by the collapse of buildings, there is a real need for orthopedic surgeons. In Sri Lanka, many houses were destroyed by the tsunami; there was a need for many orthopedic surgeons too [16]. When disaster strikes, it is necessary to secure orthopedic surgeons for emergencies.

Most deaths associated with tsunamis are related to drowning. Injuries such as broken limbs and head injuries are caused by debris in the water. These high-energy extremities wounds caused by tsunami are similar to those of war wound injuries [14]. Military troop or sealift command hospital ships, for instance, USNS Mercy, supported orthopedic care after the 2004 Asian tsunami. The ship has 1000 beds, intensive care unit (ICU), 12 operation rooms, and military transport helicopters. Hospital ship is effective for tsunami due to their proximity to the coast [17].

11.5 Medical Facility and Relief

The Municipal Shizugawa Hospital was exceeded by a wave 15 m in height (4th floor) on 11 March 2011 in Miyagi Japan. Seventy-two patients and three staff members were lost to the tsunami [1]. It is necessary that hospitals be built at high altitudes or more than five floors high. The Ishinomaki Red Cross Hospital was relocated on a high hill when it was rebuilt in Miyagi, Japan. The hospital was almost undamaged by the earthquake and tsunami and was able to function at over peak capacity after the disaster. We learned that the units must be self-sustaining for 72 h. Hospitals should have communications (satellite phone), supplies of antibiotics, insulin, tetanus antitoxin, dialysis, and an emergency electric power source.

In big cities located near the coast at low altitudes, there is a risk for tsunami after large earthquakes. Tsunami over 15 m high can occur within 30 min after an earthquake. The average distance a person can move in 30 min after an earthquake is only 500 m. The use of a vehicle is not possible in floods and tsunami since two feet of water can carry away most automobiles, and road obstruction and traffic jams are common in the early period after a disaster. Thus, it is vital that people evacuate as soon as possible. When fleeing a tsunami, there is no time to gather clothes and food. We recommend that people should not waste precious time looking for survival kits; instead, they should immediately escape to higher ground. Most victims were those who failed to escape, not those who had starved to death.

11.6 Learning from Tsunami Experience and Damages

In the case of the 2004 December 26 tsunami, most of the wounded people survived. Those who perished have drowned. The number of serious injuries was much lower than many emergency medical teams expected [18]. In the Great Eastern Japan case, there were few severe injuries despite the number of victims, and surgeons were not necessary. It is necessary to change the type of rescue work depending on the type of disaster. For instance, when most of the damage is caused by the tsunami, it seems better to send medical teams and supplies to evacuation areas. Many people lost usual drugs and prescription refills.

There were extreme shortages of gasoline and oil in Eastern Japan for about a month after the earthquake. Cities should prepare for a lack of regular energy sources in the wake of a disaster.

Another big problem in the aftermath of the Great Eastern Japan Earthquake has been radiation pollution [19]. The radiation pollution was level 7, which was the same level as that of the Chernobyl disaster in Ukraine (Union of Soviet Socialist Republic) in 1986. The radiation pollution has been a real obstacle to the recovery from the disaster. In Fukushima Prefecture, many people are still evacuated. The Great Eastern Japan Earthquake has been an eye-opening experience that has made us reconsider the wisdom of relying on nuclear power plants and has made us realize the need to look for safer sources of sustainable energy for the future of the world.

Acknowledgement We wish to express our gratitude for all the encouragement and the generous donations given to Japan after the Great Eastern Japan Earthquake by people from all over the world.

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12 Nuclear Disasters

Hironobu Tokunaga

12.1 Introduction

The most important point in radiation emergency medicine is the proper understanding of the difference between exposure and contamination by all the staff involved in transport, examination, and treatment of the patients, regardless of their specialty such as orthopedic surgery.

Radioactive material is any substance that emits radiation.

Because radiation is invisible, odorless, tasteless, neither hot nor cold, one cannot sense radiation exposure.

In contrast, radioactive material contamination refers to a state in which radioactive materials are deposited directly on the body surface or indirectly on the clothing (external contamination) or inhaled, ingested, or entering the bloodstream at wound site (internal contamination).

Decontamination is the process to remove contaminants. If decontamination is not properly carried out, the patient may suffer from preventable radiation exposure, and the unnecessary enlargement of radioactive material contamination may occur. The most important issue in radiation emergency medicine is appropriate decontamination. In addition, internal contamination must be carefully evaluated and specially treated. This evaluation of the contamination and decontamination for the external contamination must be done before usual orthopedic management, except in cases such as life-threatening emergencies [1]. The management of orthopedic trauma such as fractures may then proceed to surgical or conservative treatment with plaster cast, etc., as usual.

Throughout the United States, most clinicians, including orthopedic surgeons, do not have opportunities to treat radiation-exposed or radioactive material-contaminated patient in their daily work. And we really hope so. However, there is a reality that a variety of radioactive materials with potential radiation exposure are used on a daily basis by workers not only in nuclear power plants but also in a large number of factories, laboratories, and medical or educational institutions in our modern society. So, there is a possibility that we could be exposed to radioactive material without being shielded properly either accidentally by human error or intentionally by terrorism-related bombs such as Dirty Bomb.

This is why all citizens, of course especially medical staff, must understand the basis of radiation medicine as well as those who live near or work at nuclear power plants.

It is important for orthopedic surgeons to understand radiation emergency medicine and to have basic knowledge of the biological

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_12

effects of radiation in case of becoming a first responder. In addition, the first responders and clinicians must be sensitive to the emotional distress and anxieties of radiation-exposed victims since these stresses may impact their physical status [2].

12.2 Radiation Exposure and Pollution

First, we have to understand the meaning of terms such as radiation, radioactivity, and radioactive material. Radiation is a physical property of electromagnetic energy waves or particles to travel through matter or space, and some examples include radio waves, microwaves, X-rays, and gamma rays. Radioactivity is the ability to emit radiation from a material, such as radioactive iodine, cesium, uranium, and plutonium. These materials, existing in a gas, liquid, or solid state, emit radiation as invisible rays, requiring special detective equipment such as Geiger-Muller counter. Radiation pollution is a human-caused increase in natural radiation levels. Low-energy radiation pollution is associated with TVs, cell phones, microwave ovens, etc., and may remotely cause long-term health problems. Radiation emergency medicine focuses on the pollution by high-energy radiation, such as gamma rays with its attendant health risks.

12.3 History of Major Nuclear Reactor Accidents [3, 4]

1957 Windscale, England, United Kingdom

Graphite fire occurred causing the nuclear fuel to melt, resulting in the release of a large amount of radioactive material. Fourteen workers were exposed to excessive radiation.

1958 Vinca, Serbia

Critical accident occurred in an experimental reactor. Six researchers were exposed to excessive radiation; one died and the five survivors were transported to Paris (France) for advanced treatment.

1961 Idaho Falls, USA

Uncontrolled reactor caused by the withdrawal of the control rod; three workers were killed.

1979 Three Mile Island, USA

A valve failure of the pressurizer resulted in leakage of the primary coolant. Manual attempts to stop the leakage caused a failure of emergency core cooling system. Although this led to severe core damage, no massive release of radioactive materials into the environment occurred. The actual level of radiation measured was no more than 1 mSv. Nonetheless, the news of the accident caused a panic among nearby residents.

1986 Chernobyl, Ukraine

A sudden power surge during a system test and failure of the emergency shutdown process caused steam explosions and reactor vessel rupture. The graphite moderator ignited, releasing a massive amount of radioactive materials into the environment. 31 people died from exposure. 206 people suffered from acute radiation sickness.

2011 Fukushima, Japan

The total power and cooling functions were disabled by a massive tsunami earthquake of magnitude 9.0. Because of the lack of proper cooling, the reactor fuel rods overheated and melted. The reaction between the nuclear fuel metal cladding and the surrounding water released explosive hydrogen gas, destroying the reactor buildings. Significant amount of radioactive materials was released into the environment. No deaths from high-dose exposure have occurred so far.

12.4 Types of Radiation

There are many types of radiation. Alpha, beta, and gamma rays (almost equal to X-rays) can cause various kinds of clinical problems. Understanding the basic physics of these waves helps explain their clinical effects. Generally, the less penetrating a radiation is, the higher energy accumulates in the affected area, although this might sound strange. Therefore, for example, we have to be careful about internal contamination of the radiation source emitting alpha rays with low permeability because internal exposure caused by internal contamination could be relatively severe.

12.4.1 Alpha Rays

For every clinician, detailed exposure history is invaluable information especially when managing patients exposed to heavy uranium, a known emitter of alpha particles.

Alpha particles travel only a few centimeters in the air, can be shielded by a piece of paper, and cannot penetrate the skin. Moreover, radiation sources emitting alpha particles are used in a very small number of institutes, so this kind of accident will not be frequent. These patients are limited to be technicians working very close to the radiation source; almost no problems are expected by external contamination or exposure.

Internal contamination, however, which occurs through inhalation, ingestion, or open wounds can cause severe internal exposure as written earlier in this section. Although internal contamination can be estimated only by a special device such as WBC (Whole Body Counter) equipped in some special institutes like REAC/TS (Radiation Emergency Assistance Center/Training Site), the most essential thing is to evaluate it in the beginning by a thorough history taking (including radiation types or the possibility of internal contamination).

12.4.2 Beta Rays

Intermediate between nonpenetrating alpha particles and deeply penetrating gamma rays are "moderate" beta particles. Beta particles travel a few meters in the air, can be shielded with aluminum foil, and may penetrate a few millimeters into the skin. Although skin exposure to beta particles can be harmful, internal contamination and exposure can also cause similar damage to that caused by the alpha particles, even though its severity is relatively mild.

12.4.3 Gamma Rays (Almost Equal to X-Rays)

The most common radiation clinicians encounter is gamma rays, typically used on a frequent daily basis, such as in diagnostic imaging. Gamma rays are electromagnetic waves, traveling tens of meters in the air, and can penetrate the human body. The main medical concern of gamma rays is external exposure.

Some radioactive materials emit multiple rays. So, we have to recognize what kind of materials or rays are concerned each time. These kinds of information will be obtained usually from the site supervisors, etc.

Once internal contamination (followed by internal exposure) is suspected by the history, the medical team leader is urged to consult with trained radiation emergency specialists and/or professional organizations such as REAC/TS for a clinical discussion about that.

12.5 Half-Life of Radioactive Materials

All radioactive materials gradually lose its radioactivity with time. This decrease in radioactivity is expressed as radioactive half-life, which is the time it takes for a radioactive material to lose its natural radioactivity.

In large-scale disasters such as an accident at a nuclear power plant, it is important to consider the half-lives of radioactive materials.

For example, in the accident at the Fukushima nuclear power plant in Japan that occurred in March 2011, two kinds of radioactive materials were mainly released. Cesium-137 created a major problem, with its half-life of 30 years. Its long half-life still forces the plant's construction workers and physicians who work at the on-site clinic, as the author, to exercise extreme caution because a significant amount of residual gamma radiation still remains. Massive amount of dangerous iodine-131 (also called radioactive iodine) was also released at the time of the explosion. However, 2 years later, no iodine-131 is detected since its half-life is as short as 8 days.

12.6 Special Radiation Units

There are so many measurement units used in nuclear medicine and nuclear physics that it can easily confuse beginners. For simplicity, consider only three of them, Sievert, Becquerel, and Gray, abbreviated Sv, Bq, and Gy, respectively. These are clinically important units in radiation medicine. Sv is the unit used to measure the size of the impact of radiation exposure on biological tissue or the whole human body. It is especially important in medical field. Radiation exposure can be classified into partial or total body exposure. Sievert per hour (Sv/h) is often used as well.

Some examples are (1) 0.4–0.6 mSv mammography, (2) 10–30 mSv full-body CT scan, (3) 68 mSv as victims who lived closest to Fukushima plant (estimated), and (4) 670 mSv the highest dose received by a worker responding to the Fukushima plant disaster.

Bq represents the amount of radioactivity of the source material per unit mass of the substance. Radiation experts can convert Bq to Sv with a special computer; however, this procedure is very complicated.

Less useful in radiation medicine is Gy; the unit for the amount of radiation for the materials (not human tissues or body). But we need to know this because it is often used by radiation experts to express radiation doses. Gy can be converted to Sv through complex calculation. If the radiation source is Cesium, the number of Gy and Sv will be nearly equal.

12.7 Outline of the Radiation Medicine [5]

An orthopedic surgeon, trained for trauma, must be mainly alert to the special needs of the patients with open and closed bone fractures.

Practically, not only doctors or nurses but all healthcare workers should be trained for their participation in radiation emergency medicine regardless of the type of orthopedic trauma, in order to prevent the entire hospital and the community from being contaminated by radioactive materials.

Needless to say, radiation exposure of medical staff involved in the treatment must be as minimized as possible.

12.8 Patients with External Radiation Exposure (Can Be Lethal)

For patients with only external radiation exposure without physical trauma, no specific initial emergency treatment is indicated. Specific objective findings from high-dose radiation exposure actually emerge 24–48 hours after the exposure. So, if a patient’s condition is not good immediately after the accident, severe occult trauma or disease must be detected.

Accurate measurement of a patient’s radiation exposure dose is theoretically impossible. All we can do is to estimate it by various kinds of clues afterward. However, nausea and vomiting observed within a few hours after exposure can be a useful prodromal marker for high-dose radiation exposure with the indication of hospital admission and specialized therapy. When observing patients with these symptoms, the best way is to consult a professional facility such as REAC/TS (Tables 12.1 and 12.2).

12.9 Radiation Tissue Damage

Radiation to our body cells damages DNA during cell division. Cells are classified into three types according to their state: dividing cells, resting cells, and nondividing cells. Continuously dividing cells seen in lymphatic tissue, intestinal epithelium, and skin tissue are radiosensitive. Cells of solid organs such as liver, kidney, pancreas, or thyroid are not rapidly dividing; they are termed resting cells. However, these resting cells will divide in response to certain stimuli. They may be moderately damaged from radiation while dividing. Cells in tissues such as bone, nerves, and

Table 12.1 Guide for the management of radiation injuries based on early symptoms [6]

Clinical signs		Corresponding dose (Gy)		
WBE	LE	WBE	LE	Decision
No vomiting	No early erythema	<1	<10	Outpatient with 5-week surveillance period (blood, skin)
Vomiting 2–3 h after exposure	Early erythema or abnormal sensation 12–24 h after exposure	1–2	8–15	Surveillance in a general hospital (or outpatient for 3 weeks followed by hospitalization if necessary)
Vomiting 1–2 h after exposure	Early erythema or abnormal sensation 8–15 h after exposure	2–4	15–30	Hospitalization in a hematological or surgical (burns) department
Vomiting earlier than 1 h after exposure and/or other severe symptoms, e.g., hypotension	Early erythema, within the first 3–6 h (or less) after exposure, of skin and/or mucosa with edema	>4	>30	Hospitalization in a well-equipped hematological or surgical department with transfer to a specialized center for radiopathology

WBE whole-body exposure, *LE* local exposure

muscle are called nondividing cells. The radiosensitivity of these cells is very low.

For orthopedic surgeons, this chapter focuses on typical examples of the radiation effects on bone, muscle, nerve, and adjacent skin.

12.9.1 Bone

Bone is considered radioresistant in most adult situations. However, in fetuses, children, and adolescents with active bone growth and cell division the bone cells are radiosensitive to external radiation. Bone abnormalities may become clinically apparent many years later. These late-onset abnormalities include such disorders as growth failure, osteonecrosis, osteoporosis, and a variety of bone tumors. Children may exhibit bone growth inhibition by relatively small dose of external exposure (e.g., 1 Gy). In addition, many radionuclides which cause internal exposure are bone seekers and accumulate in the bone. These nuclides include 45Ca, 90Sr, 32P, or 226Ra, which may cause bone tumors.

12.9.2 Nerves and Muscle

Peripheral nerve and muscle cells, which are nondividing by nature, constitute nonregenerating organs. They are resistant to extremely high radiation doses since these cells do not divide.

12.9.3 Skin

Skin damage by radiation causes dermatitis (acute and chronic) and cancer.

Acute dermatitis occurs when the skin is exposed to above a certain level of radiation. Examples are epilation (3 Gy), erythema or pigmentation (5 Gy), skin bullae or erosion (7 Gy), or ulceration (10 Gy).

Chronic dermatitis: The severity ranges from mild to severe, depending on the amount of radiation. While skin lesions are limited to dry dermatitis or keratosis in mild cases, wet dermatitis or wet ulcer develop in more severe cases. Moreover, long-term chronic dermatitis can lead to skin cancer.

12.10 Patients Contaminated with Radioactive Materials (Radionuclides)

As previously noted, radioactive material contamination may be external by radionuclides being deposited on the body surface or on the clothing, and internal by entering the body through inhalation, ingestion, or open wounds.

Table 12.2 Critical phase of acute radiation syndrome

	Degree of ARS and approximate dose of acute WBE (Gy)				
	Mild (1–2 Gy)	Moderate (2–4 Gy)	Severe (4–6 Gy)	Very severe (6–8 Gy)	Lethal (>8 Gy)
Onset of symptoms (days)	>30	18–28	8–18	<7	<3
Lymphocytes (G/L)	0.8–15	0.5–0.8	0.3–05	0.1–03	0–0.1
Platelets (G/L)	60–100 10–25 %	30–60 25–40 %	25–35 40–80 %	15–25 60–80 %	<20 80–100 %[a]
Clinical manifestations	Fatigue, weakness	Fever, infections, bleeding, weakness, epilation	High fever, infections bleeding, epilation	High fever, diarrhea, vomiting, dizziness and disorientation, hypotension	High fever, diarrhea, unconsciousness
Lethality (%)	0	0–50 Onset 6–8 weeks	20–70 Onset 4–8 weeks	50–100 Onset 1–2 weeks	100 1–2 weeks
Medical response	Prophylactic	Special prophylactic treatment from days 14 to 20; isolation from days 10 to 20	Special prophylactic treatment from days 7 to 10; isolation from the beginning	Special treatment from the first day; isolation from the beginning	Symptomatic only

ARS acute radiation syndrome
[a]In very severe cases, with a dose >50 Gy, death precedes cytopenia

For external contamination, decontamination must be performed before starting any medical or surgical treatment except in cases such as life-threatening emergencies. Decontamination process includes complete undressing of the patient, whole body radiation surveys before and after the decontamination procedures, which may start with a dry cloth wiping on intact skin, followed (if necessary) by gentle washing with tepid tap water, avoiding both cold and too hot water, and repeated localized (contaminated area) radiation surveys between decontamination cycles. Decontamination procedures must be performed carefully enough to preserve the integrity of the skin and avoid inadvertent iatrogenic internal contamination through small wounds made by a rough manner of procedures. If any contamination is detected after the careful and elaborate decontamination, most of such residual radioactive materials in the skin will be gone as normal skin sloughing occurs in about 13 days.

For contaminated wound care, decontamination requires cleaning the wound with saline. When a wound is deep or extensive, surrounding bloodstream may convert an externally contaminated wound to an internally contaminated wound. In such cases, initial decontamination must be performed quicker with repeated radiation surveys and with careful debridement when indicated. The most serious situation may be open bone fractures. When associated with high levels of persistent contamination, consultation with a nuclear medical emergency agency will be the best way to discuss how to deal with the residual contamination or the appropriate timing of surgical therapy.

For internal contamination by inhalation or ingestion, history taking of the patient's activity is the most important key. When radioactivity is observed around the nose and mouth, high suspicion should be taken of contamination in orifices and mucous membrane. Since uptake of radioactivity occurs fast at these sites or open wounds, they must be decontaminated first before the other part of the skin.

First, have the patient blow his/her noses and gargle, then decontaminate wounds if any, and proceed to the decontamination of the normal skin.

More detailed management of contamination is beyond the scope of this chapter.

While consultation with radiation specialists is very important, at least those who can be the leaders in radiation emergency should consider attending radiation emergency preparedness seminars as those offered by REAC/TS.

The protective equipment shown in Fig. 12.1 is not intended to prevent radiation exposure, but just to prevent the spread of contamination [7].

12.11 Healthcare Workers' Radiation Exposure

All healthcare workers directly handling or touching radioactively contaminated patients should wear a personal radiation dosimeter. There are several types of dosimeters such as dose rate meters (the number of Sv per unit time) or cumulative dose meters, all with or without alarm. A designated worker, usually a radiology technician, should monitor all dosimeters for staff safety. When a dosimeter detects unsafe level of radiation, corrective action must be initiated for the safety of both patients and staff. In addition, each radiation information must be monitored and recorded throughout the treatment process.

It should be noted that it is very rare for clinical staff to receive harm through handling contaminated patients.

12.12 Healthcare Facility Management

The care of radioactively contaminated patients requires safety procedures to prevent cross-contamination of staff, facilities, ambulances, various kinds of equipment, etc. The designated

Fig. 12.1 Author and medical staffs at the Fukushima nuclear power plant

radiation safety worker should demark a temporary radiation-controlled area inside which all contaminated items such as plastic sheets, stretchers, bandages, tubing, and electronic monitoring cables must be held. The medical staff directly treating patients should use suitable protective clothing and shoe covers in addition to standard precautions, such as a surgical gown made of impermeable materials, mask, goggles, etc. Double-gloving technique is also useful and essential, with the inner gloves tape-fixed on protective clothing and the outer ones changed after each procedure.

All cleaning solutions used for decontamination, as described above, must be collected in a secure bucket or a special container.

Protective clothing worn by any staff involved in direct patient care must be carefully collected after the completion of the treatment. The staff must carefully remove, fold, and dispose of gears when going outside the temporary radiation-controlled area. The designated staff carefully removes all radioactive waste including liquids, protective clothing, protective sheets, etc., to prevent spreading of the radioactive materials.

In the sense of facility management also, attending REAC/TS-type seminars is highly recommended to all the staff potentially involved in the care of radioactively contaminated patients (Fig. 12.2).

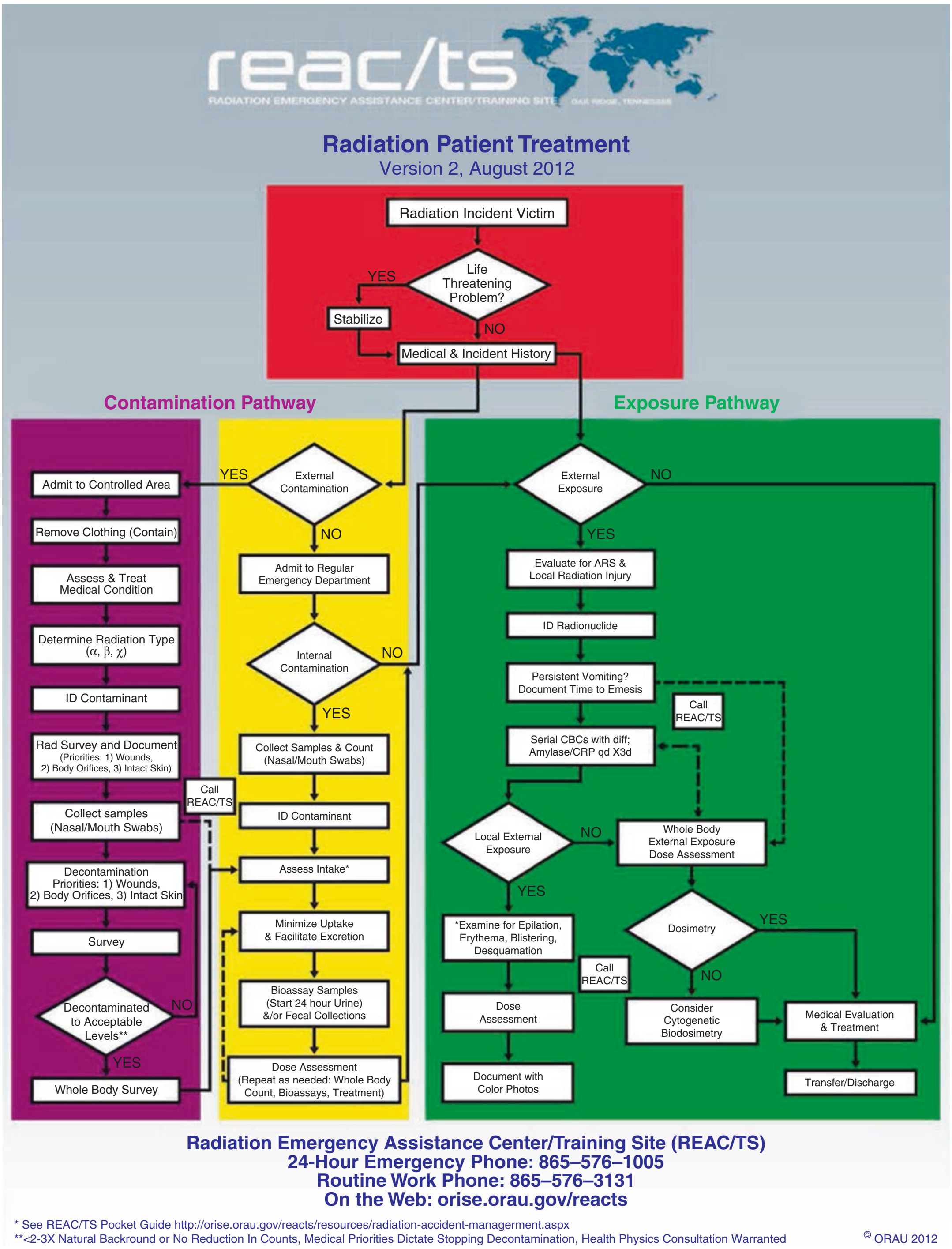

Fig. 12.2 Radiation patient treatment [7]

Conclusion

In our nuclear age, with the possibility of radiation disaster always present, any clinician might be called on to treat the victims. Primarily all the staff must completely understand the difference between exposure and contamination. Then the basic knowledge of radiation, understanding of external and internal contamination, and the outline of decontamination are essential to protect the lives of the victims (patients) and the treating staff. First clinical responders will be able to improve their skill to manage radiation disasters by attending seminars such as those offered by REAC/TS. Some cases of radiation emergency require specialty consultations. Although not emphasized in this chapter, the emotional distress and anxieties of the victims and the staff will need early, frequent, and sufficient psychological counseling.

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13 Orthopedic Injuries in Transportation Disasters

Khaled Emara and Mohamed Al Kersh

13.1 Introduction

Accidents occur anytime and anywhere. They are sudden and unplanned and affect people of all ages and in all conditions of health. They happen due to direct or indirect application of force from mechanical, chemical, or thermal energy sources or a combination thereof. Injuries of various types and degrees of severity affecting one or more body regions occur in response to the type and duration of the applied force minus possible forms of protection. In addition to the physical consequences of an accident, various distinct psychological consequences may become manifest. Accidents may affect one individual or a few or several people or may result in mass casualties (so-called heavy casualty events) [1].

Road traffic crashes (RTCs) and injuries are an ignored and perhaps unrecognized global pandemic of shocking proportion, even though they are predictable and therefore preventable. Almost 1.2 million people die in road traffic crashes worldwide, and as many as 50 million are injured or disabled every year [2]. Most affected are young people between the ages of 15–39 years; traffic injuries are the number one killer of children under the age of 15 years. The World Bank estimates the global cost of road traffic crashes to be US $ 500 billion, of which the developing countries alone are responsible for US $100 billion. This is double all the development assistance these countries receive from donor states [2].

Prevention of accidents and their consequences; emergency treatment of the injured of all ages, even in the event of a disaster; reconstructive, corrective, body-part substitution (plastic) surgery; and rehabilitation with vocational and social reintegration of the individual are humanitarian and economic obligations of the highest priority [3].

Management of this task requires maximum performance medical care facilities that must guarantee highly differentiated medical to meet the needs of very different injury patterns and respond to an unexpected number of severely injured persons, some with additional severe health disorders. This requires specialists in neurosurgery, intensive care, anesthesia, visceral surgery, orthopedics, plastic surgery, pediatric surgery, and vascular, cardiac, thoracic, and maxillofacial surgery, in addition to an established team of trauma surgeons, operating at appropriate medical care facilities according to predetermined regional requirements. In the future, it will only be possible to make these essential reserves available and efficient within an organized regional network [3].

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_13

Management of such injuries includes prevention, management at the accident scene, transfer system, management at the trauma medical care center, and rehabilitation.

13.2 Survey

Transportation accidents can occur anywhere in the world, but there are some countries in which these disasters occur more frequently, for example, India, the Middle East, and South America, etc. That can be due to economic, political, or environmental reasons. The most important issue is the availability of modern transportation methods with high speed such as cars and buses, trains and trucks, and even motorcycles and airplanes all over the world, at relatively low cost but without road infrastructure, nor law enforcement nor medical education and equipment to support this in traffic.

As an example in the Middle East, comparative data of the various aspects throughout the region are not readily available, thus developing unified policies for the region is daunting. Lack of implementation of best practices in the region is due to different levels of enforcement of legislation. Furthermore, the lack of provision of holistic trauma care has a direct impact on the outcome of road traffic crashes and injury which is visible due to the sociocultural and economic differences between the countries in the region. Professional staffs are scarce, and the deficiency must be addressed for any positive development to occur [4].

As a result, management of road traffic crashes needs to be specifically addressed at the country level with regional cooperation.

The Eastern Mediterranean Region has the world's highest traffic fatality rate among young men aged 15–29 years at 34.2 deaths per 100,000. The deaths are estimated to cost US $7.4 billion annually. Traffic fatalities from the year 2000 to the year 2020 are expected to rise by 68 %. Within this region in 2002, the mortality rate due to injury was twice that of the rest of the world [5]. Injuries caused 16 % of all deaths [6]. The low- and middle-income countries of the Eastern Mediterranean Region accounted for the second highest mortality rate after Africa.

Worldwide mortality from road traffic accidents averages 26.3 per 100,000 people per year. Global and regional records suggest there are 40 million people with disabilities who have limited access to rehabilitation and nearly nonexistent social reintegration. Trauma care is varied with some of these countries lacking acceptable prehospital emergency medical system (EMS) coverage.

Trauma care at the primary level or dispensary level is limited or nonexistent in many of the countries in the region. Even though there is a definitive desire and evidence of willingness for change with improved political will, effective injury prevention policies have not yet been conceived and/or implemented. However, the concepts of dealing with and managing road traffic crashes and injuries in the region have lately changed for the better [4].

The number of road traffic crashes has swollen with an increase in morbidity and mortality (Fig. 13.1) due in part to the increase in the number of motor vehicles and the number of driving hours, increase in the road network, industrialization, and, in some countries, burgeoning tourism [4].

In the United States, injuries constitute the fourth leading cause of death over all ages (accounting for 6 % of all deaths) and the leading cause of death among children, adolescents, and young adults. In 2003 alone, 164,002 US citizens died as a result of an injury, translating into an overall rate of 55.9 injury deaths per 100,000 populations [7].

Put in more immediate terms, over 400 people die of injuries in the United States each day; nearly 50 of these deaths are among children and adolescents. Nearly 8 of every 10 deaths in young people aged 15–24 are injury related. Indeed, more young lives between the ages of 1 and 34 are lost to injury than to all other causes of death combined. The impact of injury as a cause of death among young people is best summarized by comparing the total years of potential life lost before the age of 75 (YPLL-75) across the leading causes of death. Injuries account for more premature deaths than cancer, heart disease, or human immunodeficiency virus (HIV) infection [7].

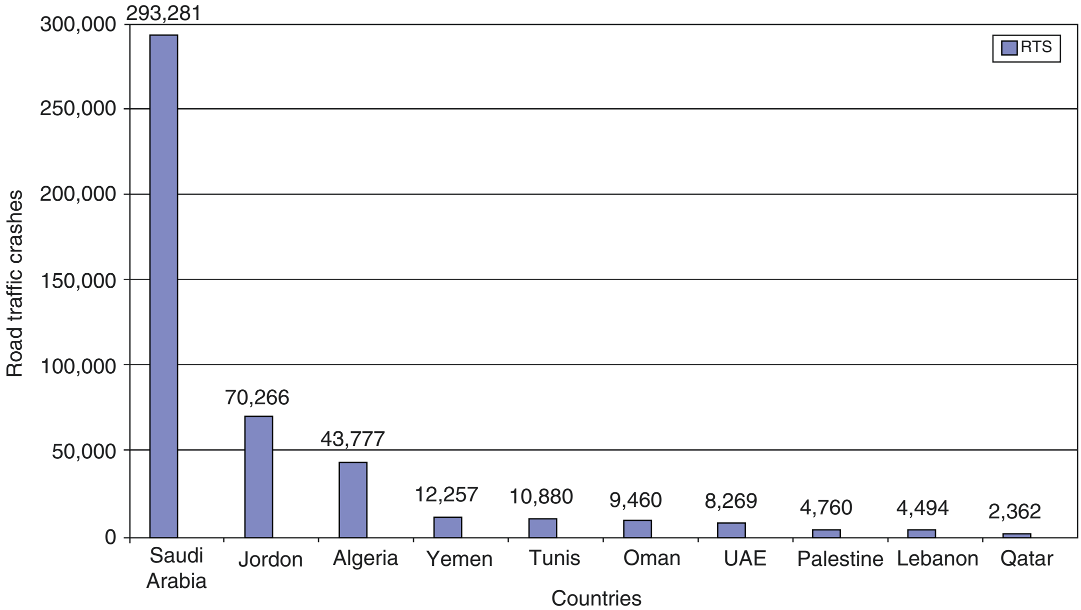

Fig. 13.1 The number of road traffic crashes recorded in some Arab countries in 2004 is shown [4]

Data on the mechanisms, frequency and consequences of accidents, and factors affecting quality of care.

From an epidemiological and socioeconomic standpoint, four accident categories can be differentiated:

- Domestic accidents
- Leisure and sports accidents
- Accidents at work and at school, including accidents en route
- Road traffic accidents

Thirty-two percent of all accidents happen at home. Almost as many accidents occur during leisure activities (31 %). Accidents at work account for 15 % and accidents at school make up 17 %. Five percent of injuries result from road traffic accidents, whereby these lead to the highest mortality [7].

Apart from international medical care studies with a defined purpose, the reported data on accident frequency, severity, and accident mechanisms are as of now only fragmentary and can be used to only a limited extent as the basis for requirement planning and structuring.

Improvements in automobile safety and rescue services, combined with advancements in medicine, have achieved both an increase in survival rates and a reduction in complications and secondary damage in recent decades [8]. Many persons who would previously have died at the scene of the accident are now admitted to hospital as critically injured patients. Over the last 10 years, there has been an average 4 % annual reduction in the number of deaths at the site of the accident and the absolute number of critically injured as a result of road traffic accidents [8]. In some poor countries, poorly maintained transportation methods such as automobiles and buses with bad tires or trains lacking proper maintenance lead to an increase in accidents and occasionally large transportation disasters.

13.3 Injuries in Fatal Aircraft Accidents

The most common cause of injury in aircraft accidents is the sudden deceleration that occurs when an aircraft hits the ground or water. However, the forces acting upon the occupants are frequently less than those applied to the aircraft. This is because the aircraft structures absorb some energy as they collapse or are crushed.

Head injury is very common in aviation accidents and was seen in two thirds of cases. In most of these, the head injury caused or contributed to the cause of death. Spinal fractures are present in 45 % of intact aircraft accident fatalities. There is no significant difference in the prevalence of spinal injury between the various categories of flying. More than two thirds of the fatalities had abdominal injury. Rupture of the diaphragm was seen in 30.6 % of unselected victims. Only 20 % of fatalities from aviation accidents escape limb fracture, 73.6 % having leg fractures and 56.6 % having arm fractures. 64.5 % of all fatalities had fractures of the lower leg and 52.6 % had fractures of the femur. The arm was also frequently fractured; 42.5 % had fractures of the upper arm and 42.3 % had fractures of the forearm or wrist.

13.4 Trauma System

A trauma system is an organized approach to acutely injured patients in a defined geographical area that provides full and optimal care and that is integrated with the local or regional Emergency Medical Service (EMS) system.

A system has to achieve cost-efficiency through the integration of resources with local health and EMS system to provide the full range of care (from prehospital to rehabilitation) [9–11].

Regionalization is an important aspect of a trauma system because it facilitates the efficient use of health-care facilities within a defined geographical area and the rational use of equipment and resources. Trauma care within a trauma system is multidisciplinary and is provided along a continuum that includes all phases of care [10–16].

The major goal of a trauma system is to enhance the community's health. This can be achieved by identifying risk factors in the community and creating solutions to decrease the incidence of injury, and by providing optimal care during the acute as well as the late phase of injury including rehabilitation, with the objective to decrease overall injury-related morbidity and mortality and years of life lost. Disaster preparedness is also an important function of trauma systems, and using an established trauma system network will facilitate the care of victims of natural disasters or terrorist attacks. The Model Trauma System Planning and Evaluation Standard have recently been completed by the U.S. Department of Health and Human Services [17].

13.4.1 Trauma System Components

The most significant improvement in the care of injured patients in the United States has occurred through the development of trauma systems.

The necessary elements of a trauma system are: access to care, prehospital care, hospital care, and rehabilitation, in addition to prevention, disaster medical planning, patient education, research, and rational financial planning. Prehospital communications, transport system, trained personnel, and qualified trauma care personnel for all phases of care are of utmost importance for a system's success (Fig. 13.2).

The Model Trauma Care System Plan introduced the concept of the "inclusive system" [11] (Fig. 13.3). Based on this model, trauma centers were identified by their ability to provide definitive care to the most critically injured. Approximately 15 % of all trauma patients will benefit from the resources of a Level I or II trauma center. Therefore, it is appropriately expected in an inclusive system to encourage participation and to enhance capabilities of the smaller hospitals.

13.4.2 Public Information, Education, and Injury Prevention

Because trauma is not considered an important public health problem by the general population, efforts to increase awareness of the public as well as to instruct the public about how the system operates and how to access the system are impor-

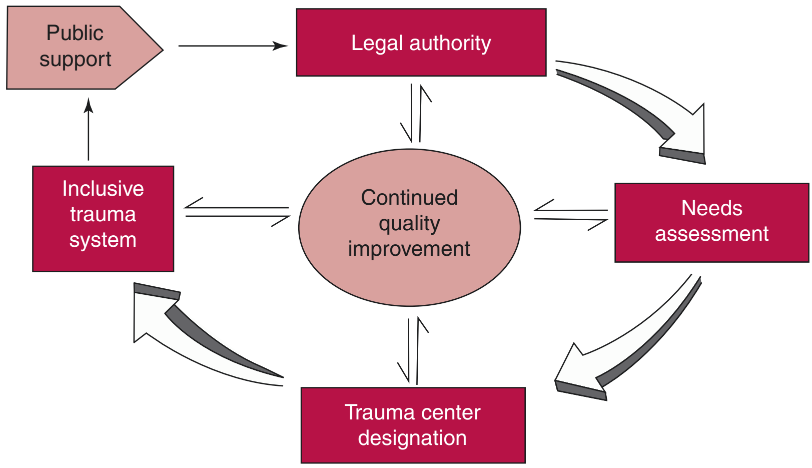

Fig. 13.2 Regional trauma system development must progress in a sequential fashion; a comprehensive needs assessment is a pivotal early step [11]

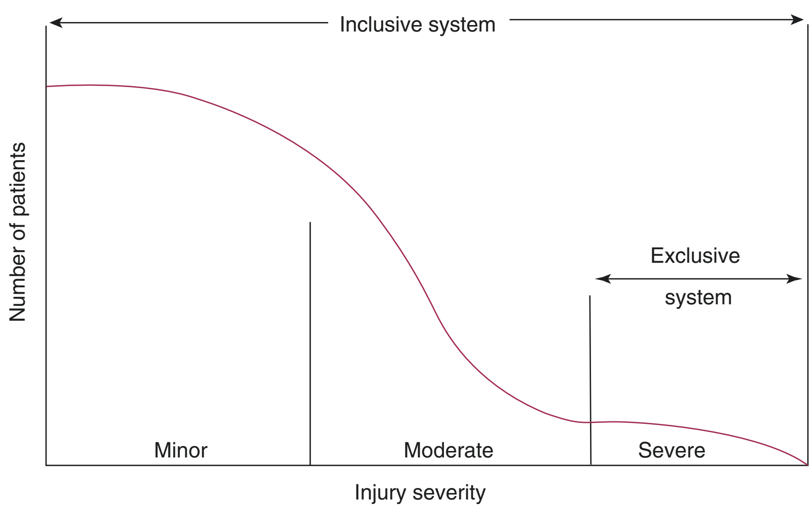

Fig. 13.3 Diagram showing the growth of the trauma care system to become inclusive. Note that the number of injured patients is inversely proportional to the severity of their injuries [11]

tant and mandatory. A recent Harris Poll conducted by the Coalition for American Trauma Care showed that most citizens value the importance of a trauma system with the same importance as fire and police services [17].

Trauma systems must also focus on injury prevention based on data relevant to injuries and what interventions will likely reduce their occurrence. Identification of risk factors and high-risk groups, development of strategies to alter personal behavior through education or legislation, and other preventive measures have the greatest impact on trauma in the community, and over time, will have the greatest effect on non-fatalities [17].

Injury prevention needs participation by big transportation companies in the education of personnel and in research programs for the development of infrastructures like Volvo Research and Educational Foundations (VREF). The overarching aim of VREF is to contribute to the development of sustainable transportation systems.

The VREF participated in the finance of the Future Urban Transport (FUT) program. The Future Urban Transport (FUT) research program—How to deal with complexity—is intended to contribute to the development of sustainable transportation systems. The program searches for solutions at the system level, because a number of components—including land use, city planning, urban freight, transport system choices, and how decisions are made—need to be addressed simultaneously to develop sustainable transportation systems.

13.4.3 Human Resources

Because the system cannot function optimally without qualified personnel, a quality system provides quality education to its providers. This includes all personnel along the trauma care continuum: physicians, nurses, emergency medical technicians (EMTs), and others who impact the patient and/or the patient's family.

In the trauma system, orthopedic surgeons have a role in the community for the prevention and management of patients with fractures after a transportation disaster.

They have a role in the education of first responders in how to manage the patient at the scene of the accident. They also participate in researches to improve the safety of transportation means.

13.4.4 Prehospital

Trauma care prior to hospital arrival has a direct effect on survival. The system must ensure prompt access and dispatch of qualified personnel, appropriate care at the scene, and safe and rapid transport of the patient to the closest most appropriate facility.

The primary focus is on education of paramedical personnel to provide initial resuscitation, triage, and treatment of trauma patients. Effective prehospital care requires coordination between various public safety agencies and hospitals to maximize efficiency, minimize duplication of services, and provide care at a reasonable cost.

Critically injured patients must receive high-quality care from the earliest post injury moment to have the best chance of survival. Most trauma victims first receive health care from the Emergency Medical Services (EMS) system, which is responsible for rendering aid and transporting the trauma patient to an appropriate facility.

The modern EMS system involves the integration of a number of complex components. Essential elements include the following: personnel, equipment, communications, transport modalities, medical control, and an ongoing quality improvement process. Different configurations of EMS systems result when these components are integrated in varying combinations. The EMS system represents a significant component of the trauma system.

13.4.5 Communication System

A reliable communications system is essential for providing optimal trauma care. Although many urban centers have used modern electronic technology to establish emergency systems, most rural communities have not. It must include universal access to emergency telephone numbers (e.g., 123), trained dispatch personnel who can efficiently match EMS expertise with the patient's needs, and the capability of EMS personnel at the trauma incident to communicate with prehospital dispatch, with the trauma hospital, and with other units.

Access also requires that all users know how to enter the system. This can be achieved through public safety and information and school educational programs designed to educate health-care providers and the public about emergency medical access.

13.4.6 Medical Direction

Medical direction provides the operational matrix for care provided in the field. It grants freedom of action and limitations to EMTs who must rescue injured patients. The medical director is responsible for the design and implementation of field treatment guidelines, their timely revision, and their quality control. Medical direction can be "off line" in the form of protocols for training, triage, treatment, transport, and technical skill operations or "on line," given directly to the field provider.

13.4.7 Triage and Transport

The word triage derives from the French word meaning "to sort." When applied in a medical context, triage involves the initial evaluation of a casualty and the determination of the priority and level of medical care necessary for the victim [18]. The purpose of triage is to be selective, so that limited medical resources are allocated to patients who will receive the most benefit. Proper triage should ensure that the seriously injured patient be taken to a facility capable of treating these types of injuries—a trauma center. Patients with lesser severity of injuries may be transported to other appropriate medical facilities for care.

Each medical facility has its own unique set of medical resources. As such, triage principles may vary from one locale to another depending upon resource availability. Likewise, established triage principles may be modified to handle a multiple casualty incident or mass casualties. Then, a different set of triage criteria may be employed which will attempt to provide medical care to the greatest number of patients. In this scenario, some critically injured patients may not receive definitive care as this may consume an "unfair share" of resources. The goal of triage and acute medical care is to provide the greatest good to the greatest numbers.

From a historical perspective, war has been the catalyst for developing and refining the concept of medical triage. Dominique Jean Larrey, Napoleon's chief surgeon, was one of the first to prioritize the needs of the wounded on a mass scale. He believed "… it is necessary to always begin with the most dangerously injured, without regard to rank or distinction" [19]. He evacuated both friend and foe on the battlefield and rendered medical care to both. He refined his techniques for evacuation and determining medical priorities for injured patients over 18 years and 60 battles while a member of the French army [19].

During World War I, the English developed the "casualty clearing station," where the injured were separated based on the extent of their injuries. Those with relatively minor injuries received first aid, while those with more serious injuries underwent initial resuscitative measures prior to definitive care. As medical and surgical care of battlefield injuries expanded, a system of triage and tiered levels (echelons) of medical care was designed. Levels of medical care and triage of single, multiple, and mass casualties remain the paradigm for military combat medical care.

There are five levels of care in the present military medicine. The first line of medical care is that which is provided by fellow soldiers. Principles of airway management, cessation of bleeding, and basic support are offered by fellow soldiers. Organized medical care begins with a medic or corpsman who participates in level 1 care. They are assigned to functional military units and serve as the initial medical evaluation and care of the injured patient. Level 2 is a battalion aid station or a surgical company. Resuscitation and basic life saving surgical procedures may be performed at these stations. Level 3 is a Mobile Army Surgical Hospital (MASH) or Fleet Surgical Hospital. Advanced surgical and medical diagnostic and therapeutic capabilities are available at these facilities. A level 4 facility is larger and has enhanced medical capacity. Examples include a hospital ship (USNS Mercy or Comfort) or an out-of-country medical facility (Landstuhl Regional Medical Center (Army), Germany). A level 5 facility is a large tertiary and rehabilitative medical facility and is located within the home country (Naval Medical Center San Diego). Each increasing level has a more comprehensive medical and surgical capacity. As patients are identified on the battlefield, they are triaged and transferred to the next higher level for care. During the Vietnam War, air medical transport enabled the triage of a seriously injured soldier from the battlefield directly to a MASH unit [20]. The time to definitive surgical care was less than 2 h compared to 6 h during World War II [21].

The lessons learned from the triage and treatment of combat casualties were slow to translate into civilian use. Injured patients, regardless of the severity of injury, were simply taken to the nearest hospital for treatment. Neither a triage system nor an organized approach to injury existed. The Advanced Trauma Life Support course was created in the late 1970s and with it the concept of requisite skills and facilities to treat injured patients emerged [15].

13.5 Conclusion and Orthopedic Surgeon Role

Orthopedic surgeons need to participate in community awareness about the problem, prevention, and treatment of mass causality due to transportation disasters. This awareness can affect the political decisions and financial support for better infrastructure for roads and public transportation, law enforcement and regulations, and also financial support for trauma medical care systems.

Orthopedic surgeons at the scene of trauma can have an important role as a first aid worker in life support and as an orthopedic surgeon in splinting fractures.

Orthopedic surgeons at the emergency room has the role to stabilize fractures starting with life-threatening fractures and open fractures to help the overall goal: save life, save limb, and save function.

The most common role for orthopedic surgeons after stabilization of life is the definitive care of fractures (either open or closed fractures). Then after several weeks or months from the mass casualty event, the orthopedic surgeon's role is treatment of residual complications and consequences of the injury such as nonunion, infection, joint stiffness, muscle dysfunction due to nerve injury, etc.

Training programs should include orientation about mass causality (not focusing only on surgical procedures, but also should include planning for management and team work in field hospitals, etc.) and the role of orthopedic surgeons at all stages from prevention to rehabilitation.

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14 Terror-Related Trauma

Asaf Acker and Dan Atar

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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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_14

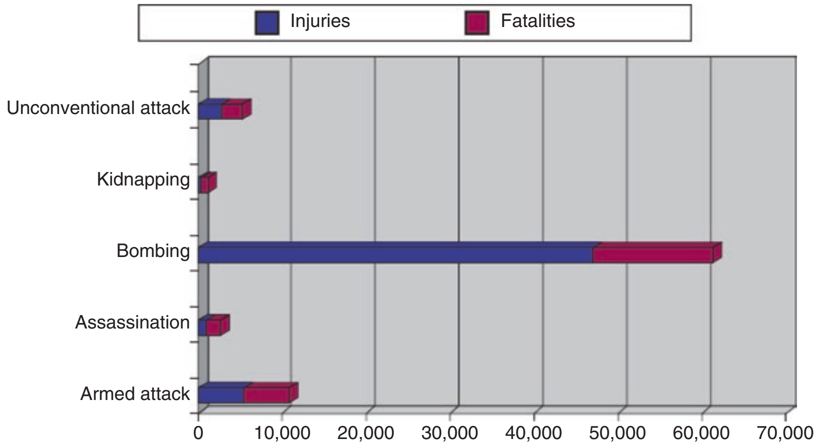

Fig. 14.1 Injuries and fatalities from terrorist incidents, 1998–2005. Data from the RAND-MIPT Terrorism Incident Database show that bomb blast injuries account for 82 % of all injuries caused by terrorists. (Available at: http://www.tkb.org/incidenttacticmodule.jsp.)

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

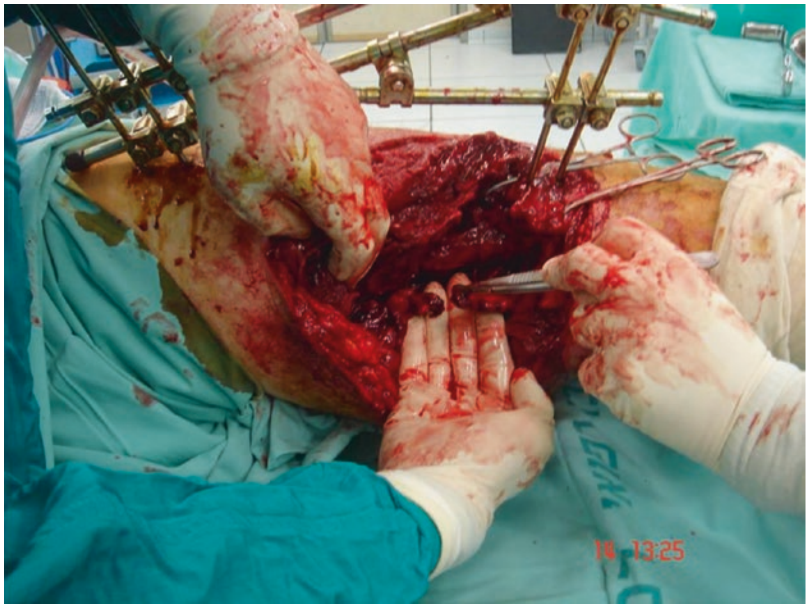

Fig. 14.3 Gustilo 3A open femoral fracture due to shrapnel injury. Notice the torn Sciatic Nerve. (courtesy of Dr. Norman, Rambam University Medical Center, Haifa, Israel)

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

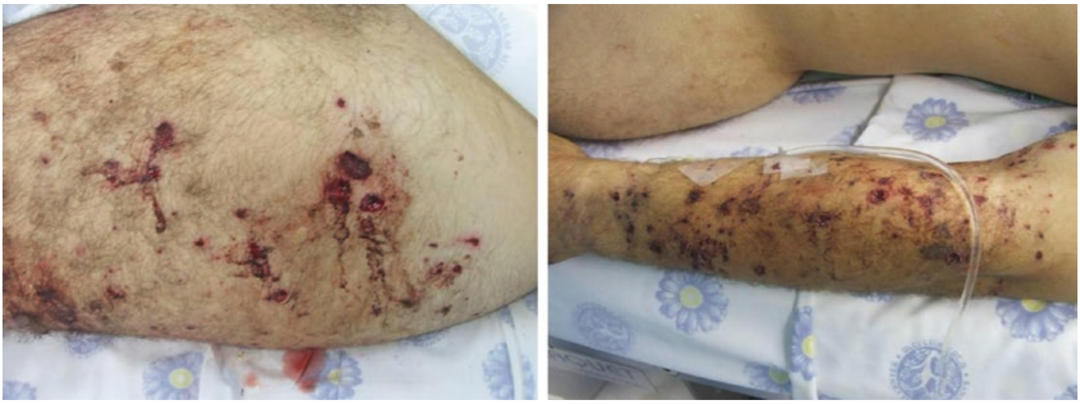

Fig. 14.5 Shrapnel injury in the lower limbs due to an explosion (courtesy of Dr. Norman, Rambam University Medical Center, Haifa, Israel)

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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Part III

Treatment of Orthopaedic Injuries: General Treatment Principles

15 Battlefield Triage

S. Rigal and F. Pons

15.1 Introduction

> The first wounded arrive and in a short time, their stream submerges us ....
> The walking wounded scramble for care, we hardly can push them aside to reach the most serious casualties
> Chagneaud, Médecin Major of a French regiment in April 1915 [1].

Triage is a process of sorting the casualties according to the severity of injury and the prioritisation of treatment or evacuation. Historically, triage in military action responds to several issues: maintaining the number of soldiers, humanitarian concerns and logistical constraints. This concept of triage has been extended to unusual situations (natural disasters, industrial accidents, terrorist bombings) which generate an unpredictable influx of victims, isolated or repetitive, sometimes aggravated by panic and insecurity. Natural disaster triage, however, is not the same as war triage. Nonetheless, many of the fundamental concepts underlying war triage also apply to disaster scenarios.

In daily practice, the standard goal of triage is to provide the greatest good for each individual patient. Thus, those who are most severely injured are typically the highest priority for treatment. In war and disaster, where there are a large number of wounded, and when the medical care system is overloaded, the principles of triage are to provide the greatest good for the greatest number, even when interventions based on the normal standard of care may not be completed for each patient.

For the majority of surgeons, triage can be an abstract concept. Triage in war or disaster conditions is a complex process, with no direct civilian medical equivalent. They may never have to use it in their daily practice.

The forward surgical units (FSU) of the French Army Medical Service are currently performing military operations around the globe. In 2014, the surgical units are simultaneously in Chad, Ivory Coast, Central African Republic, Djibouti, Afghanistan and Mali. Our teams have a great deal of experience from these military and humanitarian missions. Often times, the field surgical teams have used the triage to the benefit of the French soldiers and combatants from other countries (2004 Ivory Coast; 2008 Kosovo; 2008 and 2012 Afghanistan; 2013 Mali).

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_15

The goals of this chapter are the following: to present the principles of triage and the system of the French army and to report the challenges, the logistics and the medical issues surrounding triage.

15.2 History

Triage is a word of French origin, meaning "sorting" or "choosing". Its French definition is "draw, choose, after examination". The origin of the French word is probably Latin "terere granum": thresh grain. The French word "trier" and the English word "try" are probably of the same origin.

The need for sorting war casualties emerged especially during the nineteenth century, after the huge losses of battles in Europe (Austerlitz 1802: 4000 wounded) and in America. In France, Jean Dominique Larrey was the first to organise such triage in the field. He gave a very good description of this in his memoirs, without actually describing it as triage. He explained "you must always begin with those who are most seriously wounded without regard to rank or other distinction". He also described the various echelons of care that characterise the modern military surgery [2].

The British surgeon John Wilson, in 1846, argued that immediate life-saving surgery could only be provided for severely injured casualties if treatment for slight injuries was deferred, and only palliative measures given to those whose injuries were likely to prove fatal [3]. The French surgeon Legouest, professor at the French Military Medical Academy, École du Val-de-Grâce in Paris, wrote in 1863, following Dominique Jean Larrey's concept: "it is imperative to do the triage and limit urgent surgery when there are waves of injuried soldiers" [4].

In the French army, triage was systematically organised during World War I. At the beginning of this war, injured soldiers were quickly evacuated by train to rear hospitals, without sorting. The high mortality rate during the evacuation demonstrated the necessity for sorting patients who required treatment before evacuation. Thus, the first official regulations, the first facilities dedicated to sorting and the word triage appeared in 1917. At Verdun, the first special units devoted to triage were interposed between first aid stations and first surgical facilities. From 31 May to 7 June 1918, about 7,631 casualties were examined and categorised in such a unit [5, 6].

At present, the military triage goals that the Emergency War Surgery published in the last edition 2013 are "the return of the greatest possible number of warfighters to combat and the preservation of life, limb, and eye sight" [7].

As early as the nineteenth century, Legouest had brought up the same goal of military triage: "the light wounded must return on the front" [4]. Fifty years later, during World War I, a similar strategy was applied by the allied army. The military triage ended up with an army of French soldiers "récupérés" (more than 86,000 recovered wounded at the end of the year 1918) [1]. At the same period, Thomas Scotland and Steve Heys reported casualties of the British army in three categories: hopeless cases, several injuries but survival and lightly wounded who could be kept in forward area before returning to the front line to fight [8].

A much-discussed question is that of the expectant category: "some patients may only receive analgesics and be removed to a quiet place where they can die in comfort and with dignity" [9].

Ambroise Paré described three euthanasia cases in his memoir "Journeys in Diverse Places" during an attack on the fortified town of Turin, Italy (1536): "… i.e. trouuay quatre ſoldats morts, & trois qui eſtoyent appuyez contre la muraille, leur face entierement desfiguree, & ne voyoyent, n'oyoyent, ny ne parloyent … vn vieil ſoldat qui me demanda ſil y auoit moyen de les pouuoir guàrir, ie dis que non, ſubit il ſapprocha d'eux & leur coupa la gorge doucement & ſans colere. Voyãt ceſte grande cruauté ie luy dis qu'il eſtoit vn mauuais homme. Il me feiſt rèſponſe, qu'il prioit Dieu que lors qu'il ſeroit accouſtré de telle façon, qu'il ſe trouuaſt quelqu'vn qui luy feiſt autant, à fin de ne languir miſerablement" [10].

In his memoir, Journeys in Diverse Places, Ambroise Paré described his treatment of wounded soldiers in several military campaigns spanning more than three decades. During an attack on the fortified town of Turin, Italy, Paré encountered three mortally wounded and disfigured soldiers, propped against [a stable] wall; their features are all changed; they can neither see, hear, nor speak; and their clothes were still smouldering with the gun-powder that had burned them. "As I was looking at them with pity, there came an old soldier who asked me if there were any way to cure them. I said no. And then he went up to them and cut their throats, gently, and without ill will toward them. Seeing this great cruelty, I told him he was a villain: he answered he prayed God, when he should be in such a plight, he might find someone to do the same for him, that he should not linger in misery" [11].

It is only later in 1875 that the Russian surgeon O. Heyfelder classified the wounded in four categories: "wounded who need an immediate operation, who require a immobilization device, who are directed immediately toward the rear, and wounded who suffer from serious incurable injury that euthanasia is only solution (drinks, administration of narcotics, upgrade to the gap, religious assistance)" [12].

15.3 Triage Context

The word triage has a number of meanings. In civilian practice, the term triage is employed for Civilian Field Triage (the identification of the most appropriate scene management, destination and form of transport for any major trauma victim) and Emergency Department Triage (the process of determining the appropriate priority and period for all patients in an emergency department) [13, 14]. The prehospital triage can be performed in only one patient; in France, we do not use the word triage in this situation.

For the management of many casualties, one can distinguish:

- Triage of "multiple casualties": local response capabilities are not overwhelmed, but there are still a large number of patients requiring triage. The number of patients does not exceed the available medical facilities in the area; patients have to be evacuated sometimes to various hospitals; the objective of the triage is to get the right patient to the right hospital in the right time [13]; if the triage is judicious, every patient will receive an appropriate treatment without delay.
- Triage of "mass casualties": medical facilities are overwhelmed; some patients cannot be treated in the right time; in this case, a real triage is necessary, i.e. sorting and giving priority not only for evacuation but also for treatment.

The threshold between "multiple casualties" and "mass casualties" varies widely according to the setting. Ten casualties at the same time in a city with several hospitals, or in a large well-organised Combat Support Hospital (CSH) with several surgical teams, can be called "multiple casualties". On the other hand, ten casualties in a small FSU or in a small hospital without possible secondary evacuation would require a real triage for treatment.

In war surgery, the decision for triage can follow one of two approaches. On the one hand, it can be systematic, regardless of the number of patients. That is the rule in some military medical systems; that allows them to keep surgical facilities available. On the other hand, it can be based only on the number of casualties and/or by headquarters order.

Triage of war injured can occur within one of four circumstances:

- A military field hospital receiving waves of injured soldiers during a conventional conflict like Great World War I or World War II.
- A military field hospital involved in conflicts affecting civilian populations (Chad, Somalia, Rwanda, Cambodia, etc.), where it has to receive and triage both civilian and military casualties.
- A civilian facility from a country involved in a civil war (Lebanon, Bosnia, Syria, etc.). The available medical facilities and the necessity for triage are very different according to the development of the country.
- A humanitarian facility (Red Cross, NGO) working abroad in a country affected by a war (Afghanistan, Rwanda, Sri Lanka, Central African Republic, etc.).

15.4 French Army Triage System

There are a number of triage category systems used throughout the world today. Some are more sophisticated than others and depend on injury severity scores and physiological parameters. Each organisation has its own variation. Nevertheless, they all create priorities for who gets care or who is transported for care. The French army categorisation includes four categories identified by the letter T and a number. Each casualty will be triaged at every stage (point of wounding, FSU, CSH) and for different purposes (treatment, transport, surgery). The priority must be adjusted to the casualty's clinical condition.

15.4.1 Medical Evacuation (MEDEVAC) Categories

The French army works on the principle of "stay and play" and reduces the evacuation time from the battlefield toward a surgical unit. In the French army, a categorisation is used on the point of wounding to define the priorities of evacuation, even if the wounded patient is isolated.

Urgent Patients whose lives are in immediate danger and whose evacuation has to be done immediately. This category of patients is T1 or T4 (T4 category is not part of the categorisation use on the battlefield for evacuation), and these wounded patients are classified A (Alpha).

Not Urgent Patients whose lives are not in immediate danger and whose evacuation has to be done as soon as possible. This category of patients is T2 and T3. These wounded patients are classified B (Bravo).

The clinical deadlines of treatment are defined as slots of time. The medical actions must be undertaken during this period. If the patients are not treated during the following slots of time, we consider that the treatment was not realised in optimal conditions. However, the wounded with the most serious injuries must be evacuated immediately. So, the medical support of the military operations has to respect its various deadlines of the wounded treatment.

- 10 minutes: ("the ten platinum minutes") within 10 min following the wound, the wounded has to have received imperatively the main care under fire.
- 30 minutes: wounded's medicalisation must be done in the following 30 min.
- 1 hour ("the hour of medical evacuation"): wounded's evacuation must be done within the hour which follow the wound.
- 2 hours ("the 2 surgical hours"): before the end of the second hour, the wounded must have been transferred within an operational medical surgical unit. There, he will be taken in charge by a surgical *team* who will apply the principles of damage control surgery.

Meanwhile, it is important to consider that a maximum of 2 h can be too long to maintain the serious wounded alive. Therefore, it will be necessary to try to approach, to the extent possible, the deadline of one hour between the wound and the arrival in a first surgical unit.

15.4.2 French Army Classification

The system is based on one criterion: the possible delay between wounding and treatment according to the kind of injury. This classification used by the French army is elaborated in Table 15.1. The third column shows a few examples of the wounded for each category. There are six basic triage categories:

- T1: the wounded T1 category must be operated in the forward surgical unit and can be subdivided into two further subcategories:
  - The wounded T1 "Extrême Urgence" who are severely injured: these require resuscitation and immediate surgery at their admission. Their evacuation has to be done in less than 1 h. The surgical treatment must apply the principles of the damage control.
  - The wounded T1 "Urgent" whose lives are not in imminent danger: these do not require any immediate surgery. Those wounded can wait for a few hours (classically 4 h).

  It is very difficult to prioritise the wounded from the same category T1. The decision must

Table 15.1 French army triage categories

Priority	Surgery before	Injuries include
T1 Extrême Urgence	Unstable and requiring attention within few minutes	Haemorrhagic shock Uncontrolled bleeding Respiratory distress (chest, neck, face) Air way obstruction
T1 Urgent	Temporarily stable but requiring care within a few hours	Stable injuries of the trunk, neck, head and pelvic Penetrating head wound with neurologic signs Major vascular injuries Long-bone fractures Loss of a limb and controlled bleeding Burns 15–50 %
T2 Urgence Relative	Delay in surgical treatment without endangering life	Open fractures (humerus, forearm, knee, tibia, ankle, foot) Facial trauma (without air way obstruction) Eye injury (open globe X2) Wound of the hand Severe soft tissue damage
T3 Eclopés	No urgent surgical treatment	Closed fractures Soft tissue injuries Burns <15 %
T4 Urgence Dépassée Morituri	Long and heavy treatment with limited chance to survive	Craniocerebral wound with coma Massive burns >50 % Multiple injuries with uncontrolled haemorrhagic shock

be taken by the anaesthetist–intensivist and the surgeon according to the clinical state of the patient (response to the resuscitation, degree of consciousness) and of the type of wound.

- T2 "Urgence Relative": the wounded from T2 category can be operated later or can be transferred toward another surgical unit.
- T3 "Eclopés": the wounded from T3 category must be treated outside the surgical unit.
- T4 "Urgence Dépassée": the wounded from T4 category (expectants, patients who have such extensive injuries that they cannot be saved) must be isolated. An analgesic treatment and comfort conditions are required.

The T4 category is the most unusual and the most specific in a war context. The use of this category has to be carefully applied according to the environment (available resources, nature of the other wounded, etc.). It is necessary to keep in mind the difficulty of this classification in T4 and the importance of the context. The following are some examples of classification. It is important to note that these do not include all the possible scenarios, especially for T4. Also, the classification can be very variable under the circumstances.

For example, a major trauma with hypovolaemic shock following haemorrhage may be classified T4. However, this example can be also classified T1 in case of a brief surgical intervention. This choice could lead to an unnecessary mortality among more salvageable casualties if the surgical intervention takes too much time. The T4 category of wounded must be reviewed and treated only after the care of the T1 category wounded has been completed.

- "Urgence Potentielle" (Potential Emergency): the wounded whose lesions are of uncertain nature (in particular the polycriblage of the trunk) will be classified as Potential Emergencies. They will be reviewed regularly in the zone of triage in order to identify a decompensation of an unnoticed wound. Then these wounded will be reclassified under the T1 category.

15.5 Triage Systems (Categorisation and Assessment)

There are many classifications wherein the criteria can be varied: kind of injury, patient's physiological status, delay before surgery, length of surgical procedure, need for resuscitation, probability of intensive care, etc.. Investigation and comparison of the disaster protocols can be extremely difficult [15, 16]. Certain classifications of triage can include several other criteria; some of them could also be more complicated. In a situation of mass casualties, the complicated methods that are time-consuming must be abandoned. A triage system must be simple, safe and rapid to use.

There are three categories in each classification (Table 15.2):

Table 15.2 Comparison of triage classifications

	French army Before 2010 [17]	French army Since 2010	UK [18]	EWS 2004 [19]	EWS 2013 [7, 20]	CICR [9]
Patients to be operated	*EU* Extreme emergency	*T1* Extreme emergency (few minutes)	*T1* Immediate (<1 h) RED	*Immediate* (unstable requiring attention within 15 mn)	*Immediate* (few minutes to 2 h) Red	*Category I* Serious wounds Resuscitation and immediate surgery Red
	U1 First emergency <6 h	*T1* Urgent (<4 h)	*T2* Urgent (<2 h) Yellow	*Urgent* (few hours)		
	U2 Second emergency <18 h *U3* Third emergency <36 h	*T2* Relative Can wait for surgery or transferred	*T3* Delayed Green		*Delayed* Yellow	*Category II* Second priority wounds Can wait for surgery Yellow
Patients not to be operated because they do not require a surgical treatment	"Eclopés" Walking wounded	*T3* Walking wounded		*Ambulatory*	*Minimal* Green	*Category III* Superficial wounds Ambulatory management Green
Patients not to be operated because they are too seriously injured with a unlikely survival	*U4* Expectant	*T4* Expectant	*T4* Expectant: Blue Dead: Black	*Expectant*	*Expectant* Blue	*Category IV* Severe wounds Supportive treatment Black
	Potential emergency	*Potential emergency*				

EWS emergency war surgery

- Patients to be operated: those who require immediate or early treatment and patients who can wait to be operated and could eventually be evacuated before treatment
- Patients not to be operated because they do not require a surgical treatment
- Patients not to be operated because they are too seriously injured with an unlikely chance of survival

In Table 15.2, we have reported the French Army [17], the UK [18], the US [7, 19] and the International Red Cross classifications. It is impossible to compare the relative efficiencies of these classifications. Nevertheless, it is very important that every member within a given team knows the relevant classification scheme perfectly and should be regularly taught and trained for this purpose.

The French classification is based on only one criterion: the length of a possible delay before surgery. In the French army, the medical unit uses both the anatomical and the physiological triage systems. The anatomical triage awards priorities based on the physical injuries, while the physiological triage systems use the change in the patient's vital signs following injury. These evaluations are always performed by a doctor on the field or in the medical unit.

There are other ways of evaluation to sort the wounded based on a two-part physiological system that refers to a sieve and sort methodology [18, 21]. In order to provide safe triage, it is suitable to use the triage sieve. This one is a very simple algorithm used by the first aiders on the field who are trained but not medically qualified. It evaluates four physiological criteria: walking, breathing, respiratory rate and pulse rate. The triage sort refines the triage sieve with more detailed physiological evaluation which is generally employed by a triage officer in a medical unit. This method estimates and calculates a score for the Glasgow Coma Score, the respiratory rate and the systolic blood pressure. The Triage Revised Trauma Score is the sum of the three previous scores and assigns a triage priority. This system also integrates the paediatric triage and the triage in the CRBN (chemical, radiological, biological, nuclear) environment [18].

As author J Ryan describes, the aim of Triage Sort is "to iron out undertriage or overtriage" [21]. However, according to other authors, the START (Simple Triage and Rapid Treatment) process can lead to the overtriage of patients [22].

The US and NATO military mass casualty process uses these two systems sieve and sort which are partly based upon Medical Emergency Triage Tags methodology: the Simple Triage and Rapid Treatment (START), a sieve process that can be performed by non medically qualified staff, and the Sort, Assess, Lifesaving interventions, Treatment/Transport (SALT) system [19].

For the CICR (International Committee of the Red Cross), triage is a multiple-step process: "sift and sort" and then re-examine, re-examine, re-examine. "Sift" involves placing the patient in a general category; "sort" then decides priority within that category [9].

15.6 Issues

Triage requires planning and preparation before occurrence of the crisis. In mass casualty situations, improvising can mean waste of time and loss of patients. Thus, anticipating every detail from the arrival to the departure of wounded is necessary.

15.6.1 Logistic Problems

During conventional conflict, some facilities are dedicated to triage. In the military context, they are called triage section, forward unit, field hospital and medical company. Everything is planned and organised. One or more tents or buildings are dedicated only to triage, and some members of the medical team work specifically on the triage. It is important to point out that the triage is the first step of a staggered treatment; the wounded can be evacuated to another facility according to each category.

Every physician has to think about a mass casualty situation and attempt to plan a reception centre.

15.6.2 Triage Area

A reception centre should be located near the hospital. It should be large enough in order that the triage officer can see every patient. The reception has to have a roof and must be walled-off and heated in a cold region. It must also be well-lit and equipped with basic facilities (a shower is necessary for patients covered in mud or dirt). Each patient station should be accessible from all sides. Every item of equipment has to be conveniently located, mobile, unwrapped and accessible to both radiology and operating room.

The postoperative area has to be planned and well organised. It must usually be a separate room. However, in case of a small number of medical staff, the postoperative place should be very close to the triage area.

It is very difficult to organise an ideal area. They can get rapidly overloaded as soon as the number of casualties exceeds ten patients at a time. Schools, gymnasiums or stadiums could be the best places to use in this context depending on the relationship with the civilian population.

15.6.3 Identification and Registration

A triage card is very useful. There are many types of admission cards or triage cards. A triage label should be easily visible and firmly attached to the casualty. An effective one has to be very simple, easy to read and rapidly reconfigured in order to show a change in priority. Oftentimes, the cards can be separated from the patient or damaged by body fluids. Moreover, in a triage situation, handwriting often becomes illegible. Writing important data (category, hour of tourniquet setting, etc.) on the forehead is very convenient, and the triage officer can quickly identify every patient in the triage area without riding up blankets.

During World War I, Hits and Boyer proposed a colour code tagging method to categorise disaster victims: red triage tags for the wounded patients whose lives are in imminent danger and require an immediate medical care, white tags for the wounded patients of the cephalic extremity, yellow tags for the average wounded patients whose lives are in imminent danger but do not require immediate medical care and green tags for the wounded patients with minor injuries able to go back to the front line [1].

Nowadays, the colour-coded system has been applied by several military medical services in the field in order to have a better visibility. The UK colour tags are red for immediate, yellow for urgent, green for delayed, blue for expectant and black for dead [18]. NATO and US army do not use the same colour system; instead, they use red for immediate, yellow for delayed, green for minimal, blue for expectant/salvageable and black for expectant/unsalvageable [20].

Only one person of the team should be in charge of registration. Otherwise, there is a high risk for mistakes or double registrations. It is difficult for a surgeon to remember the exact procedure for each patient, because there can be a large number of patients suffering from similar injuries. Recordings of each operation must also be classified in real time to allow for an adequate and precise follow-up.

15.6.4 Medical Team

Every team member should know in advance his right place and task during the mass casualty situation. Training exercises include a few simulated casualties which allow the testing of the organisation and identification of problems (e.g. how to move the stretchers to OR or to X-ray without hindrance).

15.6.5 Evacuation

During a conventional military conflict, every patient should be evacuated before or after surgery according to the category. During conflicts involving civilian populations, secondary evacuations are usually difficult: local medical facilities are inadequate or overwhelmed and/or because refugees are not accepted in these hospitals. Triage and postoperative areas are soon overloaded, and patient's monitoring becomes very difficult if the evacuations are not possible. Triage and treatment can be different depending on whether evacuations are possible or not. Surgical procedures must allow simple postoperative monitoring.

15.6.6 Triage Officer

Triage is a medical task that entails moral responsibility. The triage officer needs internal stability and external authority [23, 24]. Burkle, as reported by Moskop and Iserson [25], listed the ten characteristics of a good triage officer. Nevertheless, it is extremely important to note that everybody has to respect the triage officer's decisions.

Most of the time, the triage officer is a physician. He could be a surgeon or an intensivist. We must consider them both to be equivalent. Sometimes the triage officer is not a physician. During the Falkland War, some dental officers were in charge of triage [14]. In the Red Cross hospitals, head nurses are often triage officers [9]. Choosing a nurse could pose some challenges: Can a nurse be really efficient in sorting casualties and can he (she) exercise authority over medical staff? Could "expectant" category be decided by a person other than a doctor?

In the past, the triage officer was the most experienced surgeon in the French Medical Corps. Thus, as much as possible, triage should be done by both the surgeon and the anaesthesiologist–intensivist. The anaesthesiologist–intensivist has better expertise in resuscitation and can evaluate the response to this resuscitation and the likely duration that the patient can wait. However, the surgeon is in a better position for the evaluation of the probable length of the surgical procedure. Thus, both physicians determine surgical priorities, and hence, application of effective and accurate triage is a team-based multidisciplinary activity.

For these reasons, triage must be taught through realistic training exercises. These exercises should simulate both clinical and logistical situations and proceed to gradually increase the existing medical capabilities and intensity of tactical situations.

15.7 Ethical Problems

Sorting wounded patients could involve some moral problems. The most important are the "expectant" category and the neutrality of the choice.

15.7.1 Expectant Cases

There are casualties with unstable vital functions and without a prognosis for survival under the given circumstances. Those patients might not be treated, in order to save more time and more facilities for the patients with a better prognosis. The principle is well known: achieving the "best for the most". Individual interest must respect the interests of the mass of victims.

In war surgery, it is important to stress that the mention of this category must be avoided whenever possible. If the individual medical rules may be sustained, no patient should be categorised "expectant".

There is no list of "expectant", such a list is impossible to publish because every case is dependant on the kind of injuries, the number of wounded, the available medical facilities and so on.

Two types of wounded may be classified into this category:

- Obvious cases: patients with extensive wounded that their survival should be very unlikely (comatose patients with craniocerebral injuries and other associated injuries) even if they were in optimal medical resources. Categorising these patients as "expectants" is not very difficult.
- Others cases: patients who could be possibly saved if they were alone, after a long surgical treatment and a major resuscitation. In this case, it is more difficult to take such a decision. Varied injuries are classified into this category: major abdominal defects, multiple

wounds, abdominal wounds hospitalised after long delay, polytraumas, etc.

Some other problems could be encountered:

- Nowadays, nobody seriously considers the unethical act of active "battlefield euthanasia" as suggested by Ambroise Paré [10]. In mass casualty situations, some wounded cannot be treated, and this raises a few ethical issues: is this decision of low priority for care and treatment synonymous or equivalent to passive euthanasia [26]? The concept of triage may be interpreted as unethical, but this is the best way to save the most number of wounded. The medical officer has the obligation to dictate priorities.
- It could be very difficult to explain to a wounded soldier's friend that it has been decided not to care for him (i.e. to let him die). Also, how does one explain this decision to the patient's relatives afterwards?
- Legal problems are mentioned by some authors [23]. They believe that the triage should be done by respecting human rights and humanitarian laws. They also recommend that the patient must be informed even in mass casualties situation. However, it seems a difficult task to obtain an informed consent from an unconscious patient or from his relatives in a real mass casualties situation.

It is absolutely necessary that every member of the medical team thinks about this particular category ahead of the situation.

15.7.2 Triage and Neutrality

Every military medical corps has to care for its own soldiers. Sometimes it has to treat civilian populations or enemies. According to Dominique Jean Larrey [2] and the Geneva convention [27], one should triage regardless of nationality, race, sex, religion or rank. The only criteria used for triage should be the medical status. A classification using anything other than medical principles is a violation of human rights [23, 28].

For the CICR, there is one exception to this: when an excited, and often drunk, combatant holds a gun to your head and demands that you treat his wounded comrade first. This patient immediately becomes top priority [9]. During a civilian war, wounded are often brought to the hospital by armed, undisciplined warriors, who may become aggressive in the hope of hastening the treatment. In a military unit, we are protected by soldiers. But in some unprotected civilian facilities (NGO, CICR), it could be wiser to give priority to this wounded, regardless on his real category, in order to protect the medical team or other patients.

Conclusion

The concept of triage is essential for the management of soldiers' and civilians' wounds during the wartime or natural disasters.

Triage is crucial to the effective use and efficiency of forward surgical unit in the care of mass casualties. This is not an easy task in medical services. Triage requires informed judgement, hard work and courage. To be prepared for triage, this is a moral obligation and a practical necessity. It is essential to provide a basic knowledge about the specificities of triage in war situations, and this remains the greatest challenge, because there is no practical experience on the battlefield.

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16 Fluid Resuscitation in Mass Casualty Incident

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16.1 Introduction

On April 15, 2013, at 2:50 p.m. eastern daylight time, two improvised explosive devices were detonated during the Boston Marathon, New England's most widely viewed sporting event that attracts more than 500,000 spectators and 20,000 participants each year. As a result of the bombings, three people were killed and 264 were injured, with more than 20 sustaining critical injuries. Victims at the blast scene received immediate, lifesaving aid and were rapidly triaged. The victims of this incident were loaded on ambulances; the last casualty was transported from the scene within 45 min [1]. The Boston Marathon bombing was acknowledged as a successful medical incident largely due to the medical emergency services preparedness.

Mass casualty incidents (MCI) may result from terror acts or natural occurring mishaps. The influx of the injured often poses tremendous burdens even on the most experienced medical facility.

MCI is characterized by an unexpected presentation of a large number of injured at an incursion that exceeds the normal hospital surge capacity and capabilities [2].

The treatment goal in MCI is to deliver an acceptable quality of care while preserving as many lives as possible. Mass casualty management strategies are closely linked to the quality of the existing trauma system. Achieving excellence in the treatment of a single trauma victim in everyday situations is the cornerstone of preparedness to an MCI.

The aim of the following chapter is to highlight the principles and algorithms of resuscitation strategies in the context of a mass casualty incident, considering the past, present, and future practices and to offer management protocols while facing such a disastrous incident at the scene level as well as in the hospital setting.

16.2 Triage

"Aiming for the maximum good for the greatest number" [3].

Triage is the process of categorizing patients according to the severity of their injuries, in order to determine priorities for medical management. Triage protocols are delivered by care providers at the scene level as well as at the hospital arena.

At the scene, medical care personnel provide rapid primary survey and aim at sorting patients according to priorities designed to maximize the number of survivors based on their injury

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_16

complex. Immediate medical care is confronted by the presence of limited resources.

As field triage is conducted close to the time of injury, with limited diagnostic resources, under-triage may result, leading to unfortunate outcomes [4, 5].

On the other hand, over-triage may consume human resources and decrease the available resources for patients with greater needs [6, 7]. The most effective triage systems accept an over-triage rate of up to 50 %. This high rate is essential to reduce the under-triage rate to below 0.5 % [8]. Higher over-triage rates paradoxically increase the critical mortality by allocating vital resources in need for the management of the critically injured and are therefore undesirable [9].

16.3 Prehospital Care

Primary triage is the first level of assessment and prioritization of the injured, occurring before initial trained medical personnel arrive at the scene.

Physicians with appropriate training may operate safely and integrate with the out-of-hospital care providers, especially in incidents in which the number of victims exceeds transport resources or prolonged rescue times are anticipated.

Crippen et al. described four major classes of victims in MCI (Table 16.1). Class 1 victims correspond to instant deaths while classes 2–4 correspond to potentially salvageable victims who if left untreated will die [10]. Patients should be continuously reassessed and re-triaged as their condition and the available resources change.

Secondary triage occurs after additional assessment and initial interventions are conducted, while *tertiary* triage involves assessment of the value if definitive care will change patient outcomes [11].

Table 16.1 Definitions

Description	Injury class level
Unsalvagable	Class I
Seriously injured	Class II
Potentially salvagable	Class III
Lightly injured	Class IV

As opposed to tertiary triage, which generally occurs in a more proactive fashion, primary and secondary triage usually takes place before the medical system responds effectively. Determining the likelihood of resource utilization in such major incidents may be an evolving process. Difficult triage decisions must be taken by the triage officer and the medical director of the incident mainly due to inability to estimate peak demands of human and medical resources.

Hick et al. [12] proposed three principles of triage to be considered during MCI, which may simplify the decision-making process:

1. Inverse relationship between the number of casualties and the time spent on interventions.
2. Managing triage according to the scope of the incident. Fifteen percent of the patients will be critical (higher number when considering terrorism/blast-related injuries) [13].
3. Direct relationship between the scope of the incident and the focus on treatment offered to moderately injured patients – considering the high likelihood of these patients to achieve full recovery, while undergoing basic lifesaving procedures [8, 11].

16.4 Hospital Care

In face of the ongoing change in hospital needs during an MCI, hospital capacity may be categorized into subclasses:

Conventional capacity: Hardly carried out in major MCI and mostly represent care as regularly provided at the institution.

Contingency capacity: Represents the needed adaptations to medical care services and facilities. Staffing constraint and supply shortages during an MCI need to be addressed to avoid negatively impacting medical care quality.

Crisis capacity: Carried out in catastrophic situations, with a significant impact on standard of care. When management and treatment are provided to the maximal level possible, given the resource gap, the risk of morbidity and mortality rises. The lack of resources defines the care provided in this phase. Implementing resource-use strategies in advance may minimize this risk [12].

The objective of mass casualty medical system response is to remain in the conventional and contingency phases or invert from crisis phase back to them as quickly as possible. Preparedness activities increase the capacity of the system to provide conventional and contingency care.

16.5 Resuscitation

16.5.1 Introduction

Resuscitation in MCI is based on a broad spectrum of life support strategies, from basic life support (BLS) to definitive solutions of trauma surgery (DSTS) protocols.

These management protocols are divided in MCI into three highly interdependent components [14]:

1. Basic life support (BLS) or life-supporting first aid (LFSA), usually administered by uninjured bystanders or first responders, focusing on cerebral resuscitation and control of hemorrhage (e.g., tourniquets).
2. Advanced life support (ALS) is administered by trained emergency medical personnel. ALS usually is delivered within 1 h of injury during everyday emergency. Trauma care can be delayed for several hours or days and shifted almost entirely to the prehospital setting during an MCI. Its main purpose is to prolong the window of opportunity for the delivery of resuscitative life support to the most salvageable severely injured casualties, within 24 h of injury.
3. Prolonged life support, definitive and intensive care, administered by medical specialists functioning within a well-organized emergency medical and trauma care system.

16.5.2 Volume Resuscitation

16.5.2.1 Fluids Administration

Alfred Blalock was the first to extensively document the importance of volume replacement therapy in the treatment of shock. He documented that hypovolemia is the main cause of death in severely injured patients. The development and implementation of the concept of damage control resuscitation, a strategy combining techniques of liberal hypotension, hemostatic resuscitation, and damage control surgery, has been widely adopted and is now the preferred method of resuscitation in patients with hemorrhagic shock.

Fluid therapy is one of the primary components of a complex hemodynamic resuscitation strategy, targeted primarily at restoring intravascular volume. The ideal resuscitation fluid, should result in an expected and sustained increase in intravascular volume, have a chemical composition similar to that of extracellular fluid and be metabolized and excreted without accumulation in tissues all while not producing adverse effects.

Resuscitation fluids are broadly categorized into colloid and crystalloid solutions; when examining the pros and cons of both solutions, the volume-sparing effect of colloids is an advantage with a 1:3 ratio of colloids to crystalloids to maintain intravascular volume. Colloids are expensive and impractical for use as resuscitation fluids in field conditions. On the other hand, crystalloids are inexpensive, widely available, and have an established role as first-line resuscitation fluids. Sodium chloride 0.9 % is the most commonly used crystalloid solution. Unfortunately, it holds wide range of adverse effects if administered in large volumes [15].

Ley et al. prospectively analyzed collected data from 3,137 trauma patients at a level I trauma center, in an attempt to identify the factors responsible for increased mortality after trauma. Emergency room administration of IV crystalloid solution (more than 1.5 L) was found

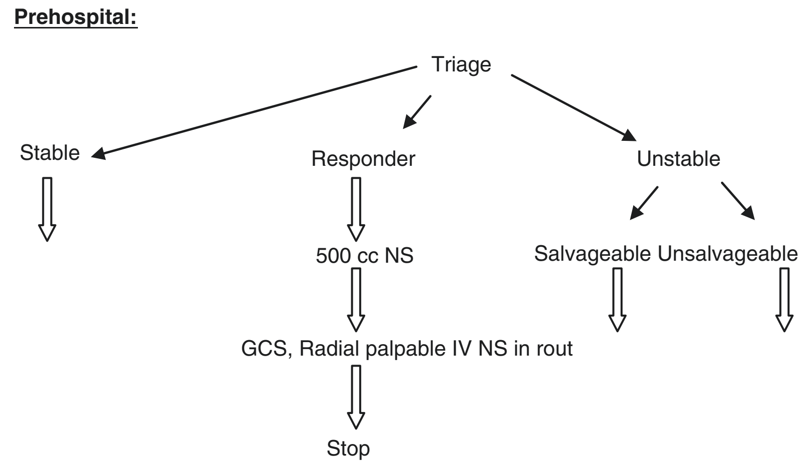

Fig. 16.1 Management and resuscitation in mass casualty incident in the prehospital phase, A stable patient: heart rate (HR) ≤100, systolic blood pressure (SBP) ≥90, A Responder patient- trial of 500 cc normal saline (NS), Goal: paplpable radial pulse, glasgow coma score ⇑, An unstable patient: HR>100, SBP<90

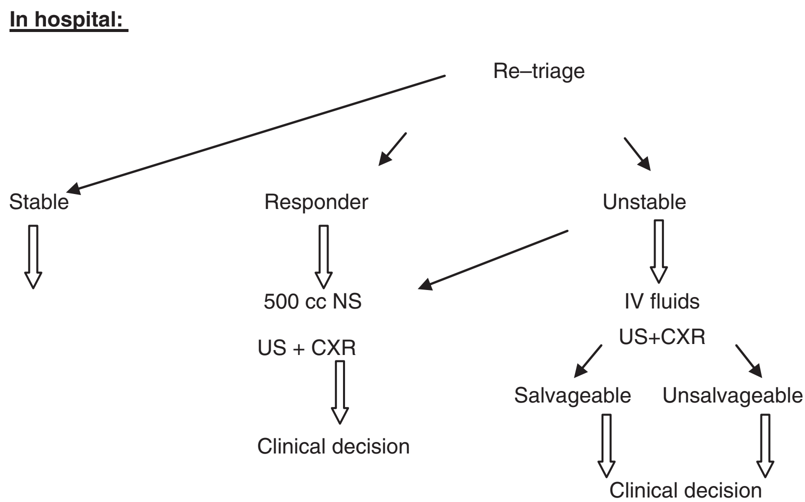

Fig. 16.2 Management and resuscitation in mass casualty Incident in hospital phase

to be independently associated with mortality regardless of age [16].

In the early prehospital and hospital phase of resuscitation of the exsanguinating victim, permissive hypotension should be allowed, with systolic blood pressure goals of 80–90 mmHg to minimize bleeding from the injured vessels (Fig. 16.1). Aggressive crystalloid resuscitation in this phase has been linked to coagulopathy and worse outcome compared with restrictive fluid strategy [17].

Although fluid resuscitation of a single trauma victim should be based on the administration of blood and blood products, the availability of such products is limited during an MCI. A large retrospective series using data from 23 centers found that larger crystalloid volumes of at least 1 l per 1 unit of RBCs in the absence of available fresh frozen plasma are associated with improved survival and fewer overall complications among patients receiving plasma-based resuscitation that either received or did not receive a massive transfusion [18]. A trend toward crystalloid restricted plasma-based transfusion practices is currently noted [19]. Figures 16.2 refer to our suggested steps and decision-making algorithms for fluid management of the injured at the scene and in the hospital. These algorithms are based on the assumption that hypotensive resuscitation reduces bleeding and that re-triage is an ongoing process that starts in the field and continues throughout the evaluation in the hospital by dedicated medical teams.

16.5.2.2 Blood and Blood Products Administration

Hemorrhage remains the leading cause of death in injured patients admitted to a level I trauma center, occurring in 40–60 % of lethal cases, with 81 % occurring in the first 6 h and 94 % in the first 24 h of admission. This data emphasizes the need for early and prompt diagnosis and treatment [20]. Outcome improvement is achieved by targeted replacement therapy. Transfusion methods have been altered dramatically during the twentieth century, when practice changed from using whole blood to blood components therapy, mainly because of the need for better resource utilization and in order to reduce transmission of infectious diseases.

Blood products, such as packed red blood cells, fresh frozen plasma, platelets, and cryoprecipitate, play an essential role in the management of trauma patients, both during resuscitation and definitive treatment.

16.5.2.3 Coagulopathy of the Injured

Tissue trauma, shock, hemodilution, hypothermia, acidemia, and inflammation play a major role in the development of acute coagulopathy of trauma patients. Rewarming efforts, early correction of acidosis, and restriction of crystalloid became the pivotal principle of trauma resuscitation strategy.

Resuscitative focus on early correction of physiologic derangements prompted the era of damage control resuscitation.

In severely injured bleeding patients, coagulopathy precedes resuscitation, representing the outcome of extensive tissue injury and diffuse microvascular ischemia/reperfusion injury and thrombosis, which results in a massive consumptive process, combined with significant endogenous fibrinolysis [21]. Early onset coagulopathy of trauma was recognized on arrival in 25 % of these patients and has a direct correlation with increased mortality [22].

Holcomb et al. indicated that early administration of coagulation factors can potentially decrease the rate of hemorrhagic deaths by more than 75 % for severely injured bleeding patients. Moreover, observation of combat casualties from Iraq, by military physicians, demonstrated that mortality from acute hemorrhage was reduced in severely injured soldiers when coagulation factors, predominantly fresh frozen plasma (FFP), were given immediately, rather than after laboratory confirmation of the coagulopathy [20, 23, 24]. However, unnecessary transfusion of FFP or platelets can increase the rate of complications, such as infections, organ dysfunction, and even death [25, 26].

16.5.2.4 Early Transfusion

Early transfusion (ET) is defined as transfusion required within 24 h of admission. Studies showed that ET is necessary in approximately 5 % of trauma patients, of which 3 % will be in need of a massive transfusion [27].

Sisak et al. aimed to evaluate the ET practice in all admitted trauma patients and to identify relevant transfusion triggers and to investigate potential over-transfusion in the acute setting.

They noted that ET patients are severely injured and require procedural bleeding control in 41 %. In this population the conventional transfusion trigger (hemoglobin level) is not appropriate, whereas vital signs, level of acidosis results, injury patterns, and anticipated major bleeding represent proper indicators for transfusion [28].

16.5.2.5 Massive Transfusion (MT)

The definition of massive transfusion varies in the literature. The most common definition is transfusion of ten or more units of packed red blood cells (PRBC) over the initial 24 h [29].

Three percent of civilian and 8 % of military patients require massive transfusion with injuries that are predictably associated with high mortality (27–51 %) [27].

Dente et al. established early clinical markers that correlated with the need for MT; they noted that all patients with trans-pelvic and multiple gunshot wounds required MT, while many of the patients with isolated transabdominal or transthoracic bullet wounds did not require MT. However, a systolic pressure less than 90 mmHg and a base deficit of greater than 10 units were strong predictors of the need for MT [30].

Considering civilian MCI, Soffer et al. analyzed 18 consecutive terrorist attacks and found that the number of PRBC units transfused per patient was related to the incident magnitude. In limited MCI (<25 evacuated casualties), the number of PRBC transfused to patient per incident (PPI) was 0.7. In larger MCIs the PPI was 1.5 [31]. These figures must be taken into account by the hospital transfusion services to facilitate optimal management of MCIs.

Borgman et al. reviewed 252 trauma cases for which massive transfusion protocols were applied. A pronounced difference was found in regard to mortality between patients who had low, medium, or high plasma to PRBC ratios; the higher the plasma/red blood cells (RBCs) transfusion ratio, the lower the risk of mortality [32].

Holcomb described similar results in 466 MT civilian patients transported to level I trauma centers. 30 days survival was significantly increased in patients with high FFP/PRBC ratios (>1:2) compared to those with low plasma/RBC ratios (<1:2). They also showed that a combination of high plasma and high platelet ratios (>1:2) increased 6 h, 24 h, and 30-day survival [23].

16.5.2.6 Multiple Transfusion Protocol (MTP)

Kutcher et al. prospectively analyzed 174 critically injured trauma cases which required activation of the institutional MT protocol within 24 h of admission. They observed trends toward reduced overall transfusion practices, earlier empirical plasma transfusion, plasma-based FFP/PRBC transfusion ratios, and consequently improved survival [19].

Recognition and improved understanding of the mechanisms of coagulopathy support the modern use of massive transfusion protocols (MTPs) which aim to deliver a RBC/FFP/platelets ratio of 1:1:1 [33].

Riskin et al. showed that application of institutional MTPs significantly decrease mortality in trauma victims [34]. However, activating MTPs in MCIs is a more complicated process and might be impractical, given the magnitude of the incident and the nature of injuries. A thoughtful triage during the prehospital phase should reduce the unnecessary activation of MTPs and the wastefulness of invaluable resources such as blood and blood products.

One should emphasize that the current evidence regarding blood products ratio is based on observational studies only; therefore a survivor bias is noted [35].

16.5.2.7 Other Blood Products

Fibrinogen

Loss of one unit of blood results in the loss of 1000 mg of fibrinogen. Commonly, this deficit is replaced with one unit of RBC and one unit of FFP, which restores approximately 500 mg of fibrinogen. It is necessary to further supplement the remaining fibrinogen at a later stage usually with cryoprecipitate.

Stinger et al. showed that a high fibrinogen/RBC ratio (>0.2 g of fibrinogen/RBC) is independently associated with survival [36].

As one unit of cryoprecipitate contains 0.25 g of fibrinogen that ratio can be achieved by transfusing cryoprecipitate and RBC in a 1:1 ratio. This is accomplished by transfusing 10 units of cryoprecipitate for every 10 units of PRBC. This maintained ratio is significantly related to a reduced 24 h and 30-day mortality in patients undergoing MTP [37].

Lyophilized Plasma

Lyophilized plasma (LP) is suggested as a superior alternative to FFP. Lee et al. conducted a series of studies using anesthetized swine, presenting a model of polytrauma and hemorrhagic shock. Fluid resuscitation was randomized using reconstituted LP fluids and conventional blood products. They concluded that LP resuscitation fluid can provide an effective hemostatic replacement therapy with superior logistical properties, provided minimal volume of reconstituted LP and optimizing its anti-inflammatory properties [38].

16.6 Imaging

16.6.1 Focused Assessment with Sonography in Trauma (FAST) in MCI

Significant improvement in technology and availability of portable ultrasonography machines may significantly improve the care of victims in the prehospital or field hospital settings [14].

Extended FAST offers evaluation for hemothorax and pneumothorax and evaluation for pericardial effusion [39].

Using FAST to screen earthquake victims for intra-abdominal injuries showed sensitivity and specificity approaching that of a CT scan [40].

The use of FAST in MCIs provides the medical command physician, an immediate tool for the triage of patients in need for surgery or ancillary diagnostic investigation.

Conclusions

Mass casualty incidents pose a significant impact on any medical system.

To the inexperienced observer, the management of MCI by the medical staff seems chaotic. Nevertheless, effective decision-making by trained medical personnel and adherence to strict mass casualty protocols will significantly optimize resource utilization and improve overall survival.

Vast scientific evidence shows that the application of evidence-based replacement therapy protocols for the prehospital and hospital phase reduces mortality, improves resources management, and reduces the cost of care in mass casualty incidents.

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17 Transfusion Service and Blood Banking in Natural Disasters

Eldad J. Dann

17.1 Introduction

Natural disasters are unpredicted events that erupt abruptly and are characterized by mass casualties and failure of infrastructure. The damage in such cases depends on two main factors, i.e., the magnitude of the natural event and human behavior. Collapse of houses and public facilities often results from non-adherence to building standards. Such a disaster is an ultimate test to executive capabilities of the community and authorities. Its successful management depends on efficient preemptive organization, including application of standard operating procedures (SOP) at both regional and state levels. Previous mega disasters have demonstrated that blood demand in such events increases only moderately, if at all, so that it may be easily covered by regional or central blood supply. Severely wounded patients require about 8 units of blood; however, these patients comprise about 5% of casualties that need blood transfusion. In cases when no electricity is available, most injured patients requiring emergency surgery would be airlifted to uninvolved areas and only minimal stock of blood products should be kept in the involved area. Fibrinogen and fresh frozen plasma are currently available as freeze-dried products which may be kept in the room temperature, not requiring refrigeration. The most important factor for maintaining adequate blood product supply is having a national or regional voluntary, non-remunerated blood donation system and appropriate SOP that are periodically tested. Collection of blood products beyond demand at time of such events is usually unnecessary and wasteful.

17.2 Guidelines for Blood Centers

The American Association of Blood Banks (AABB) has devoted a special chapter of its technical manual to the preparation for natural disasters as well as human-created ones, like terrorists attacks. Of note, this manual is recognized worldwide as one of the most reliable sources of information in blood banking and transfusion medicine. As defined in this manual, the four pillars of emergency management are (A) mitigation, (B) preparedness, (C) response, and (D) recovery. *Mitigation* is the most important step to reduce casualties and damage. Adherence of constructors to building standards can save lives more than any later medical intervention. An example of such events was an earthquake in Turkey two decades ago that left 500-year-old public structures like churches and mosques

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_17

intact; however, newly constructed buildings were demolished by the thousands burying their occupants alive. A similar phenomenon happened in China where school buildings collapsed on children. Preemptive fixation of cupboards and furniture as commonly done in ships may be useful. *Preparedness* at the local and state levels is essential for effective management of such an episode. Currently, extensive data regarding the management of a large-scale disaster are available online and may be obtained from federal and voluntary organizations.

Response to such a scenario strongly depends on the mitigation and preparedness to the event. It is of vital importance to establish stable communication in order to report about the magnitude of the damage and describe the current needs at the place of the disaster. Recovery of the infrastructure and medical services following the disaster depends on governmental and sometimes international assistance. If local well-trained staff and financial support are available such recovery can be rapid.

17.3 Calculation of Blood Requirement

The need for blood supply at the place of the disaster is never a restrictive factor, since functioning of the local operating theater is usually very limited, and air lifting of the more seriously injured to hospitals in unaffected areas is required. The need for blood products is calculated on the basis that about 8 units of blood are required to a severely wounded patient. While these patients account for only 3–8 % of casualties requiring blood products, they demand urgent surgical interventions to be salvaged. Such interventions require stable power supplies to ensure functioning of the operating theater and proper preservation of blood components. In general, only 8 % of trauma patients require blood transfusion, and it is safe to estimate that 0.9 unit of blood per casualty is needed. In the USA, the established amount of red blood cells (RBC) required in mass casualty episodes is between 100 and 250 units, a quantity that is easily supplied from a routinely maintained storage [1]. Recommendations of the Israel Ministry of Health for blood supply estimate the need for packed red blood cells (PRBC) as 7 units for moderately or severely injured patients. Fifty percent of the units should be of uncrossmatched group O and 10 % of them should be O Rh negative. The estimated supply of plasma units (fresh frozen plasma, FFP) is 50 % of the PRBC with 20 % of the units being of the AB type (Table 17.1, Fig. 17.1).

In countries where blood supply is centralized and non-remunerated blood donors regularly donate blood, there is usually no need for special efforts, and a blood campaign should be initiated only if the demand overrides the routine supply. In the majority of events, this is not the case, and an influx of blood donors will result in waste of blood components which become outdated and overstrain the blood collection and processing facility.

If the power supply is damaged, blood products cannot be properly stored and may actually become dangerous. In such cases a minimal amount of blood products should be kept in ice boxes that are brought by airlift teams coming to evacuate the casualties to a functioning medical facility.

Recovery of a blood bank facility is essential for restoration of the surgical capability of an affected hospital. One has to bear in mind that from blood donation until its safe use, at least 48 h will pass if the current viral tests are performed.

Table 17.1 Massive transfusion protocol for adult patients used at the Rambam Health Care Campus, Haifa, Israel

	Massive transfusion protocol
Pack number	Blood products released
Pack no 1	4 PC+3 FFP
Pack no 2	4 PC+ 3 FFP
Pack no 3	3 PC + 2 FFP+ 10 units cryoprecipitate ±6 units platelets
Pack no 4	4 PC + 4 FFP
Pack no 5	4 PC +4 FFP ±6 units platelets ± cryo According to platelet count

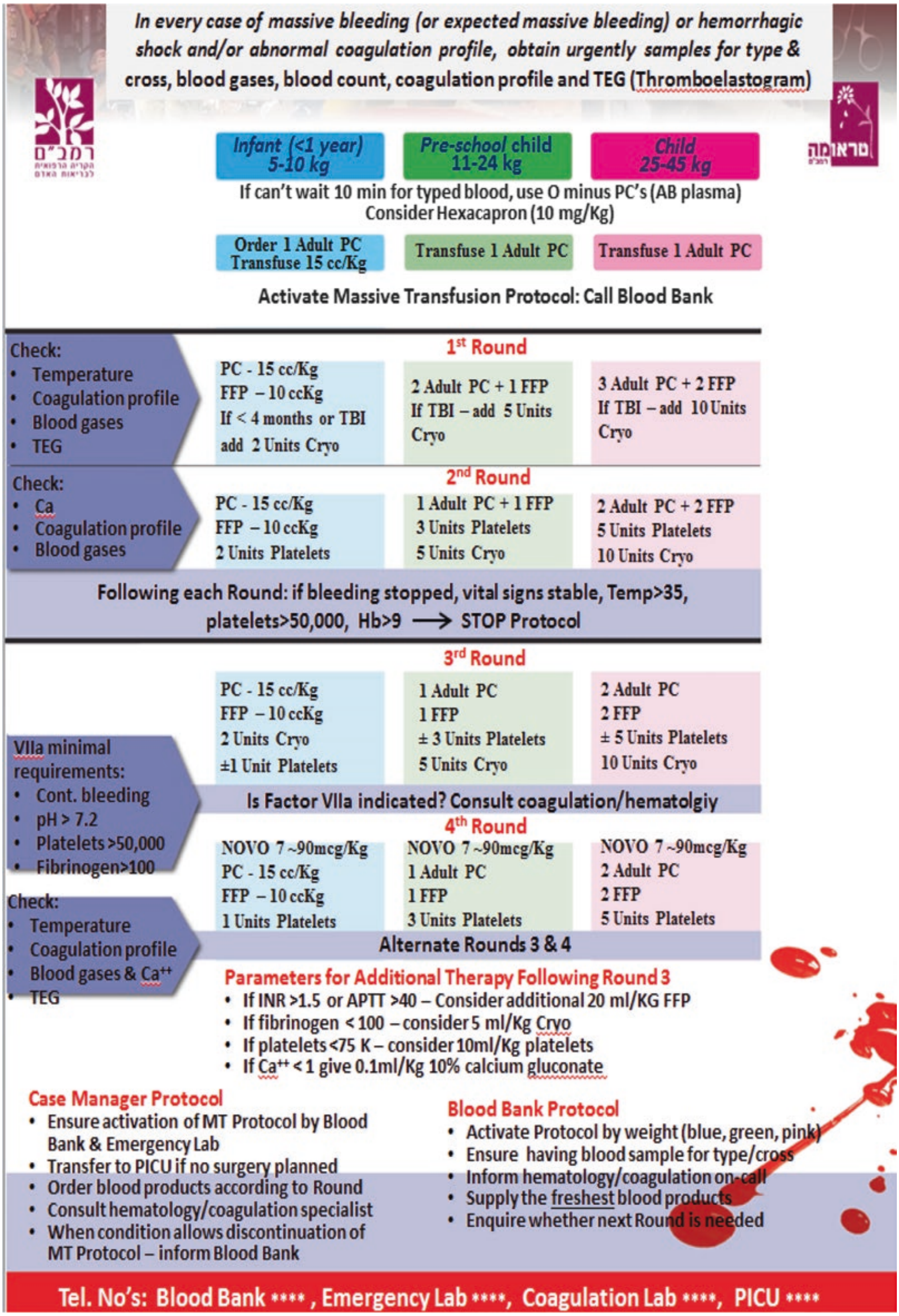

Fig. 17.1 Massive transfusion protocol for pediatric patients used at the Rambam Health Care Campus, Haifa, Israel

17.4 Historical Examples of Blood Use in Major Natural Disaster Events

Several recently published papers were devoted to blood service functioning during a major natural disaster. In Sri Lanka, an island populated with 19 million people, there is a centralized blood service system with nine regional blood centers located in hospitals. This system had to cope with the tsunami of December 26, 2004, that caused 30,000 deaths and left 23,000 injured. The blood use in the hospital near the affected area was within the magnitude of the use prior to the disaster with no shortage of blood products. However, the blood collection capability was impaired, necessitating blood supply from unaffected areas. The author emphasizes the need to explain to the general public which usually becomes altruistic and motivated to donate blood that the donations should be made at the proper time in order to avoid waste of blood products and overwhelming of the collection facility. The author recommends continuous maintenance of a combined hospital and collection facility of 7-day inventory [2].

The blood supply chain is vulnerable to infection outbreaks. During the 2003 outbreak of severe acute respiratory syndrome (SARS) in Southeast Asia, blood donations decreased by 20 % in Hong Kong, with 14 % reduction in blood utilization. The reasons are deferral of blood donors, reduction in blood donation due to a fear of acquiring infections in a crowded environment, and shortness of staff related to the symptomatic disease.

17.4.1 Wenchuan County (Sichuan Province) Earthquake (May 2008)

The earthquake, measuring 7.9 on the Richter scale, that occurred on May 12, 2008, killed approximately 70,000 people and left 18,000 missing and 374,000 injured. Fifteen million people were displaced from their homes. Lu-Ping Zhao et al. reported their experience from the People's Hospital of Deyang City, located 99 km from the epicenter, which is the closest tertiary care center with a capacity of 1200 beds [3].

Originally, 1878 injured from the earthquake were recorded in the hospital database. One thousand and nine patients were defined as having severe injury (53 %), 643 injured underwent critical orthopedic intervention (36 %), 162 had a non-orthopedic surgery, and 82 patients were transfused (4.3 %). These numbers clearly show that the blood supply is not the limiting factor under such conditions.

17.4.2 Haiti Port-au-Prince Earthquake, January 2010

The magnitude 7 earthquake that hit Port-au-Prince, Haiti, on January 12, 2010, left approximately 250,000 injured and 230,000 killed [4]. During the earthquake, the buildings where the National Center for Transfusion and the National Blood Safety Program were located were destroyed. Of note, blood products were not available during the first 7 days after the earthquake. Response of the international community was immediate and included, among other urgent measures, dispatching of emergency facilities and multiple teams of experts in the fields of humanitarian aid, disaster response, and blood banking. The Israeli Medical Corps set up a field hospital with four operating beds within 4 days of the disaster. Out of 1111 admissions, 700 patients were hospitalized, 39 % of them had fractures, and 27 % had open wounds. During the first 3 days of the hospital activity, 80 % of admitted patients were those with trauma, and gradually the percentage of trauma patients decreased. Only 20 units of O^+ PRBCs were available in the hospital, with no FFP or platelets. Cross-and-match services or blood donation capability were also missing [5]. The US Navy hospital ship USNS Comfort that arrived in the area 7 days after the earthquake played an important part in the rescue operation and became a tertiary care center for the next 40 days. This ship hospital has a capability of 1000 beds, 12 operating theaters, and fully equipped laboratories, including a blood bank. The medical team of the ship took care of 1056 admissions, performed 843 surgical procedures, including 669 trauma-associated operations. During this period, 177 type and crossmatch as well as 60 type and screen tests were carried out. Only 386 units of blood, 16 units of plasma, 12 units of platelets, and one unit of cryoprecipitate were transfused, with no more than 27 units per day [6]. As one can notice, the blood requirement was relatively small, and no massive transfusions were given, which in all likelihood could be explained by the 7-day lag between the event and the initiation of hospital activity. The capability to ship fresh platelets from the USA, despite their short (5-day) shelf life, is impressive.

17.4.3 The Great East Japan Earthquake, March 2011

The Japanese blood transfusion services were assessed by Nollet KE et al. from the Fukushima Medical University [7]. The disaster took the lives of 20,000 people and was mainly a mass casualty event rather than a mass injury one. The majority of casualties were carried away by tsunami or drowned. In this situation, the blood usage in eight evaluated inland hospitals was 60 % of the regularly used amount. Moreover, only 70 % of the regular number of transfused patients received blood. These disaster-response hospitals operated during 11–24 days. Since the regional center for nuclear antigen testing that performs the virology tests became dysfunctional, there was no point in collecting blood in the area, and blood was shipped by the Japanese Red Cross (JRC) which is the national central blood supplier. As the platelet shelf life is very short (5 days only), which requires constant replenishment of the hospital supply, a group of university employees willing to donate platelets was screened, including virology tests, and their platelets were planned to be collected using the apheresis machine available in the local medical center. However, there was ultimately no demand for these donors. PRBCs as well as platelets were supplied by the JRC. Adequate quantities of fresh frozen plasma units which have a shelf life of a year were available in the local medical centers.

The San Francisco earthquake of 1989 that killed 62 people was a natural disaster that took place in the USA. The blood transfusion needs were only 40 units during the first 24 h.

The terrorist attack of September 11, 2001, took the life of 4000 people, who were killed in the collapse of the World Trade Center's Twin Towers and in the Pentagon. Of interest, in the 2800 wounded patients, only 258 units of blood were used during the first 24 h. Half of the 600,000 extra units collected by blood centers within 6 weeks after the event were ultimately discarded.

17.5 Coagulopathy of Massively Bleeding Patients

Recent literature has demonstrated that trauma-associated coagulopathy is a major adverse prognostic sign and its early correction is vital [8–10]. Coagulopathy usually resolves after cessation of hemorrhage, which can be achieved using surgical means or angiography followed by selective embolization of a bleeding vessel. Until this happens only a transient short-term correction of coagulopathy is possible [11]. Early use of plasma and platelets was advocated based on military experience in Iraq and Afghanistan; however, one needs to keep in mind that the mechanism of injury is completely different in blast injuries caused by explosives and those inflicted by crush related to building collapse. Early use of plasma and cryoprecipitate or fibrinogen concentrate may correct trauma-associated coagulopathy in 30–60 % of patients. It is frequently recommended to employ lab tests like PT, PTT, fibrinogen, and a point-of-care apparatus like thromboelastograph or ROTEM thromboelastometer that can supply essential data regarding both coagulation process and platelet activity within less than 30 min, with very simple training for its use. One may also consider using tranexamic acid for patients with enhanced fibrinolysis. The accurate ratio of PRBC to plasma is not really known; the 1:1 ratio initially recommended by the US military [12] is derived from retrospective data and is not evidence based for the civilian milieu. Currently, a ratio of 1:2 or 1:1 is accepted, and a recent randomized trial demonstrated the superiority of tailoring therapy based on point-of-care and other lab results [13]. The European guidelines recommend the use of plasma at a dose of 10–15 ml/kg if bleeding is controlled, or a ratio of 1:2, i.e., one unit of FFP to 2 units of PRBC which is substantially lower than the 1:1 ratio [14].

17.6 Blood Products for Bleeding Patients

The life span of each blood product is different. PRBC may be kept for 35 days at 4±2 °C in case CPDA is used as an additive. FFP may be stored at −18 °C or lower temperature for up to a year if kept frozen, and it takes about 13 min to thaw it prior to use. Recently introduced freeze-dried plasma units need to be solved in 200 ml of sterile water before injection. This product, which is more expensive and contains about 50 % of fibrinogen of FFP, is employed by several armed forces for conditions where no deep freezing is available [15]. This product is especially useful for medical services that are being restored after a long period with no power supply, and it may also save the need to ship FFP. Fibrinogen is vital for restoring the coagulation system as its level is often reduced following massive bleeding. Fibrinogen could be supplied in the form of cryoprecipitate that is stored like FFP and supplied in portions of 10 units. An alternative is fibrinogen concentrate that is available in 1 g units.

Current technologies could provide coagulation factors for massively bleeding patients; however, in areas with suboptimal storage conditions even a refrigerator with a controlled temperature of +4 °C would be sufficient to provide appropriate solutions for an operating theater. The only commodity that might be in shortage is platelets that should be kept at 24 °C, and their shelf time is 5 days only. During the Great East Japan earthquake in March 2011, the decision was taken to perform virology and the *Treponema pallidum* screening in a group of university employees. They were ready to donate platelets; however, this was ultimately not required.

Conclusions

The preparedness for a natural disaster should always start in peaceful time with adherence to building standards. In countries with an established centralized or regional donor-based blood supply, there is likely to be enough blood to cover the needs occurring during a natural disaster due to availability of the stock of blood in the close-by regions. Countries that do not have a national blood supply system or their stock of blood is based on family and friend donation are prone to shortage of blood supply in events of natural disasters. These countries should have a well-planned program and ready solutions for states of emergency.

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18 Diagnostic Imaging in Mass Casualty Events

Sameer Jain and Peter V. Giannoudis

18.1 Introduction

A mass casualty event (MCE) is defined as a disaster that results in serious harm to the local population and one that overwhelms the response capabilities of the available resources [1]. Typically, this involves such large numbers of victims and severe or unique injuries that local medical resources are unable to cope with the sudden surge in demand [2]. Causes include natural disasters, major road traffic accidents, structural collapse, explosions, military conflict, civil unrest, and terrorism. The main aim of treatment is to decrease mortality and morbidity for the entire affected population, even at the cost of providing less than routine treatment for any given individual patient [3]. A multidisciplinary team including experts in the field of disaster medicine, emergency physicians, and local response teams must work together with available resources to manage MCEs as efficiently as possible. Prehospital triage allows identification of victims who are most likely to benefit from medical intervention and reflects a key principle of disaster management.

Radiology plays an extremely important role in assessing critically injured victims of MCEs by identifying life-threatening injuries and assisting medical triage. The first report of diagnostic radiology during a MCE was during the Abyssinian War in 1896 where radiographs of two soldiers were taken showing forearm fractures and the presence of retained bullets [4]. These radiographs were taken only 6 months following Roentgen's discovery of the X-ray [5]. Toward the end of the nineteenth century, further global military conflict ensued, and correspondingly there was a change in technology where soft lead bullets were subsequently encased in steel shells to ensure greater penetration. As a result, entry wounds became much smaller and military doctors began to routinely use radiographs to locate retained bullets rather than rely on surgical exploration. During the First World War, Marie Curie developed portable X-ray technology in the form of cars containing radiography equipment which could be driven to the battlefield [6]. Later, technological advances in X-ray tubes and diaphragms allowed faster and more efficient mobile radiography which could be delivered to the front line. By the Second World War, these improvements meant that military radiology was seen as a profession in its own right which was able to save many more lives than before. Modern developments in radiological

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_18

techniques also allow for therapeutic interventions to be provided which can reduce mortality and ease the burden on surgical resources. This primarily involves angiography which is able to rapidly locate and treat multiple sources of bleeding.

The provision of adequate radiological services in MCEs provides many unique challenges. Both the severity and complexity of numerous multiply injured patients cause intense pressure on local medical resources. Knowledge gained from the response to previous MCEs can be used to help develop a system whereby radiological investigations can be performed efficiently in order to improve clinical outcomes. The aim of this chapter is to present an overview on the planning and setup of radiological facilities to allow an efficient assessment of MCE victims through multiple imaging modalities, i.e., conventional radiography, ultrasound (US), computed tomography (CT), and magnetic resonance imaging (MRI).

18.2 Planning and Setup

In order to reduce mortality and morbidity following a MCE, radiological imaging and reporting must be available rapidly so that medical decisions regarding definitive patient treatment can be made without unnecessary delay. This requires an efficient system incorporating suitable buildings, radiological equipment, workforce stations, personnel, communications, and adequate training. The need for prior planning cannot be overestimated, and while most hospitals have contingency plans for MCEs, these need to be available for all potential team members to review. This involves adequate training for all team members and preparation for such events can be delivered via simulations and in-house expert lectures. Collaboration with nearby hospitals, medical facilities, and suppliers is essential in order to provide materials and additional imaging equipment such as portable X-ray units, fluoroscopic C-arms, and US machines [7]. Existing radiology departments will usually need to be reorganized according to the nature of the incident and expected number of casualties. For example, in the case of a major road traffic accident, the use of X-ray and CT may be considered more vital than other resources and must be made more readily available. All nonurgent clinical duty should be suspended until crisis resolution in order to make all resources available for MCE victims. Noncritical patients may need to be transferred to a nearby hospital or alternative care facility. A suggested hospital departmental framework is presented in Fig. 18.1. Following a large-scale natural disaster, local hospital infrastructure may be severely compromised, and therefore, a mobile field radiology service may be required as represented in Fig. 18.2.

Field triage allows patients to be categorized at the site of the MCE, and this information must be delivered to the radiology department by prehospital responders to enable faster allocation of resources. In addition, it helps to distribute casualties to hospitals with different levels of specialization. It can be expected that most critically ill patients will be delivered to a major trauma center or a nearby institution with similar capabilities. Secondary triage occurs following radiological assessment and this enables transfer to the definitive care team. Provision must be made to receive those with the highest clinical priority first with these patients often requiring multiplanar CT imaging. Due to their precarious clinical picture, close proximity to operating theaters and intensive care units is critical to avoid unnecessary delay during patient transfer. Great care must also be taken to correctly identify patients in order to prevent potentially fatal errors. Individual identifiers should be given to patients as per preexisting protocols, and these should be written clearly on patient wristbands. Radiology reports and other documentation can either be color coded with the appropriate colored sticker placed on the patient or printed and strapped to the patient to allow continuity of care [8, 9]. Importantly, dedicated workstations should be created for nursing staff to allow the safe monitoring and passage of patients through the department. A surge in the demand for oxygen and fluid therapy should also be expected and provided for. Separate workstations must also be made

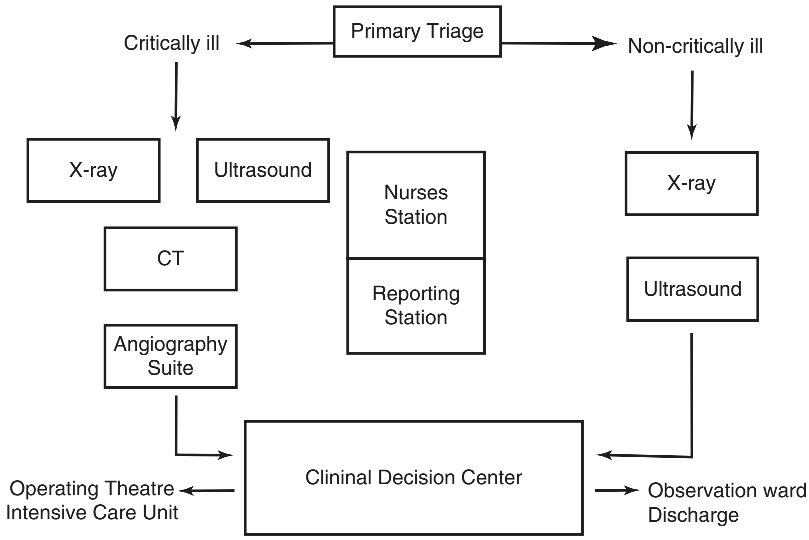

Fig. 18.1 Hospital set-up

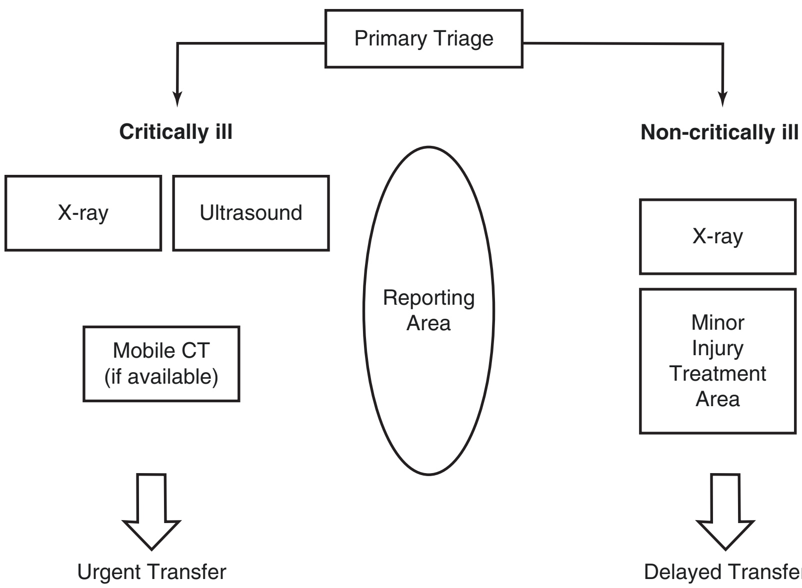

Fig. 18.2 Field set-up

available for radiology staff to rapidly process digital images and provide both verbal and written reports.

Perhaps, the most challenging aspect in organizing an efficient radiology system in a MCE is providing adequate personnel, e.g., radiologists, radiographers, technicians, nurses, hospital porters, and information technology staff. Radiologists with expertise in emergency radiology, neuroradiology, body imaging, musculoskeletal imaging, and vascular imaging are essential to this team. However, in the absence of subspecialty radiologists, general radiologists should be prepared to interpret a variety of scans and provide appropriate reports. A variety of leadership skills are required by senior radiologists in order to assist in triage and decision-making and to provide advice to junior colleagues. In addition, this can help build confidence and self-belief in a team already under pressure [9]. A particular leadership role that should be identified is that of a triage radiologist who can assist both in diagnostic and administrative duties. However, large-scale MCEs might require separate radiology medical decision-makers and/or multiple subspecialty triage radiologists to prevent overburdening individual team members [7]. Specially designated "case managers" can increase capacity by improving efficacy and patient care by providing continuity of care and directing treatment decisions [10]. These should be members of medical or nursing staff who follow each patient through the initial diagnostic and therapeutic cascade until arrival at the definitive care destination. By allowing administrative tasks to be designated to certain individuals, clinical duties can be more effectively performed by the remaining team members.

By definition, personnel are already limited, and while obtaining extra staff during daytime hours can be difficult, recruitment overnight poses its own challenges. Korner et al. reported the use of an automated alarm system provided by an external telecommunications provider in a radiology department during a MCE simulation at a major trauma center [11]. Of the 49 employees, 29 (59 %) were accessible, of which 23 (79 %) persons declared themselves to be available to come to the department. The average estimated time of arrival was 29 min, and the authors concluded that this was a satisfactory method of recruiting radiology personnel in a MCE. In addition to recruitment, further challenges lie in the process of communication between staff members. Depending on the scale of the MCE and number of casualties, mobile telephone networks or standard hospital paging systems may be overloaded and unreliable. Natural disasters or large-scale explosions may also render public telecommunication methods useless due to external damage, and therefore, other methods of communication must be made available. Walkie-talkie devices are effective means of communication during MCEs when normal hospital phone lines are overwhelmed, but additional methods of communication may include e-mail, the hospital radiology information system, and automated emergency pagers [12].

Anticipated challenges also include system failures, network problems, and complete power failures that would require an arrangement for reserve power via electrical generators. While modern electronic order entries are the most efficient method of requesting radiological investigations, provision must be made for paper-based requests to be available in the event of a system failure [13]. Consideration must also be given to the risk of equipment contamination with blood, chemicals, radioactive substances, biological substances, and other toxic agents. Decontamination products must be made available for rapid cleaning between cases. Finally, it is important to recognize the extra psychological burden these traumatic incidents place on team members, and mechanisms must be made available for debriefing and post-traumatic stress management. Some may require an extended period of time away from work to recover, and therefore, deficiencies in regular staffing levels should be anticipated.

18.3 Conventional Radiography

Conventional radiography is often the primary imaging modality for most patients and forms a vital adjunct to the primary survey in the Advanced Trauma and Life Support (ATLS) management of MCE victims. Radiography can be performed rapidly and is relatively inexpensive. Plain radiographs can be interpreted by members of the trauma team and usually do not require specialist radiologist reporting. Therefore, conventional radiography has the ability to provide fast diagnostic information in order to expedite triage to appropriate definitive care during a MCE. Conversely, plain radiography is less sensitive than CT for the diagnosis of injury in trauma patients and may cause unwarranted radiation exposure when performed in addition to CT [14]. However, the use of a low-dose X-ray technique can give equivalent diagnostic information to conventional doses with a substantial reduction in time taken for resuscitation [15]. Currently, as there is no consensus as to whether CT should be used over primary survey radiographs, clinical judgment on the mechanism and severity of injuries should be used.

According to ATLS guidelines, cervical spine, chest, and pelvic images should routinely be obtained as part of the initial workup of these patients. However, this should neither interrupt nor delay resuscitation, and radiography may be postponed until the secondary survey, which may also include radiographs of the spine and extremities [16]. Cervical spine radiographs are usually not indicated in alert patients who have no neck pain or midline tenderness, who have no neurological compromise, and who have a pain-free range of motion [17]. Distraction injuries require careful consideration and due to the high incidence of cervical spine injury should command radiological investigation. Radiographs should include a lateral view, an open-mouth odontoid view, and a swimmer's view in order to adequately visualize the occiput through all seven cervical vertebrae. Any uncertainty should mandate further imaging in the form of either CT or MRI while maintaining strict spinal immobilization. Chest radiographs are indicated in the presence of either blunt or penetrating trauma. While hemo- or pneumothorax is usually a clinical diagnosis, other mediastinal injuries can be recognized and treated early. They should also be used to confirm adequate placement of central venous lines and/or chest drains. Pelvic radiographs may identify displaced fractures that are associated with a high rate of mortality. A recent study showed that 23 % of deaths due to hemorrhage following trauma were due to bleeding from pelvic fractures [18]. External circumferential compression devices should be applied at the level of the greater trochanter in all cases of suspected pelvic injury [19]. Due to the risk of dislodging a hemostatic clot, these should not be removed for the purposes of radiology until the pelvis has been cleared from injury.

During the secondary survey, suspected musculoskeletal limb injuries warrant radiographs in two orthogonal in order to confirm the presence of fractures or dislocations. The use of fluoroscopic C-arms can help relieve pressure on the main X-ray machines when imaging non-life-threatening limb injuries. In the case of penetrating injury with metallic objects, orthogonal views are essential in order to aid accurate localization of the foreign body and subsequent treatment. However, multiple shrapnel injuries are more complex to identify on plain radiographs, and therefore, multiplanar CT imaging may be more beneficial [8]. Radiographs of the thoracolumbar spine are also warranted if there is posterior spinal tenderness, increased distance between the spinous processes, boggy swellings, or neurological compromise. Once all images are obtained, they can be viewed initially on purpose-made monitors and then subsequently uploaded onto a picture archiving and communication system (PACS) for the transfer of information and reporting, if required.

18.4 Ultrasound

The principal indication for US in the context of assessing MCE victims is focused assessment with sonography for trauma (FAST) scanning as an adjunct to the primary survey. It provides a useful screening test for bleeding arising from visceral injury, e.g., hemoperitoneum and pericardial effusion. Typically, four areas are examined for the presence of free fluid – the perihepatic space (Morison's pouch, hepatorenal recess), perisplenic space, pericardium, and the pelvis. An extended FAST scan can be performed which includes both lungs and can identify the presence of either hemo- or pneumothorax. Triage to clinical observation, CT, or laparotomy can then be performed according to the results of this initial screening and the hemodynamic status of the patient. In general, advantages of US include speed, bedside availability, absence of radiation exposure, and the relative ease of performing repeated examinations. Specifically, FAST scans are less invasive than diagnostic peritoneal lavage and can be performed faster and less expensively than CT, while achieving a similar accuracy [20]. However, interpretation of the scan images is heavily operator dependent and requires skilled technicians with adequate training. It is poor at localizing and grading the severity of organ injury and carries a significant false-negative rate, e.g., due to obesity, subcutaneous emphysema, and retroperitoneal bleeding. In cases of ongoing clinical concern and a negative result, repeat examination is recommended. In addition to FAST scanning, US may also be used for image-guided chest drain insertion, vascular access, and the detection of nonmetallic foreign bodies.

Despite the perceived advantages of US imaging, the literature regarding the efficacy of FAST scanning in MCEs is conflicting. Following an earthquake in Armenia in 1988, Sarkisian et al. reported on the use of emergency sonography in 400 patients [21]. They reported an average time of 4 min spent on each patient with over 130 follow-up examinations required due to ongoing clinical concern. Trauma-related pathology of the abdomen and retroperitoneal space was detected in 12.8 % with only a 1 % false-negative rate. Dan et al. reported on a much larger earthquake in China in 2008 involving a total of 1,207 patients who were initially assessed through bedside US [22]. Among them, 115 (9.5 %) patients received ultrasound-guided interventional treatments. Trauma-related pathology was identified in 84 (7 %) patients with no reported false positives. However, false negatives were seen in five of 89 (5.6 %) patients. Based on these results, the authors of these studies considered US to be an invaluable screening tool in identifying MCE victims with potentially life-threatening injuries. However, Sztajnkrycer et al. evaluated FAST results in 359 trauma patients, of which 27 (7.5 %) results were classed as positive [23]. Of these, six (22.2 %) patients had false-positive results, while 24 of 186 (12.9 %) patients had false-negative results. Overall, six (22.2 %) patients underwent appropriate emergency operative intervention following triage with FAST. Due to the low sensitivity and specificity seen in this cohort of patients, the authors questioned the reliability of FAST. However, this study was performed on adult trauma patients in a non-MCE capacity following retrospective triage to those with non-life-threatening injuries. The results of this simulated MCE model must therefore be applied with caution.

18.5 Computed Tomography

CT imaging provides the primary imaging modality for MCE victims and should be considered the gold standard of diagnostic radiological assessment in centers with the appropriate resources. The main aim of CT in a MCE is to provide efficient and appropriate triage to definitive management, i.e., clinical observation or surgery. In accordance with ATLS guidelines, this is commonly used following the secondary survey in order to assess suspected brain, thoracic, abdominal, spinal, and pelvic ring injuries in stable patients. The advent of spiral CT, and particularly multidetector CT (MDCT), has led to reduced scanning times as a result of increased speeds of image acquisition [24]. High-resolution images of multiple body parts can be rapidly obtained with the ability to format multiplanar reconstructions. These technological advances have led to the introduction of CT as part of the primary survey in patients who are stable enough for transfer to the scanner. However, a MCE provision must be made to allow ongoing resuscitation in the CT department while preparing the patient for scanning. Following analysis of 126 survivors of an airplane crash, Postma et al. reported that while overall compliance with ATLS radiological guidelines was low, deviation from these guidelines in a major trauma center to include full-body CT was safe and did not result in delayed diagnosis of serious injury [25].

A standard trauma CT would include imaging of the head, chest, abdomen, spine, and pelvis with helical contrast studies performed for suspected vascular injury. Indications for CT include either blunt or penetrating trauma with evidence of altered consciousness, pupillary abnormality, suspected basal skull fractures, suspected facial fractures, paradoxical chest wall movement, suspected spinal injury, abdominal tenderness, peritoneal irritation, and urethral bleeding. Advantages of CT in polytrauma patients are that it is noninvasive, is organ specific, has a high sensitivity and specificity, and allows multiplanar imaging which can guide surgical intervention. Importantly, by accurately excluding patients without life-threatening injury, unnecessary surgical exploration can be avoided which can prevent morbidity and free up critical resources. Disadvantages are that it requires a hemodynamically stable patient, it can be time consuming, it requires specialized technicians and radiologists, and in some centers, it may be limited by expense. Also, large doses of radiation exposure are delivered to both the patient and trauma team with reports of over 20 mSv being measured following trauma CT [26].

Simplified and standardized CT protocols should be designed in order to allow maximal patient throughput and should be able to scan rapidly from range from head to pelvis. The number of images should be kept low to enable quick review and reduced computer processing time. Thick transverse images should be taken to rule out life-threatening injuries and to avoid time-consuming reformats. All patients should be log-rolled until spinal injury has been excluded. Requirements include an enhanced and efficient workforce, a dedicated CT scan protocol for MCE triage, and workflow calculations to include maximum time capacities for patient transfer and preparation, image reformatting, transfer of images to PACS, and reporting. Korner et al. developed an accelerated triage MDCT protocol for MCE victims incorporating the use of a 4-detector-row CT scanner with 5 mm slice images of the brain, cervical spine, thorax, and abdomen [27, 28]. In order to decrease image number and image calculation time, no high-resolution or multiplanar reformats were performed. Time frames were compared to a control group consisting of non-MCE patients with polytrauma undergoing standard MDCT. Mean patient transfer, examination, and reporting times were considerably less in the MCE protocol group indicating that adjustments in CT protocols are feasible and can be successful in improving patient flow. More recently, the same authors investigated the use of 64-detector-row CT scanners and volume image reading of thin section images during a simulated MCE and reported significant improvements in image processing time compared to a 4-detector-row CT scanner [29]. Currently, these scanners are in routine use by the UK military at Camp Bastion in Afghanistan and allow increased scanning efficiency during times of multiple casualty arrival [30]. Furthermore, the use of mobile MDCT scanners has also been reported with successful forensic imaging occurring within 15 min and subsequent full radiological analysis within 1 h [31].

Currently, MDCT is recommended in major trauma centers where necessary systems are in place to obtain imaging without compromising initial resuscitation maneuvers. Senior clinicians should be responsible for decision-making regarding optimal timing for CT, and this should be guided by clinical signs and hemodynamic parameters. ATLS guidelines should be consulted but final radiological decisions should be individualized to the patient. MCEs apply increased pressure on CT resources, and therefore, advanced planning is required in order to maximize the benefit from this vital imaging modality.

18.6 Magnetic Resonance Imaging

MRI uses nonionizing radiation to create detailed multiplanar images. The absence of ionizing radiation allows safer imaging than CT and may be particularly relevant in certain patient groups, i.e., pregnant women and young children. MRI permits superior visualization of soft tissue anatomy and the use of advanced techniques allows for specific soft tissue characterization, e.g., short tau inversion recovery sequences and gadolinium contrast. Also, some vascular images can be obtained without the use of contrast material. Despite these perceived advantages, MRI has a relatively limited role in the primary radiological assessment of MCE patients. This is because it is time consuming, it is difficult to monitor unstable patients while scanning, it provides a less detail with respect to bony abnormalities, and it is claustrophobic and image acquisition is extremely sensitive to movement artifact [32]. Important contraindications to MRI include the presence of pacemakers, aneurysm clips, cochlear implants, and metallic foreign bodies which may be problematic in certain MCEs, e.g., blast injuries. Therefore, for the purpose of providing rapid imaging in order to identify patients with potentially life-threatening injuries, other imaging modalities should take precedent, e.g., conventional radiography and trauma CT.

However, MRI can provide important information in the subsequent radiological assessment of injuries identified during the secondary survey. For example, it is the investigation of choice in the diagnosis of acute spinal cord injury, cervical spine ligament injuries, occult fractures, and multi-ligament joint injuries. MRI is also better than CT in detecting axonal injury, small areas of contusion, and more subtle neuronal damage which may be present in milder cases of head injury [33]. Additionally, as the ability of MRI to detect hematoma improves over time, it is more accurate in diagnosing brain injury more than 48 h after injury [34]. Furthermore, it can be used in the postoperative monitoring of abdominal trauma patients following laparotomy and can thus avoid the accumulated radiation dose from repeat CT examinations.

18.7 Interventional Radiology

In addition to providing essential diagnostic imaging for emergency triage, certain clinical situations may benefit from interventional radiological procedures. Most commonly, this involves techniques employed in order to stop life-threatening hemorrhage from vascular injury without the additional physiological insult from explorative surgery. Vascular injury may occur due to blunt abdominal trauma, displaced pelvic fractures, shrapnel injury, or penetrating foreign bodies, e.g., bullets. Common interventional procedures used in the trauma scenario include diagnostic angiography, transcatheter endovascular arterial embolization, and stent grafting. Specialist input is required from interventional radiologists and technicians along with dedicated angiography suites in close proximity to the operating theater complex and intensive care unit. Interventional radiology has a well-established role in the management of hemodynamically stable patients with visceral organ injuries. However, there is ongoing debate as to the efficacy of performing angiography in the context of critically unstable patients who may instead benefit from emergent explorative surgery. Therefore, angiography has traditionally been reserved for hemodynamically stable trauma patients. Practically, this decision should be determined by the clinical condition of the patient and availability of local resources, such as the angiography suite and expertise of the treating surgical team [35].

Engel et al. reported an incidence of 7.6 % of vascular injury in 511 injured patients treated at their institution as a result of military conflict in Lebanon in 2006 [36]. Each of these was due to either penetrating missile or shrapnel injury and was associated with abdominal, bone, or soft tissue trauma. CT angiography of cerebral, abdominal, carotid, coronary, and peripheral arteries gave 88 % sensitivity and 100 % specificity for the diagnosis of vascular injury. In patients in whom CT angiography was inconclusive, conventional vascular imaging methods were successfully employed, i.e., fluoroscopic digital subtraction angiography. Approximately half of patients who underwent diagnostic angiography underwent endovascular treatment in the form of internal iliac artery embolization, inferior gluteal artery embolization, subclavian artery stent grafting, and superior gluteal artery stent grafting. Further evidence supports the use of interventional radiology techniques in the context of major trauma. Duchesne et al. reported on a series of 154 patients with splenic injury and found that the survival rate of 85 % with embolization was equivalent to historical controls treated with splenectomy [37]. Osborn et al. compared the results of pelvic packing to embolization in 40 patients with hemodynamically unstable pelvic fractures and reported equivalent outcomes with respect to mortality and transfusion requirements [38]. However, a recent study of 68 patients who underwent pelvic angiography highlighted the time-critical nature of this procedure and reported that embolization within 1 h of arrival to the emergency department significantly improved the survival rate [39].

18.8 Blast Injuries

The radiological investigation of victims of blast injuries requires particular attention as these patients suffer more severe injuries and have higher mortality rates than other causes of mass trauma [40]. In addition, more hospital resources are required in order to treat these patients who are often critically ill. Typically, these injuries arise as a result of bomb blasts and other explosions. Terrorist attacks account for approximately 60 % of bomb blasts with the victims being younger and requiring more surgical interventions than those involved in other MCEs [41]. While many die at the scene, survivors sustain different forms of injury which can be classified into:

- *Primary* – injuries that result as a consequence of the shock wave and occur in up to 57 % of survivors and result in fatality in 86 % of victims.
- *Secondary* – blunt or penetrating injuries from ballistic trauma, e.g., shrapnel wounds.
- *Tertiary* – blunt injuries that occur when victims or environmental objects are thrown due to changes in wind velocity.
- *Quaternary* – injuries that arise due to delayed effects of the blast, e.g., burns, toxins, and inhaled materials [42, 43].

The requirement for the radiological examination of patients exposed to explosive attacks has been well studied. Haddad et al. reported on 150 casualties of a terrorist bomb attack in Lebanon in 2005 [44]. Plain radiographs and CT scans were performed in 19 % of patients with major injuries seen in 63 % of these individuals. More recently though, Raja et al. reported on 50 victims of explosive devices during the Iraq war in 2008 and found an overwhelming requirement for radiological assessment [45]. Specifically, 92 % received imaging during initial evaluation including 90 % who received CT, 70 % who received conventional radiography, and 38 % who received extended FAST examinations. Of the CT investigations, 93 % were part of a trauma scan and 49 % revealed clinically significant results requiring surgical input. Therefore, in order to provide an adequate radiological response, these situations require a significant allocation of resources.

In order to provide rapid and thorough assessment of these critically injured patients, radiological protocols need to be adjusted, and therefore injuries specific to blast attacks require special consideration. Severe head injuries are a leading cause of mortality in these patients and occur in up to 55 % of victims [46]. Facial and basal skull fractures may present concurrently and as previously discussed, CT is the primary investigation of choice for an acute head injury. Blast lung injury occurs as a result of the shock wave and is also a major cause of fatality. It occurs in approximately 11 % of blast-injured patients and can often be challenging to manage [47]. Pathological changes include parenchymal contusion, hemorrhage, edema, and alveolar rupture. Patients present with symptoms of hypoxia and usually require treatment with assisted ventilation, e.g., intubation and bi-level positive airway pressure. The first-line investigation in these patients is a plain chest X-ray which would initially reveal bilateral “batwing” shadows which may progress to a complete whiteout in more severe cases of pulmonary edema. If required, more detailed imaging can be provided by CT which can help distinguish blast lung injury from other pathologies, e.g., lung lacerations, pneumothoraces, and foreign bodies [48]. It can also help to define the extent of injury and therefore anticipate the need for ventilation in significantly injured patients. Abdominal injuries occur in about 10 % of patients injured in blast attacks and may be due to either blunt or penetrating trauma [49]. As with the respiratory system, the gastrointestinal system contains air making it susceptible to primary injury from the shock wave. Bala et al. reported on 181 patients who underwent laparotomy for abdominal trauma of which 21 patients were injured in a terrorist blast injury attack [49]. Compared to civilian trauma, there was a higher incidence of bowel injury with penetrating shrapnel, the most common cause of injury. Signs of peritonitis may not be present during initial evaluation, and therefore, patients with abdominal pain must be evaluated with either FAST or CT in order to identify the presence of free fluid or perforation [50].

Penetrating injuries from shrapnel, bomb components, and high-velocity flying objects can cause serious injury and are of particular importance in blast attacks. While visual inspection forms the initial evaluation of these injuries, deeper wounds and internal injuries require CT imaging for accurate evaluation. Plain radiographs are only useful for metallic foreign body objects, and while they can provide an initial screening tool, they do not have the three-dimensional benefits of CT images. Practically, performing multiple orthogonal radiographs in MCE patients may be more time consuming and less informative than obtaining a trauma CT scan. Furthermore, a whole-body scout image can be obtained quickly and can help in isolating body parts for further detailed evaluation [51]. A variety of musculoskeletal limb trauma can also be expected ranging from mild sprains to open fractures with severe vascular compromise. The initial radiological assessment of these injuries should occur via plain radiography as an adjunct to the secondary survey with CT indicated for suspected spinal trauma. Due to the extensive nature of these injuries, a rapid assessment protocol is required in order to efficiently triage multiply injured bomb blast victims. Lessons learnt from past explosions and the immediate healthcare responses are critical in planning and improving emergency response services. Radiologists and emergency doctors should familiarize themselves with injury patterns unique to blast attacks and their subsequent radiological assessment.

Conclusion

In conclusion, MCEs present numerous challenges to hospital resources but despite these complexities, fast and direct radiological assessment is critical in performing efficient triage of patients to the appropriate definitive care teams. Components of this system must include disaster planning, predefined trauma team leaders, suitable buildings, radiological equipment, workforce stations, personnel, recruitment, communications, and adequate simulation training. By using a range of appropriately indicated imaging techniques, a thorough and complete radiological examination can be performed rapidly and can reduce the high rates of mortality and morbidity associated with MCEs. Life-threatening vascular injury can also be treated with embolization or stent grafting depending on the availability of local resources and the general condition of the patient. When performed expediently, this can prevent death from hemorrhagic shock without the additional physiological insult from surgery. Bomb blasts are becoming increasingly common as a result of worsening military conflict and terrorist activity. They require close attention from all members of the trauma team as the severity and complexity of injuries are far greater than other causes of MCEs.

Experiences gained from the London terrorist bomb attacks in 2005 lead to the following recommendations published by Hare et al.:

- All elective patients should be cleared from the hospital, in particular from the emergency and radiology departments.
- All staff should be allocated to key areas of the radiology and emergency department.
- A radiologist should also be stationed in the major trauma bays in order to perform FAST in patients with suspected significant abdominal injury and to provide immediate reporting.
- All critically ill patients require a chest, cervical spine, and pelvis radiograph, as well as additional plain films, based on the site of penetrating wounds.
- Hemodynamically unstable patients should be transferred straight to the operating theater for explorative surgery.

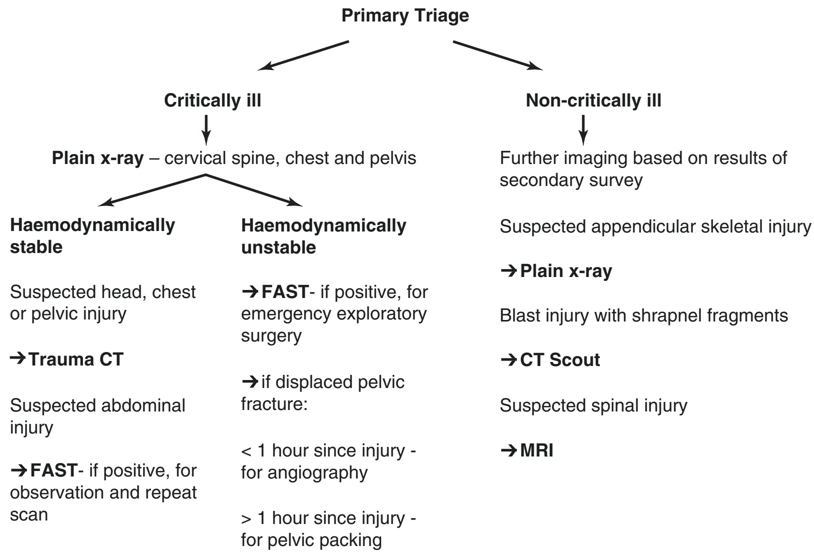

Fig. 18.3 Patient flow algorithm

- Hemodynamically stable but critically ill patients can be transferred to CT for an initial scout view to cover the entire body (to identify shrapnel and undetected fractures) and be followed by CT of the head, neck, chest, and pelvis.
- Noncritically ill patients should be deprioritized and treated as per clinical assessment in order to maximize patient flow through the emergency and radiology departments [46].

A suggested algorithm for the flow of patients through the radiology department during a MCE is presented in Fig. 18.3.

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19 Mass Casualties and Damage Control Orthopedics

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19.1 Introduction

In general, a mass casualty is defined as any incident in which the existing medical service in terms of personnel resources and equipment is overwhelmed by the number and severity of injured patients generated at one time. Accordingly, the routine course of preclinical and clinical healthcare services could not be maintained. Based on this definition a wide range of events with different variations of severity and diversity of injuries are covered: major accidents (e.g., road traffic, railroads, aircraft) with a large number of injured persons, especially when taking place in rural areas; military situations with explosion and gunshot injuries served by small combat hospitals with marginal medical staff; natural disasters in medical immature systems such as the earthquake in Haiti (2010) with multiple crush injuries; disaster situations in medical well-provided, but dense populated areas with substantial destruction of infrastructure like the earthquake and tsunami in Japan (2011); and casualties of terroristic origin such as the bombing attacks in Madrid (2004) and London (2005) with a mass of injured patients suffering from blast and blunt trauma. Depending on the amount of injured patients, the Advanced Trauma Life Support (ATLS®) concept distinguishes between incidents with multiple casualties (*multiple casualty incidents*) and mass casualty victims (*mass casualty events*).

Basic considerations concerning effective management of mass casualties are related to preparedness, awareness of medical resources, and diversity of injury pattern. Today, mass casualties mostly arise abrupt and with no warning to the medical system.

This chapter comprises an approximate overview about the on-scene action and triage in mass casualty incidents and describes characteristics of different mass casualty situations (military conflicts, nature disaster, and terrorist attack) including common injuries. Furthermore, the concept of damage control orthopedics (DCO) in contrast to early total care (ETC) treatment is described as laying a special focus on the amputation of limbs as a lifesaving procedure in mass casualties.

19.2 Triage

The concept of triage describes the process of evaluation and classification of multiple and mass casualty victims in order to save and help

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_19

as much patients as possible with reduced emergency and medical resources [38]. According to the ATLS® concept, the aims of triage concept differ substantially between multiple casualty incidents and mass casualty events. As only local healthcare resources are overwhelmed in multiple casualty incidents, on-scene triage needs to identify patients with life-threatening injuries in order to provide the limited transportation capacities to those patients. In contrast, the focus of triage in mass casualty events is the identification of those patients with the highest probability of survival. In general, one of the most difficult steps in the triage process is getting a quick and appropriate overview about the different types of injuries and their need for urgent or delayed treatment without over- or underestimation. In this context, the initial triage depends on the setting of the multiple or mass casualties as well as on the medical system. In countries providing an emergency medical service based on the "scoop and run" principle, the real triage process will take place at the time of admission to the emergency department. This may lead to ineffective disposition of trauma victims and overcrowding of the hospital [29, 51]. In emergency medical systems using the "stay and play" or "stay and stabilize" concept, injured patients are assessed and stabilized on scene by an emergency physician. After the initial stabilization of their physiological status, trauma victims are allocated to different hospitals depending on their personal needs. This system is fragile in view of the qualification of the emergency physician and the possible waste of time on scene. There is still an ongoing discussion on the advantages and disadvantages of these two principles of emergency medical service. Beyond this questionable aspect of on-scene management, a structured procedure for treating the variable injured casualties is needed. In order to facilitate the transport and further treatment, avoiding the overload of hospitals' capacities due to the admission of minor injured patients, various concepts with multiple overlapping are used worldwide. Mostly, four different triage categories are distinguished: mild or marginal injured patients with delayed treatment, moderate injured patients with urgent treatment, severely or life-threatening injured patients with immediate treatment, and unsavable patients. Some systems only have three categories with immediate, urgent, and delayed treatment. Within this system, unsavable patients get a delayed treatment. Usually, a color code is used to facilitate the allocation of the patients to the different groups for further treatment. In most systems, red means immediate treatment, yellow urgent, green delayed, and blue or black means expectant/unsavable [38]. In cases of major disasters with complete destruction of the medical infrastructure, such as the earthquake in Haiti in 2010 with more than 230,000 dead and 300,000 injured people, other approaches could be reasonable [36].

After initial assessment based on the priority-based ABC scheme (airway, breathing, circulation) according to the ATLS® concept, an immediate treatment is recommended for [9, 29] injuries to the respiratory tract including tension pneumothorax, massive hemorrhage in the chest or abdomen including cardiac tamponade, and persistent bleeding including pelvic ring injuries. Patients with initially wide and nonreactive pupils and/or cardiac arrest are categorized as unsavable and do not receive further treatment [20]. The problem after the initial treatment and stabilization of patients' physiological status is the allocation to the correct hospital. In a retrospective analysis of 20,815 trauma patients, Huber-Wagner and colleagues described eight variables associated with emergency operations [21]:

1. $AIS_{abdomen} \geq 3$
2. ISS $\geq$35
3. Hemoglobin level $\leq$8 mg/dl
4. Pulse rate on hospital admission <40 or >120/min
5. Blood pressure on hospital admission <90 mmHg
6. Prehospital infusion volume >2000 ml
7. GCS $\leq$8
8. Anisocoria

Additionally, a mean cut to suture time of 130 min was described in this trauma population giving the emergency physician a reference for the required operation capacities and the allocation to the different hospitals. Admitting multiple patients with the above-listed variables to one hospital at the same time could create unnecessary problems. An appropriate allocation of injured patients helps to improve the treatment of each patient. Furthermore, secondary time-consuming interhospital transfers of patients could be avoided. Due to the limited transportation capacities, trauma patients are admitted to the emergency departments in waves depending on the distance to the scene [41]. Usually, the time between two waves for a near hospital is approximately 30–45 min giving the chance for further preparation.

19.3 Different Settings of Mass Casualty

19.3.1 Military Conflicts

As almost 70 % of all acquired injuries are related to the musculoskeletal system, 54 % involving the extremities, orthopedic surgeons have always played a role in military conflicts [15]. Whereas in the past centuries the injuries were mostly caused by gunshot wounds, the injury pattern has changed today, and more blast injuries are noticed as the improvised explosive device (IED) is the most common weapon from insurgent forces in Afghanistan or Iraq. Approximately 75 % of injuries are related to IEDs, just 16 % are gunshot wounds [37]. That results in several specific injury pattern: first of all most fractures are open (82 %) with severe soft tissue damage. As the use of the IEDs increases, limb amputations and unsalvageable leg injuries with pelvic trauma are also on the rise [8]. Therefore, the most common mortality is related to hemorrhage and shock. Due to this and the fact that blood supply is very limited in the field, especially in case of mass casualty, the priority-based scheme of ATLS® was changed into <C>ABC in 2005. In this context, <C> means the control of catastrophic hemorrhage representing the most common cause of death in the field [19]. Different tools were developed to control the initial bleeding.

Among them the Elastic First Field Dressing, the Combat Application Tourniquet (CAT) which has found its way into the civilian sector as an adjunct to hemorrhage control and hemostatic dressings [8]. Furthermore, explicit flowcharts were developed for the hemostatic early resuscitation. Central points after <C>ABC are warming, tranexamic acid, calcium, fibrinogen, and transfusion in case of need [11]. After initial stabilization and transport to a hospital, the injured limbs are mostly treated with external fixation and debridement of the soft tissues [15]. Primary internal fracture fixation has been reported to be associated with high complication rates and cannot be recommended [8]. Beyond that, external fixation represents a timesaving procedure compared to definite fracture care and should be used particularly in case of military mass casualties.

19.3.2 Natural Disasters

During the last decades, extreme weather conditions and subsequent natural disasters increased [40]. According to the Centre for Research on the Epidemiology of Disasters (CRED), in 2005, 88,117 people were killed in natural disasters. Natural disasters are characterized by a complex set of factors including climate change, global warming, and socioeconomic factors causing poorer people to live in risky areas. Problems are not only caused by the immediate injuries, but also by the subsequent increase of other illnesses aroused by the disaster. Furthermore, natural disasters are often accompanied by the destruction of infrastructure. In overall, four different natural disasters are generally related with injuries, illnesses, and mass casualties [23]. The eruption of a volcano represents a rare natural disaster causing typical injuries to the airway and burn injuries with a small amount of trauma victims. Floods and tsunamis regularly cause drowning and asphyxiation, injuries to the musculoskeletal system including crush injuries, hypothermia, respiratory infection, and risk of leptospirosis due to contaminated water supply. Hurricanes result in the same injury pattern.

However, diarrheal diseases because of the enclosed people aggravation as well as burn injuries and carbon monoxide poisoning due to the extensive use of petroleum lights as a result of collapsed electricity are specific for hurricanes. In earthquake disasters, the treating physicians are usually confronted with a big amount of musculoskeletal injuries due to collapsed structures. The initial, more severely injured patients with massive bleeding or head injuries are not savable as the medical system is demolished and the roads are blocked. This explains why earthquakes with 60 % have the highest mortality of all disaster-related death during the past decade [4]. The earthquake that hit Haiti in 2010 caused multiple deaths and nearly 300,000 injured patients. As the medical maintenance was completely demolished or not accessible, medical staff from all over the world entered Haiti in order to provide medical supply [4, 30]. As the most survivors seeking help within the first 3–5 days, the incoming medical teams were confronted with a massive patient load as they were able to work at day 4–5 depending on the region and access [30]. Here a proper triage is vitally important. For all nature disasters, an increase in motor vehicle collisions is described as the people trying to flee [23]. Furthermore, the rate of infections and diarrheal diseases increases as no clean water supply is available.

19.3.3 Terrorist Attack

In the last decade, terrorist attacks and their severity increased with subsequent more mass casualty situations such as the attacks in London 2005 [2] or the train bombing in Madrid in 2004 [48]. Most attacks today are with high explosives and result in a similar injury pattern as in military conflicts today. However, in contrast to military conflicts, terrorist attacks arise out of the blue, result mostly in mass casualty, and often encounter a sparse prepared medical system. Furthermore, the victims of a terrorist attack have in a higher proportion life-threatening injuries than in other trauma events which can overstrain the local medical supply [38]. A proper triage and allocation has to be done in order to save as much patients as possible. In contrast to other scenarios with mass casualties, it has to be underlined that the initial rescue teams and the following medical staff are in danger for a so-called second wave, a second bombing of the scene at the time of arrival of the rescue teams. Furthermore, the possibility of biological or radioactive contamination has to be kept in mind [38]. The necessary decontamination and quarantine of injured patients is a challenging and dangerous situation for all the medical staff [31].

19.4 Injury Pattern

19.4.1 Compartment Syndrome

The most common causes for compartment syndrome are fractures, with tibial fracture comprising 40 %, and vascular damage. In only 23 % a compartment syndrome occurs by soft tissue damage without fracture [28]. The development of a compartment syndrome depends largely on two points: the muscle compartment pressure and the compartmental perfusion pressure. An increase of the muscle compartment pressure, for example, by bleeding or swelling or a decrease in the compartmental perfusion pressure, can lead to an apparent compartment syndrome with muscle necrosis and late fibrous contractures [28]. To avoid these severe complications, a fasciotomy has to be done if compartment syndrome is suspected [4, 28, 52].

19.4.2 Crush Injuries and Syndrome

With an incidence of approximately 2–15 %, the crush syndrome is one of the most common injuries, especially in earthquake disasters [6]. The crush syndrome is a special form of rhabdomyolysis resulting from continuous pressure to a muscle group, in most cases a limb, with consecutive muscle necrosis and tissue damage. After releasing the pressure and revascularization, the whole necrotic products including potassium, lactic acid, myoglobin, and creatine kinase are released into the cardiovascular system [4]. Especially the potassium can cause early problems including sudden cardiac arrest. In the further course, accumulating myoglobin and uric acid damages the tubular system of the kidneys leading to renal failure with a high mortality rate. Therefore, experts recommend the use of a urine dipstick in earthquake disasters to check for myoglobin while triage in the hospital [42]. The initial treatment before extrication should consist of aggressive administration of fluid and alkalinization to protect the renal tubules. Nevertheless, approximately half of the patients with crush syndrome develop renal failure, and nearly half of those patients need dialysis [4]. The fasciotomy of the affected limb is controversially discussed. On the one hand, it restores the circulation with all positive and negative effects; on the other hand, it increases the infection rate dramatically and turns closed fractures into open ones [4, 14, 52]. In overall, fasciotomy is only recommended in case of vascular compromise. Additionally, there is still an ongoing controversial discussion on the amputation of affected limbs in terms of a crush injury as primary amputation does not seem to improve the outcome [14]. However, crushed extremities potentially represent the origin for infection and subsequent sepsis with poor outcome [34].

19.4.3 Blast Injury

In the setting of terrorist attacks and military conflicts, the most frequent injuries are related to explosions. Thereby, the injury pattern after explosions is fundamentally different from those of conventional trauma. It is characterized by a higher proportion of deceased patients, serious injuries, and patients with injuries of more than three body regions. Additionally, patients are suffering more often from penetrating and blunt injuries simultaneously. Depending on the mechanism blast injuries are divided into primary, secondary, tertiary, and quarterly lesions [50]. The primary blast injury is caused by an acceleration-deceleration mechanism as a result of the blast wave. Therefore, the lungs and visceral hollow organs are at special risk for primary blast injuries. Secondary blast injuries are penetrating lesions due to shrapnels such as metal fragments, screws, or nails especially in terrorist attacks placed around the explosives in order to increase the damage. Explosion-related deaths are most frequently caused by secondary injuries. Tertiary injuries are blunt lesions due to the crash of victims against objects, fall from height, or collapse of buildings. Quarterly injuries are caused by heat, fire, and toxic agents [24]. In overall, multiple soft tissue damage, open fractures, and injury severity are significantly more frequent in blast injuries compared to other mass casualty situations [48, 50]. Rescue services and medical resources are usually exceeded by mass casualties after explosions making a sufficient triage of injured patients imperative. Triage of patients suffering from blast injuries is challenging due to blast-specific injuries and atypical conditions. Especially, the distinction between traumatic brain injuries and psychomotorical disturbance as well as hemorrhage and atypical shock might be difficult. Patients with wide pupils, amputated limbs, and not moving are supposed to be dead. The incidence of traumatic amputations among explosion victims is 1–7 % [1, 45]. Traumatic amputations are often accompanied by severe primary blast injuries. With an overall mortality rate of almost 95 %, traumatic amputations represent prognostic injuries in explosion mass casualties [13, 22]. Furthermore, an extensive requirement for intensive care unit (ICU) admission can be anticipated in explosion mass casualties. Singer et al. described an ICU admission in nearly 23 % of explosion victims after a suicide bombing in Israel [44].

19.4.4 Hypothermia

Trauma patients in mass casualty situations are often suffering from accidental hypothermia. In general, hypothermia is defined as body core temperature below 34 °C. The severity of hypothermia is graded into mild (<35–34 °C), moderate (<34–32 °C), and severe (<32 °C) hypothermia [26]. Approximately 66 % of all

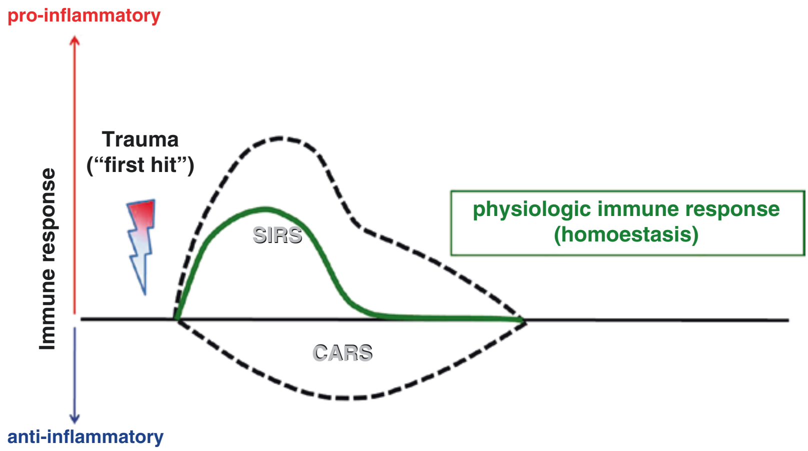


Fig. 19.1 Posttraumatic immune response

multiple injured patients incur at least a mild hypothermia [47]. The problem with the trauma patients and hypothermia is the so-called deadly triad consisting of hypothermia, acidosis, and coagulopathy potentially resulting in uncontrolled bleeding [16]. The mortality increases directly with the hypothermia. Patients with severe hypothermia (below 32 °C) display a 100 % mortality rate [26]. Therefore, the prevention of hypothermia should be the aim after stabilization of vital functions [27]. Warm blankets and warm crystalloid infusions should be administered, and as soon as possible, an active external rewarming with warm dry heat should be taken into account [10].

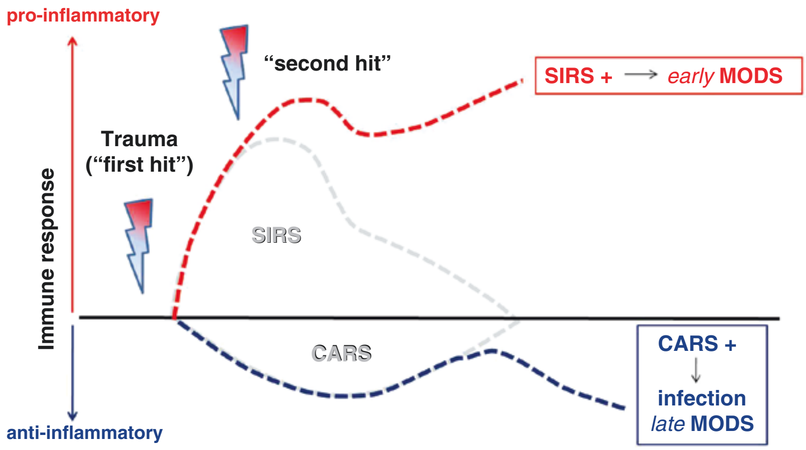
19.5 Damage Control Orthopedics (DCO) and Early Total Care (ETC)

The immune response after trauma is characterized by a complex set of pro- and anti-inflammatory reactions aiming to restore homoeostasis. The pro-inflammatory response accounts for the systemic inflammatory response syndrome (SIRS) and the anti-inflammatory part for the compensatory anti-inflammatory response syndrome (CARS) (Fig. 19.1).

An additional trauma, the so-called second hit, due to prolonged surgical procedures in terms of primary definite fracture stabilization may result in an overwhelming pro- or anti-inflammatory immune response leading to posttraumatic complications such as acute respiratory distress syndrome (ARDS), multiple organ dysfunction syndrome (MODS), infectious complications, and increased mortality [32] as shown in Fig. 19.2.

Therefore, the concept of damage control orthopedics (DCO) was introduced in severely injured patients with accompanying long bone fractures. In contrast to the early total care (ETC) treatment with primary definite fracture stabilization by intramedullary nailing, according to the DCO concept, fractures are temporarily stabilized by external fixation in order to reduce the time and effort and blood loss during the primary surgical procedure [46, 49]. These are extremely important aspects especially in the setting of mass casualties thinking of the high number of severely injured patients and the increased need for blood supply. However, there is still an ongoing discussion on the question which patients are eligible for DCO or ETC treatment in the "normal" setting. In general, it is an accepted standard that stable multiple trauma patients could be treated in accordance to the ETC concept, whereas unstable patients or patients "in extremis" should receive DCO treatment. Furthermore, the definition of "borderline patients" was introduced in 2002 in order to characterize a multiple trauma population with a physiological status right in between, who probably benefit from DCO treatment. Based on the physiological status, a treatment

Fig. 19.2 Second hit theory



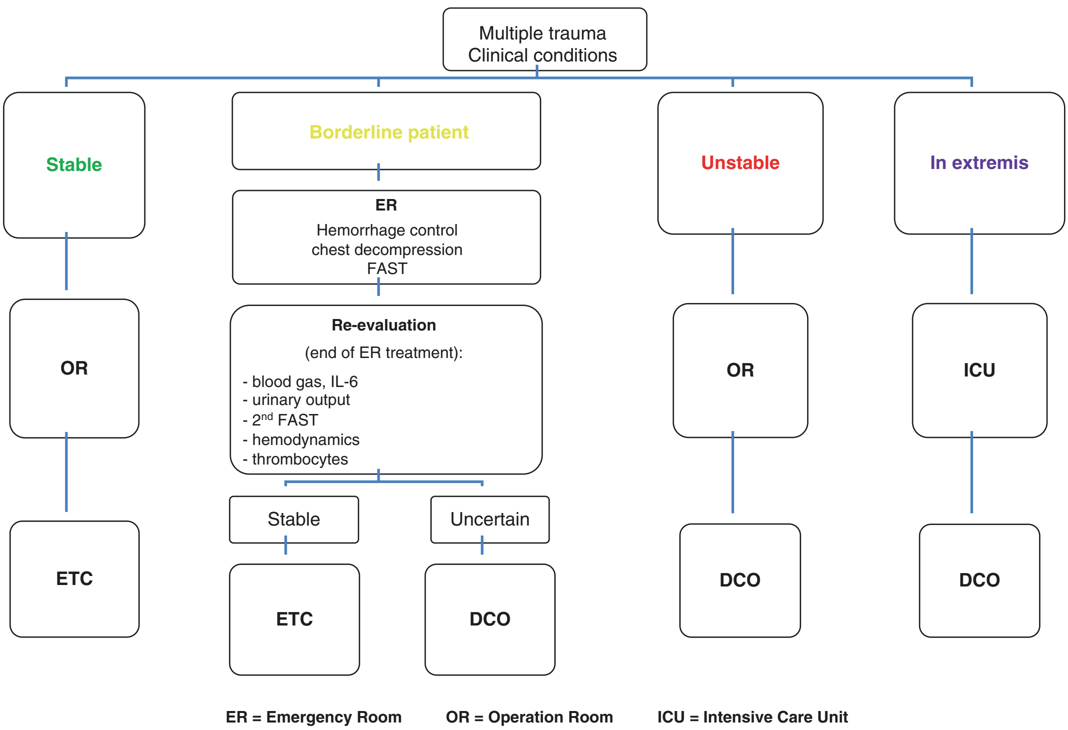


Fig. 19.3 Treatment algorithm of multiple trauma patients (*ER* emergency room, *OR* operation room, *ICU* intensive care unit) (Pape et al. relevance of doc *Am J Surg*, 2002)

algorithm for multiple trauma patients is shown in Fig. 19.3.

Following criteria for the definition of "borderline patients" were defined [39]:

1. ISS >40
2. ISS >20 with chest trauma (AIS >2)
3. ISS >20 with abdominal or pelvic trauma (AIS >2) or hemorrhagic shock (systolic RR <90 mmHg at the time of admission)
4. Patients with moderate or severe traumatic brain injury
5. Radiographic evidence of pulmonary contusion

6. Patients with bilateral femoral fractures
7. Body temperature <35 °C
8. Presumed operation time >6 h

Especially a presumed operation time of more than 6 h is a crucial factor for multiple injured patients in terms of outcome and has to be critically considered in planning the surgical procedure. Additionally, Harwood et al. reported no differences concerning the infection rate in patients who underwent stabilization according to DCO or ETC concept when the conversion from temporary to definite fracture stabilization (intramedullary nailing) was performed within the first 2 weeks after trauma [17]. Due to the decreased operation time, reduced blood loss, and equal infection rates in DCO treatment compared to ETC concept, temporary fracture stabilization with external fixation should be applied in case of mass casualties as thereby more patients can safely be treated without negative effects for the individual. In major mass casualties such as the earthquake in Haiti in 2010, the application of external fixators is also acceptable for definitive fracture treatment as otherwise the patient rush cannot be handled [30]. A rare and special situation is the so-called combined injury syndrome consisting of the simultaneous occurrence of mechanical (blunt or penetrating), burn, and radiation injuries. In this case, definite primary treatment of musculoskeletal injuries within the first 48–72 h should be performed as surgical interventions in the further course need to be avoided due to the increased infection and bleeding risk as a result of the radiation-induced bone marrow depression (hematopoietic radiation syndrome) [7, 12].

19.6 Musculoskeletal Trauma: Amputation and Late Presentation

Amputation is an irreversible and radical procedure and should be the last option in our well-equipped medical system. Although their reliability is controversially discussed in severely injured patients, different prognostic tools for decision-making towards amputation or limb salvage such as the Mangled Extremity Severity Score (MESS) [18] or the Limb Salvage Index (LSI) have been developed in the past [5, 35]. Furthermore, there are various treatment options for the management of mangled extremities: vacuum therapy, temporary stabilization, local or free tissue flap coverage, and bone transportation techniques. However, these therapeutic surgical options are time- and human resource-consuming procedures, which are limited or even unavailable in the setting of mass or disaster casualties. Additionally, a lot of patients with musculoskeletal injuries are admitted to emergency departments with significant delay due to the impaired infrastructure. Therefore, formerly simple fractures could become a problem for further surgical treatment due to infection, crush injury, or compartment syndrome [3]. Additionally, an adequate aftercare in outpatient departments is not always guaranteed because of restricted medical capacities. In the preclinical setting, an adequate triage has to be done following the priority-based ABC scheme of the ATLS® concept [9]. In case of persistent extremity bleeding, a compression bandage or a tourniquet has to be applied [52]. Afterwards, the injured should be quickly admitted to a proper hospital. Massive destruction, irreparable vascular damage, or subtotal amputation represents indications for amputation as they do in the "standard" situation, whereas the decision-making for lifesaving amputations is not that easy. Lifesaving amputation could be indicated in case of late presentation with infectious situation or crush syndromes. The most challenging and complicated situation appears if the limb could be preserved under normal circumstances, but the lacking medical resources demand amputation.

In the disaster situation in Haiti in 2010, after the earthquake a motivated surgical team from abroad tried to save limbs instead of performing early amputation. As people heard about that, the hospital was overwhelmed by patients with musculoskeletal injuries, and medical as well as human resources were exhausted very quickly.

Furthermore, the safety of the medical staff was impaired demanding the retrieval of the surgical team to the airport escorted by the military service [33]. In general, considerations concerning available aftercare, socioeconomic and cultural aspects, and the expected number of admitted patients as well as urgency of surgical interventions have to be taken into account for the decision towards limb salvage or primary amputation. Additionally, decision-making has to be done by the most experienced surgeon. However, local surgeons are not always experienced in this field, particularly in the setting of mass casualty or disaster situations.

In 2011, the Humanitarian Action Summit Surgical Working Group published a consensus statement regarding the multidisciplinary care of limb amputation patients and the decision-making for amputation in disaster situations [25]. Although the authors declare that the definitive decision for amputation is a very individual one, they note significant points. First of all, adequate anesthesia has to be warranted in order to preserve phantom limb and somatic pain. In this context, multimodal concepts are needed as the treatment does not end with the surgical intervention of amputation. Good rehabilitation programs as well as an adequate prosthesis supply are essential to allow the patients a self-sustaining life.

Concerning the surgical technique, a maximal limb length should be aimed, but not by accepting an insufficient debridement [52]. So the first step is a debridement of the soft tissues and bone as aggressive as necessary, but as gentle as possible. If available vacuum-assisted closure is recommended, the formerly preferred procedure of guillotine amputation with secondary skin traction is not recommended as it does not really preserves limb length, and multiple debridements can be necessary [25, 52].

Forty-eight to seventy-two hours after the initial debridement, a second look operation has to be performed and repeated as often as necessary before definitive wound closure. A primary closure cannot be recommended in mass casualty and disaster situations as there has been reported a high rate of wound dehiscence and infections [3, 52]. The definitive closure of the soft tissues should be performed 5–6 days after the initial debridement as beyond this time point the healing rate seems to drop dramatically [43].

Conclusions

Mass casualties are a challenge for every physician worldwide. In addition to the hard decisions which have to be made, the medical staff can be involved personally especially in disaster situations. That can overstrain the individual as well as the medical care in its entirety. The basis for an effective treatment of the victims is a quick and proper triage on scene according to the ATLS® principles and an adequate hospital allocation. Thereby, the best treatment for the most instead of the individual is the goal. In terms of preparedness, adequate emergency and organization plans for various scenarios should be established. Furthermore, regular training of these scenarios is mandatory. The treating physicians should be aware of the typical injury pattern of each disaster situation as this offers the chance of acting instead of reacting. Blast injury with organ failure or crush syndrome should be kept in mind, and the treatment strategy should be clear. For orthopedic surgeons, difficult decisions regarding fracture stabilization (ETC versus DCO) and limb salvage have to be made. As a timesaving procedure, DCO treatment should be recommended in mass casualty situations. The question regarding primary amputation or limb salvage is still controversially discussed. As the time and effort for an adequate amputation is comparable to initial limb salvage with soft tissue debridement and fracture stabilization, primary amputation should only be performed in unsavable limbs or in case of life-threatening extremity injuries. The definitive decision towards amputation or limb salvage could be made in the further course, if possible in agreement with the patient.

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20 Prevention of Infection in Open Fractures in Mass Disasters

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20.1 General Considerations

In mass disasters a considerable strain is put on the medical system of the affected area with adverse public health consequences [1]. Most of the injured have minor cuts and bruises, some have simple fractures, while a small percentage of patients (which still may be overwhelmingly high for existing treatment capabilities) sustain multiple fractures, crush syndrome, or internal injuries and require interventional treatment [2, 3].

Contrary to everyday medical practice where the aim is to offer the best possible service to the individual, the key principle of disaster medical care is to do the greatest good for the greatest number of patients. This strategy, called the mass casualty incident response, has the primary objective of reducing the morbidity and mortality associated with the disaster by allocating available resources in the most efficient possible way [3]. Immediate health priorities include search and rescue for survivors, providing surgical and medical services, preventing wound infection, offering the best functional recovery after the disaster, and providing shelter, food, clean water, and sanitation. Coordination of all involved agencies is essential in mass disaster situations.

20.2 Epidemiology of Open Fractures in Mass Disasters

The most common injuries occurring in populations affected by mass disasters are soft tissue injuries and fractures of the extremities and spine [1]. Orthopedic injuries in mass disasters differ from everyday injuries in a number of ways that complicate management. Patients may present with a delay due to prolonged evacuation, wounds are often contaminated, and fractures are usually open [4].

Musculoskeletal injuries are more common than that of other systems in physical disasters such as earthquakes, and it has been estimated that 26,000 people are injured due to earthquakes every year [5]. Dai et al. reported their experience from an earthquake registering 8.0 on

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_20

the Richter scale that struck in China in 2008. Of 249 patients admitted in two teaching hospitals, 205 (82.3 %) had musculoskeletal injuries. Fractures were present in 78 % of patients with musculoskeletal injuries, and 34.4 % of them were open fractures. The lower extremities were predominantly involved and 70 % of patients sustained multiple fractures [5]. Similarly, in the reported experience of Medecins Sans Frontieres in postearthquake in Haiti in 2010, 170 (83.3 %) of the 204 major long bone fractures involved the lower extremities, and the cohort demonstrated a large number of open fractures of the lower limb and closed fractures of the upper limb [6]. In the same Haiti earthquake, the Israel Defense Forces field hospital reported that fractures were present in 46 % of trauma cases and 25 % of these fractures were open. Specifically, 40 % of tibia and fibula fractures, 9 % of femoral fractures, and 6 % of humeral ones were open [7]. Görmeli et al. reported that 14.6 % (21/144) of fractures from the 2011 Van earthquake in Turkey were open [8].

In cases of terrorist attacks with explosive devices, the body regions most frequently injured are the head, neck, and face, and the most prevalent fractures are maxillofacial and long-bone fractures. Open long-bone fractures are more common than closed ones, and in the 2004 terrorist bombings in Madrid, 77 % of fractures were open [9].

20.3 Open Fracture Management in Mass Disasters

Open fractures are associated with an increased risk of complications, such as infection and nonunion. The goals of management are prevention of infection, union of the fracture, and restoration of function of the extremity.

Management of open fractures is based on the principles of patient assessment, injury classification, temporary coverage, and immobilization of the fractured extremity during transportation, early antibiotic therapy, extensive debridement, fracture stabilization, wound management, and soft tissue coverage [10, 11].

20.3.1 Patient and Injury Assessment

Open fractures usually result from high-energy trauma, and the treating physician must be aware of the potential for associated injuries that may be life-threatening. A patient with an open fracture is first and foremost a trauma patient. Application of Advanced Trauma Life Support (ATLS) protocols and damage control principles is the first step in dealing with all injured patients [4, 7]. All patients should be triaged by the severity of their injuries, and treatment should be prioritized in terms of available resources and chances for survival.

The neurovascular status of the injured extremity should be evaluated, and the possibility of compartment syndrome should not be ruled out based on the presence of an open fracture wound. The size and location of the wound, the degree of muscle damage, and the presence of gross contamination should be evaluated. Fracture characteristics, such as anatomic location, articular involvement, and comminution should be evaluated as well [10, 11].

20.3.2 Open Fracture Classification

Classification of open fractures in different types based on the severity of the injury has treatment and prognostic implications. The classification proposed by Gustilo and Anderson is commonly used [12, 13]. Type I open fractures include those with minimal contamination and muscle damage with wounds <1 cm. Type II open fractures include those with lacerations >1 cm with moderate soft tissue injury and minimal comminution. Type III open fractures include three subtypes: Type IIIA involves extensive soft tissue damage but with adequate bone coverage. Usually there is severe comminution and heavy contamination. Type IIIB involves extensive soft tissue that requires flap coverage of the exposed bone. Type IIIC involves arterial injury requiring repair, regardless of the degree of soft tissue injury.

However, the reliability of this classification has been questioned [14]. It is important to remember that the degree of contamination and soft tissue damage, which are important factors in the classification of open fractures, may be erroneously overlooked in a wound of small size. In mass disasters, and especially earthquakes, crushing injuries are common and open fractures may be associated with extensive soft tissue damage that is not readily apparent. For this reason a complete assessment of the injury is not possible before wound exploration and debridement. Imaging capabilities may not be readily available in the medical teams responding to mass disasters, thereby complicating assessment of open fracture characteristics.

The severity of the injury as evaluated by the Gustilo and Anderson classification is a major determinant of the common complication of infection. Patzakis and Wilkins reported on 1104 open fractures in a civilian setting and found an overall infection rate of 7.0 %. Type I open fractures had a 1.4 % infection rate, type II had 3.6 %, and type III open fractures became infected in 22.7 % [15]. Type III combat-related fractures are complicated by a high infection rate as well. Deep infection rates of 27 % for type III open tibia shaft fractures and 31 % for type III open proximal femoral fractures have been reported in combat casualties [16, 17].

While open fractures are prone to infection due to the soft tissue trauma that creates communication of the fracture site with the outside environment and contamination, in the setting of a mass disaster additional factors can lead to an increased infection rate. Patients often have other associated injuries and may be unstable. Treatment may be considerably delayed, since search and rescue of traumatized patients can take a long time, means of proper transportation may not be available, and treating facilities may be inadequate to promptly deal with a large number of patients due to lack of personnel and/or equipment.

After the first few days following a mass disaster, infection becomes the primary threat to the lives and limbs of injured patients [7]. Every effort to prevent development of infection is therefore extremely important.

20.3.3 Temporary Coverage and Immobilization of the Fractured Extremity

The open fracture wound should be irrigated, gross contamination should be removed, and the wound should be covered with a sterile dressing. Fractures with dislocations must be reduced. The fractured extremity should be immobilized during transportation, preferably with a splint. In the setting of mass disaster, however, means for application of splints may not be always available. In the absence of more sophisticated equipment, any material, such as sticks and sheets wrapped around the extremity, may be used for extremity immobilization.

20.3.4 Antibiotic Administration and Tetanus Prophylaxis

20.3.4.1 Antibiotic Administration

Open fracture wounds have a high risk of infection and early antibiotic administration is recommended. Patzakis et al. in a prospective randomized study showed that use of antibiotics decreases the infection rate in open fractures [18].

Current antibiotic protocols for open fractures recommend 3 days of a first-generation cephalosporin (e.g., cefazolin), which is active against gram-positive organisms. In addition, aminoglycosides (e.g., gentamicin), which are active against gram-negative organisms, are recommended in all open fractures [11, 15] or selectively in type III open fractures [19]. In wounds with severe contamination, which are often present in mass disasters, anaerobic organisms are likely present in the wound and appropriate coverage should be added. Dai et al. reported a high number of infections complicated with anaerobic or gram-negative bacteria during the Wenchuan earthquake in China in 2008 [5]. The World Health Organization recommends administration of penicillin G and metronidazole for prevention of wound infection [20].

Early administration of antibiotics has been shown to be beneficial in a study conducted in a civilian setting [15]. Given the adverse circumstances of a mass disaster, early administration of antibiotics when the patient is found and rescued, although preferable, may not be feasible and may have to be delayed until the patient is transferred to a treating facility. Cultures of open fracture wounds are rarely predictive of the infecting organism if a deep infection subsequently develops [17].

20.3.4.2 Tetanus Prophylaxis

Tetanus is a serious infectious disease caused by *Clostridium tetani*. Wounds are considered to be tetanus prone if there is devitalized tissue in the wound, contamination with soil or manure, delay more than 6 h until surgical treatment, and clinical evidence of sepsis. Burns, frostbites, puncture wounds, and high-velocity missile injuries are also tetanus prone. The overall tetanus case fatality rate varies between 10 and 70 %, depending on treatment, age, and general health of the patient [3]. Mass disasters offer a favorable environment for such incidents, as they involve a high number of patients with tetanus-prone injuries and may occur in developing countries with low or nonexistent immunization coverage [21]. Yasin et al. reported on seven deaths from tetanus from their experience in the earthquake in Pakistan in 2005 [1].

All open fractures are tetanus-prone injuries. Individuals with incomplete or unknown immunization are not considered immune and require passive immunization with tetanus immune globulin and initiation of immunization with either tetanus toxoid or tetanus-diphtheria vaccine [22].

20.3.5 Wound Irrigation and Debridement

Appropriate irrigation and debridement of an open fracture wound are necessary [11, 20, 23]. Antibiotics and host defense mechanisms will not be effective in the presence of devitalized tissues and/or foreign material in the wound.

20.3.5.1 Irrigation

The wound should be washed with large quantities of soap and water and irrigation with saline should follow [20, 24]. Normal saline is the solution usually favored for wound cleansing as it is isotonic and does not interfere with the normal healing process. In emergency situations, however, tap water can also be used because it is easily accessible, efficient, and cost-effective. In the absence of potable tap water, boiled and cooled water as well as distilled water can be used [20, 25].

A recent Cochrane review evaluated the use of tap water for wound irrigation and concluded that there is no evidence that using tap water to cleanse acute wounds increases or reduces infection, and there is no strong evidence that cleansing wounds per se increases healing or reduces infection [25]. As the authors of the review emphasized, the findings should be interpreted with caution as most of the comparisons were based on single trials, some of which do not report the methodology in sufficient detail to enable assessment of quality. Museru et al. compared the infection and healing rates in open fractures irrigated using distilled water, cooled boiled water, or isotonic saline, but this study did not have enough power to detect differences between the three types of irrigation fluid [26]. The availability and cost of resources may determine which solution is used for cleansing wounds in any given setting.

The use of topical antibiotics or washing wounds with antibiotic solutions is not recommended [20, 24]. Antiseptics, such as povidone-iodine 10 % solution, should be applied to the skin but not inside the wound. Antiseptics should not be used within the wound [23].

20.3.5.2 Debridement

The wound should be meticulously and systematically debrided to remove any foreign material (such as dirt, grass, wood, glass, or clothing) and any devitalized tissue. Free fragments of bone with no obvious blood supply should also be removed, but muscle and periosteum should not be stripped away from the fractured bone. Dead or devitalized muscle is dark in color, does not bleed, and does not contract when pinched. Bleeding is minimized by gentle handling and controlled with compression, ligation, or cautery. Debridement should initially be performed to the superficial layers of soft tissue and subsequently to the deeper layers. Then the wound should be again irrigated, and the cycle of surgical debridement and saline irrigation should continue until the wound is completely clean. Debridement procedures may be repeated as often as necessary to obtain a clean wound [5, 8, 20, 22, 23].

It is generally suggested that debridement should be performed within 6 h of injury, as it has been believed that a delay beyond 6 h would increase the risk of infection in open fractures. Jacob et al. evaluated 37 open fracture cases sustained by US military personnel during a 1992 conflict in Panama and reported a significant difference in the infection rate for type III open fractures that were debrided in Panama (22 %) as compared to those that were debrided only after transport back to the USA (66 %) [27]. Other studies have not shown a direct relationship between timing of initial operative care and infection, thus not supporting this historic 6 h rule [15, 28]. The adequacy of debridement is the key factor in preventing infection. Moreover, timely debridement of open fractures may be inapplicable in many mass disasters. In cases of earthquakes, for example, injured people may be found and rescued days after the disaster. Moreover, due to the massive confluence of traumatized patients, life-threatening situations have priority leading to unavoidable delays.

20.3.6 Fracture Stabilization

Stabilization of open fractures prevents damage to surrounding soft tissues and adjacent neurovascular structures, diminishes pain, promotes bone and soft tissue healing, and helps prevent infection.

In mass casualty situations, damage control orthopedics is the treatment of choice and external fixation is the optimal method of stabilization of long bone open fractures [4, 7, 8]. External fixation offers the advantages of decreased operative time and decreased blood loss compared to other methods of fixation. External fixation provides adequate stabilization to facilitate nursing, wound care, and physical therapy [4, 7, 29]. The external fixator can be left in place as definitive treatment or can easily be converted to internal fixation in staged fashion and in the absence of signs of infection [4, 7].

Often in the setting of a mass disaster, intraoperative fluoroscopy may not be available. Although this may complicate optimal pin placement, it makes external fixation preferable to intramedullary nailing. It should be remembered that in mass disasters, the goal is not optimal fracture reduction. Instead, the treating surgeon should aim for gross restoration of length, alignment and rotation, as assessed by inspection and palpation of the extremity, and fracture stabilization [7]. Readjustment of an external frame is possible and can usually be easily performed once radiography is available. Pin track infections complicate the use of external fixators but are considered a minor complication and can be minimized by pin tract care with iodine-soaked dressing [7].

In the absence of appropriate equipment, facilities, or personnel, other fracture stabilization techniques can be used, such as application of a plaster cast with a window over the wound or use of traction [7, 30].

In the presence of adequate resources, definitive internal fixation of open fractures can be performed. Intramedullary nailing is a commonly used technique for diaphyseal fractures of the femur and tibia and plate fixation for periarticular fractures and diaphyseal fractures of the humerus and forearm [11].

Open fractures complicated by a vascular injury requiring repair present a challenge and time delays should be minimized. Available options include rapid fracture fixation followed by arterial repair, arterial repair followed by fracture fixation, and use of an arterial intraluminal shunt to reestablish perfusion [11].

20.3.7 Wound Management and Soft Tissue Coverage

There are several options for wound management (following debridement), including primary closure, delayed primary closure, healing by secondary intention, and soft tissue reconstruction with local or free flaps. Prior to definitive soft tissue management, the wound may be managed with the antibiotic bead pouch technique or with negative pressure dressings.

Primary wound closure following a thorough debridement has not resulted in increased infection rates and may reduce secondary contamination, surgical morbidity, hospital stay, and cost [31]. However, in mass disasters, the severe contamination of the wounds, the delayed presentation of rescued patients, and the limited resources may preclude timely and radical debridement, and primary closure carries the risk for the catastrophic complication of clostridial myonecrosis.

The open fracture wound should be left open to allow healing by delayed primary closure or by secondary intention. Small wounds, especially in type I open fractures, may heal by secondary intention and split-thickness skin grafts may be applied on well-vascularized granulation tissue. Delayed wound closure prevents anaerobic conditions in the wound, facilitates drainage, and allows for repeat debridements. In type I and II open fractures, the surgical extension of the wound that was made to allow thorough inspection and debridement of the wound may be closed primarily, leaving the original injury wound open [32]. According to the WHO, the wound should be packed lightly with a damp saline gauze and covered with a dry dressing that should be changed at least daily [20]. However, frequent dressing changes in the ward may lead to secondary contamination, which may be avoided if the wound remains sealed with a dressing, such as in the antibiotic bead pouch or negative pressure technique.

In the antibiotic bead pouch technique, which is most often used for type III open fractures, antibiotic-impregnated polymethylmethacrylate beads are inserted into the open fracture wound, which is then sealed with a semipermeable barrier [11, 33]. The antibiotic selected should be heat stable, water soluble, and available in powder form, such as tobramycin or gentamicin. The bead pouch technique results in a high local concentration of antibiotics, as well as a low systemic concentration that may prevent the adverse effects of aminoglycoside administration. Moreover, the semipermeable barrier seals the wound from the external environment and prevents secondary contamination, while maintaining an aerobic wound environment.

Negative pressure wound therapy can also be useful if available [29, 34]. Negative pressure wound therapy results in edema reduction and increased blood flow, reduces the size of the wound, and stimulates granulation tissue formation in the wound. Sealing the wound may also prevent secondary contamination.

In type IIIB open fractures, the severity of the soft tissue damage leads to bone exposure and necessitates soft tissue reconstruction [7, 11, 29]. Soft tissue coverage is important because it prevents secondary contamination as well as further damage to bone, cartilage, tendons, and nerves. Restoration of a well-vascularized soft tissue envelope enhances fracture healing and helps prevent infection by improving delivery of antibiotics and host defense mechanisms at the site of the open fracture. Soft tissue reconstruction may be accomplished by local or free muscle flaps. Local pedicle muscle flaps include the gastrocnemius and the soleus for fractures of the proximal and middle third of the tibia, respectively. Free muscle flaps are necessary for distal third fractures or for more proximal fractures if local muscles are traumatized.

20.3.8 Amputation

Amputation is a useful alternative to limb salvage in cases of traumatic amputations, nonviable limbs associated with type IIIC open fractures, or mangled but perfused extremities with severe soft tissue and bone injuries. Each case requires very careful evaluation, since limb salvage with replantation, revascularization, or complex reconstruction procedures may not restore function of the extremity and will submit the patient to multiple procedures and a lengthy treatment plan.

A number of scoring systems have been developed to aid in the decision for amputation versus salvage in severely traumatized extremities, such as the Mangled Extremity Severity Score

(MESS); the predictive salvage index (PSI); the limb salvage index (LSI); the nerve injury, ischemia, soft tissue injury, skeletal injury, shock, and age of patient (NISSSA) score; and the Hannover fracture scale-97 (HFS-97). However, the lower extremity injury severity scores (LEAP) study, a prospective longitudinal study of 556 patients with a severely injured lower limb, could not validate the clinical utility of any of the aforementioned scores. The authors concluded that these scores were useful in predicting limb salvage potential, but the opposite was not true and they could not accurately predict need for amputation [35].

The LEAP study also showed that, among civilians, functional outcomes for amputation and limb salvage following lower extremity trauma were similar at 2 years [36]. The Military Extremity Trauma Amputation/Limb Salvage (METALS) study found that amputation resulted in better outcomes than limb salvage in military patients [37]. However, one should keep in mind that the characteristics of the patients in a mass disaster situation, as well as the conditions under which care is provided to these patients, differ from both the LEAP and METALS study.

While limb salvage versus amputation remains an unresolved topic and decision-making is unavoidably clouded by subjective bias, it should be kept in mind that amputation may help stabilize a multiply injured and unstable patient, prevent infection, and expedite care of the patient. This is particularly important in a mass disaster emergency situation, in which the number of patients is large, the risk of infection is high, and available resources are limited. On the other hand, in countries with limited resources and an inadequate amputee rehabilitation system, the functional outcome of amputation would probably be inferior compared to countries with superior resources [7].

The level of amputation should be determined by the quality of tissue and by the requirements for prosthetic fitting. Guillotine amputation can be used as a first-line procedure as a quick means of removing diseased or damaged tissue in emergency cases [22].

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21 Primary Skeletal Stabilization and Role of External Fixations

Alexander Lerner, Nikolaj Wolfson, William Henry Boyce, and Arshak E. Mirzoyan

21.1 Introduction

Injuries related to natural disasters and wars are typically high-energy trauma or crush injuries. The majority of these are injuries to the musculoskeletal system [1, 2] and more specifically the extremities. Adequate limb stabilization is of major importance. It protects the injured from devastating complications, such as hemorrhage and fat embolisms [3]. High-energy fractures are often open fractures and secondary injuries due to the movement of bone fragments. These processes can lead to an increase in the contamination of bone and soft tissues, resulting in infection, nonunion, and wound healing complications [4]. The rapid and effective stabilization of high-energy trauma wounds can be a life-saving tool in complex trauma patients.

Some simple technical tips can be very useful in performing external fixation in resource-poor environments and in austere conditions, where there are no facilities for fluoroscopy and a scarcity of commercially available external fixators [34, 35].

In this chapter, we will outline the indications, principles, and techniques of external fixation systems used in austere environments. The medical response to mass casualty situations mimics battlefield conditions in many ways; therefore, we have drawn upon the military-designed protocols of Damage Control Orthopedics [7]. Originating in reference to sinking Naval boats, the medical use of the term designates the practice of enacting exigent, life-saving treatments, while deferring more invasive and timely definitive care. Once stabilization and resuscitation have been achieved, definitive procedures are implemented.

The temporized treatment measures of Damage Control Orthopedics (DCO), such as external fixation are used on unstable or borderline patients to secure major orthopedic injuries, halt ongoing musculoskeletal injury, and control hemorrhage and can be applied to battlefield and disaster wounds.

For example, a precise anatomical reduction of the bone fragments at the stage of primary wound

The original version of this chapter was revised. An erratum to this chapter can be found at DOI 10.1007/978-3-662-48950-5_46

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_21

debridement in patients with high-energy injuries may not be the ideal initial goal for gravely injured patients. The surgical procedure for treating severely injured patients must be minimally traumatic and performed as quickly as possible, so as to be the least disruptive of the patient's general condition [14, 30]. The aim of DCO in this case would be to achieve stable fixation by eliminating gross bone fragment displacements and to relieve pressure on the skin and neurovascular structures [7–9].

21.2 External Fixation

External fixation permits immediate fracture stabilization, swift evacuation, mobilization of the patient, and an enabling of adjacent joint movement, contributing to functional rehabilitation [5, 6]. In the treatment of polytraumatized patients and patients suffering from extensive trauma to a single limb, external fixation provides a quick and minimally invasive approach [1, 10–13, 31]. With minimal blood loss, external fixation may be applied to a site distant to the injury (extra-focal), thus circumventing primary wound management. Even if external fracture fixation is planned only as a provisional measure, it is desirable to carry it out as precisely and carefully as possible (in view of the general and local condition of the patient), as this temporary method can be successfully used as preliminary and definitive treatment in some cases [40].

The principle behind the stabilization of fracture fragments by a combination of transfixion of fracture fragments and an externally stable framework is that the frames are distanced from the wound, allowing for unimpeded concomitant care and allows for repeated adjustments as needed [16]. The wounds are easily accessed and local treatments, including future surgical procedures, are easily applied. This versatile method of bone fixation can be employed in almost any fracture configuration, locality, severity, and/or degree of tissue damage.

Internal fixation techniques require the placement of large, exogenous hardware that can destabilize an already fragile system and may require further incisions and dissection, resulting in unnecessary additional soft tissue trauma. Utilizing external fixation accomplishes fracture stabilization and is achieved without further compromise to the already damaged soft tissue envelope [5, 18].

21.3 Advantages of External Fixation

- Extra-focal fixation technique avoids additional traumatization and devascularization of the fracture zone and bone ends (retention of the fracture hematoma without disturbing local soft tissue).
- Relatively easy, rapid, and sufficiently stable fracture fixation uses few parts with average time of the frame application – 20–30'.
- Adequate skeletal fixation for any fracture configuration.
- Low morbidity, minimally invasive, while improving pain control.
- Permits temporary trans-articular bridging in intra- and juxta-articular injuries.
- Facilitates safe medical evacuation.

21.4 Disadvantages of External Fixation

- Patient discomfort and daily pin-tract care during long-term time of external fixation.
- Risk of local pin-tract infection.
- Occasional interference with soft tissue reconstruction
- Muscle transfixion can result in neighboring joint stiffness.
- Need for prolonged ongoing follow-up.

21.5 External Fixation Frames

Whatever forms of external fixation equipment are used, they should be practical, easy to learn, stiff, and modular enough to accommodate a wide variety of complex fracture patterns and clinical situations. A small number of parts of the set allow a wide variety of fixation frame assemblies (Fig. 21.1).

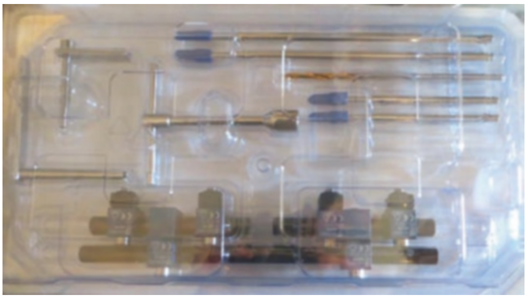

Fig. 21.1 External fixator tubular set

The stability of the frame and the reduced fracture are of primary importance. The frame should be stiff enough to maintain alignment under adverse loading conditions, while maintaining a modular and broadly applicable treatment for a wide variety of injuries.

21.5.1 Unilateral Tubular External Fixation

Unilateral tubular external fixation (Fig. 21.2) is a rapid, efficient, and simple method of primary fracture stabilization, facilitating vascular repair, easy wound access, monitoring of compartment pressure, maintaining distance between bone fragments, and preventing contracture of the muscles, while allowing mobilization of the limbs and evacuation, all of which are needed in the mass casualty and acute trauma setting [8, 17, 21–27]. The ease of mounting the unilateral tubular external fixator in most fracture patterns is also a great advantage. Thus, unilateral tubular external fixation frames for primary fracture stabilization applied away from the zone of tissue damage is the preferred tool in severe trauma to the limbs [10, 11, 28, 29, 39, 40].

The unilateral application of the fixation device and the one-sided technique for insertion of half-pins to the bone can minimize the risk of iatrogenic soft tissue damage, possible injury to the main vessels and nerves, and undesirable "transfixation" of the musculotendinous units. The assembled unilateral fixation device allows physicians to perform the initial debridement and the future secondary procedures on soft tissues without having to remove the fixation frame. As well, the unilateral fixation frame is more comfortable for the patient's personal hygiene and daily activities during prolonged periods of external fixation, especially when treating patients suffering from proximal femoral and proximal humeral fractures (Fig. 21.3).

Fig. 21.2 Unilateral external fixator

21.5.2 Trans-articular Bridging Frame

Temporary trans-articular bridging of the injured limb is indicated in the treatment of patients suffering from complex periarticular and intra-articular fractures, extensive osteoligamentous injuries and severe intra-articular penetrating injuries, in the presence of damage to the capsule and the ligamentary complex of joints adjoining the fracture site [5, 15, 20, 28, 36] (Fig. 21.4).

Fig. 21.3 External fixator for humerus crush injury fracture

Fig. 21.5 Modified delta frame

Fig. 21.4 Trans-articular frame

Temporary trans-articular bridging serves as an effective tool for increasing the stability of fixation in patients with fractures with a very short para-articular bone fragment. Technically, such trans-articular fixation can be achieved by inserting two or three additional half-pins into the bony diaphysis from the opposite side of the fixed joint. The external ends of these groups of half-pins are fixed to each other and then to the primary external fixation device, thereby augmenting the stability of the fracture fixation itself. Two longitudinal tubes are enough for this trans-articular crossing. Such a construction, although appearing outwardly to be substantial, has relatively little weight and allows for early patient mobilization. *Deltoid frame* is one of the examples of trans-articular bridging (Fig. 21.5).

21.5.3 Circular, Ilizarov-Type Frame

The high-efficiency of Ilizarov technique in cases of mass admission of severe trauma patients is reported in a monograph by Arshak Mirzoyan and Vladimir Shevtsov [19]. The monograph summarizes the treatment outcome of 67 victims from the 1988 earthquake in Armenia, with fractures on 92 segments. Forty-one of them had the most severe injury: comminuted open and close fractures combined with crush syndrome. In the majority of cases, urgent osteosynthesis by Ilizarov technique was performed as an important part of general antishock therapy. Primary-postponed osteosynthesis was performed in cases of extremely severe local trauma. Urgent osteosynthesis on the first hours/days of admission increased patient mobility and functional activity, provided for a combination of fracture treatment and all the necessary procedures to improve the patient's general condition, such as dialysis, hyperbaric oxygenation, having a beneficial impact on their psychoemotional condition. The insignificant percentage of secondary amputation, particularly in cases when comminuted fractures combined with the crush syndrome, allows to affirm that (a) the Ilizarov device allows to fix fragments by thin wires, which minimize additional trauma, and (b) the stitching of muscles in the event of crush syndrome may lessen interfacial pressure and reduce the necessity of subcutaneous or percutaneous fasciotomy (Fig. 21.6).

The Advantages of the *Ilizarov* Device

1. Interchangeability and universality of its parts/modules allow, if necessary, to move on from the objective of fixation onto dynamic control of fragments.
2. Possibility to adjust frame assembly according to circumstances and varying orthopedic goals.
3. Possibility to fix fragments of almost any localization and size.
4. Possibility to tend to soft tissue lesions, perform additional surgery if needed.
5. Possibility of dynamic regulation of rigidity (bone training).

Disadvantages

1. Assembly time in emergencies
2. Awkwardness, relative bulkiness of the frame and patient's sense of discomfort, particularly in femur and shoulder osteosynthesis
3. Requires special training and may appear to some as very complex in the way of application

21.5.4 Hybrid External Fixation

This types of frames are the simultaneous use of different external fixation systems, such as the tubular together with the circular (Ilizarov) that forms a hybrid modular fixation system. Hybrid constructions can be achieved with a relatively small number of components, providing options for the optimal fixation of complex, severe high-energy injuries.

Hybrid external fixation combines the desirable properties of different kinds of external fixators. It combines the advantages of both unilateral cantilever and ring/wire external fixation systems and is a good solution to metaphyseal and intra-articular fractures with severe soft tissue damage. This modular non-constrained apparatus provides the orthopedic surgeon with more options to solve complex problems common in patients suffering from disaster-induced injuries.

Great care must be taken to secure the proper rotational alignment of the bone fragments before tightening the clamps. Accurate positioning of the bone fragments in the primary fixation frame is important, taking into account that conversion to the final definitive skeletal fixation may be delayed or even impossible in some patients [37].

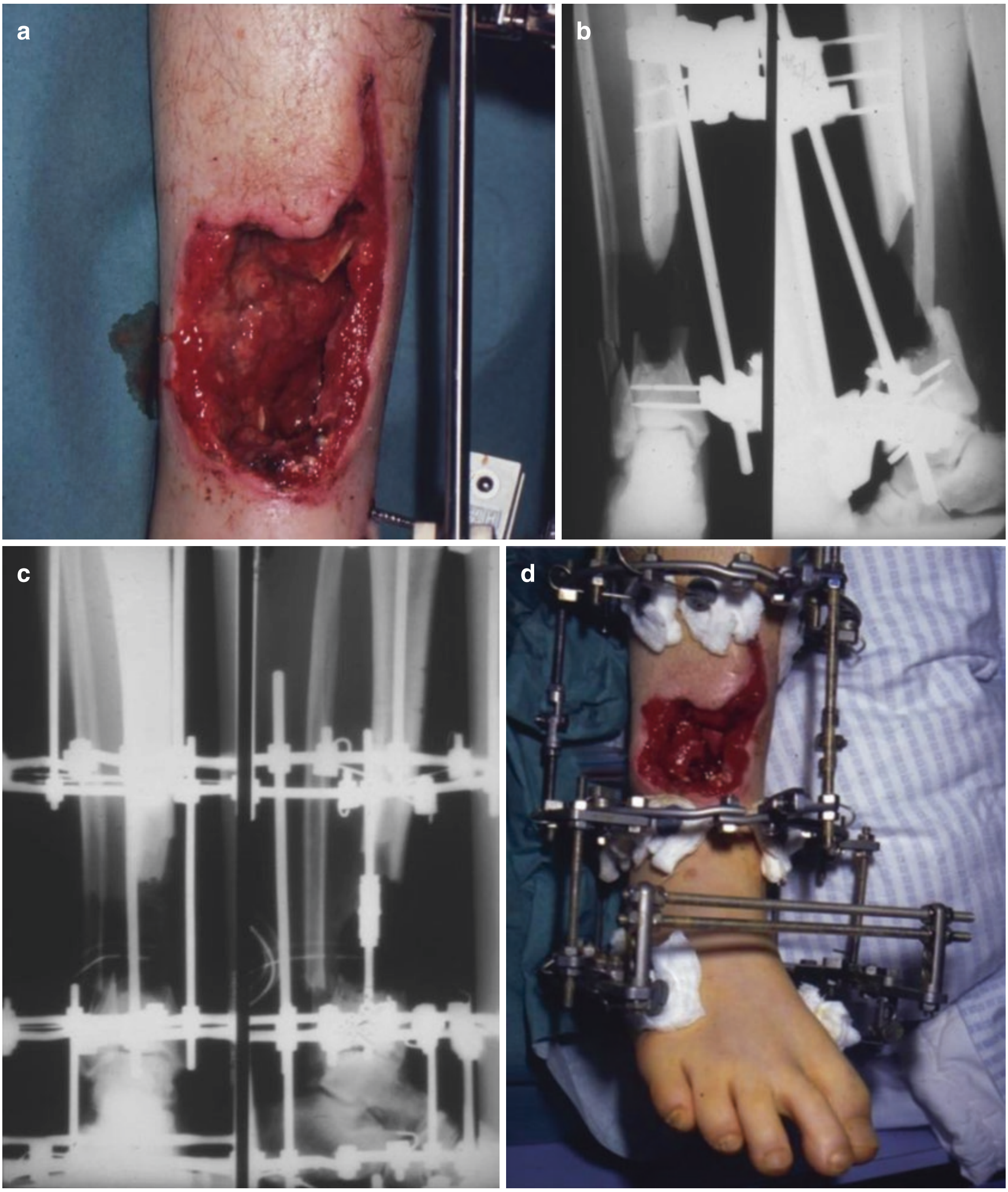

Fig. 21.6 (**a, b**) Soft tissue and bone defect of lower third of tibia. Treated with debridement and unilateral external frame. (**c**, **d**) Because of insufficient fixation and inability to manage fragments, the ultimate goal of treatment was unlikely to be achieved. The unilateral frame was removed. An *Ilizarov* device was applied; an irrigation system with active wound vacuuming was set. (**e**, **f**) Through the device, gradual recurvatum deformity was carried out in order to approximate soft tissues of anterior group of tibia. (**g**, **h)** Suturing of tibialis anterior and osteotomy of proximal tibia for bone transport to eliminate the defect. (**i–l**) Concurrent with bone transport, axis of extremity gradually restored. A need arose for additional surgery on the docking side; union was achieved by closed compression. Leg's weight-bearing capacity was completely restored, as well as active dorsiflexion of the foot

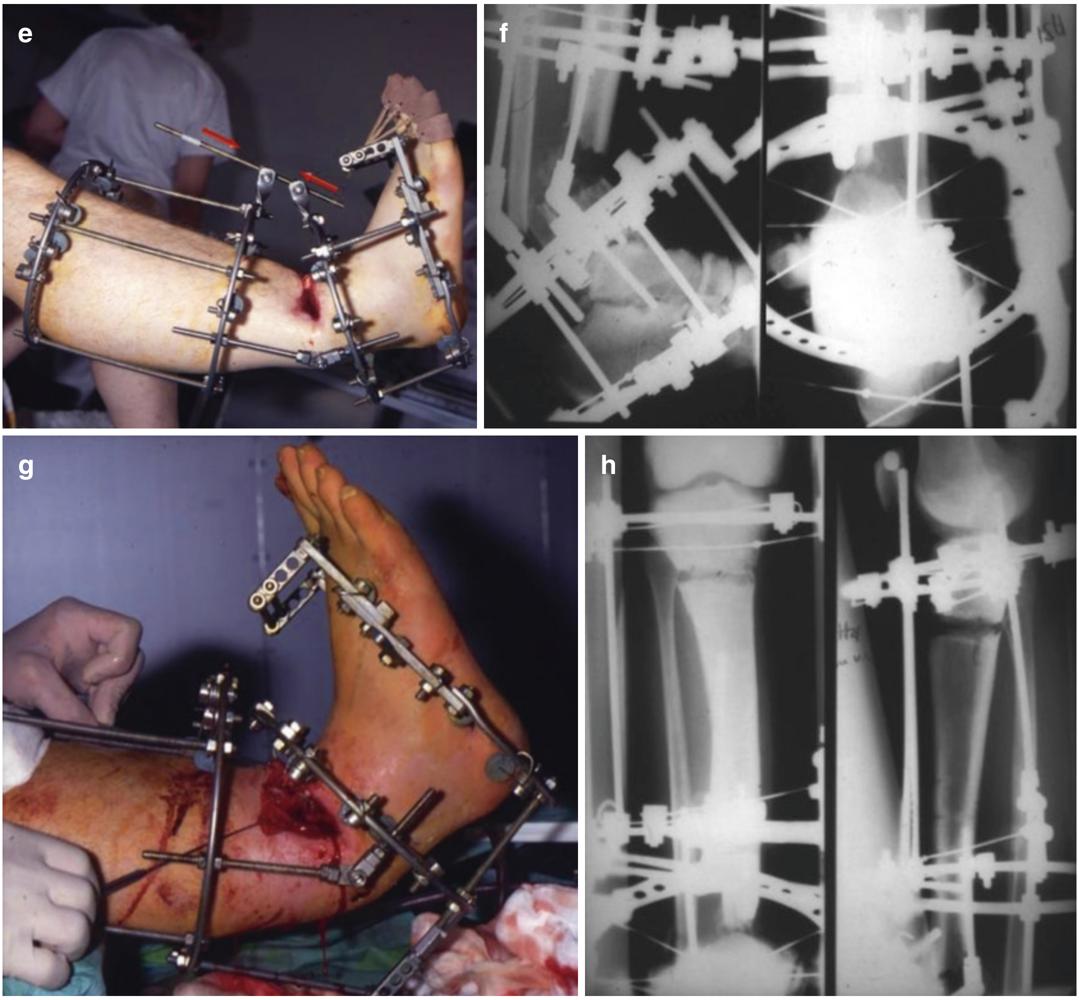

Fig. 21.6 (continued)

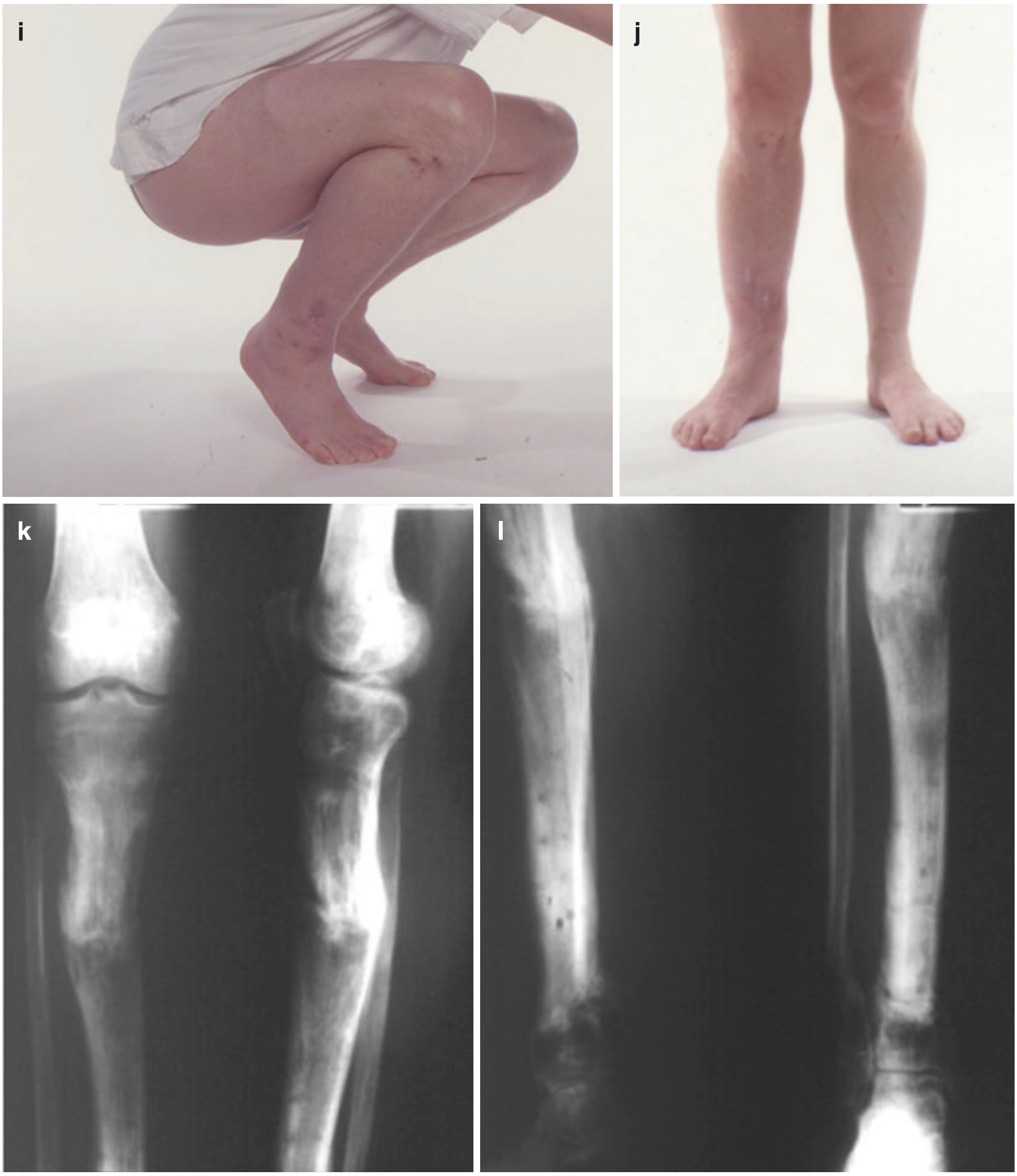

Fig. 21.6 (continued)

21.6 External Fixation Technique and Hardware

Reducing the distance between the bone and the longitudinal tube increases the stiffness of the frame. The shorter the length of the half-pins (the distance from the skin to the longitudinal tube), the more rigid the external fixation will be. For fractures with large areas of segmental comminuting or bone loss, a stiffer double-tube or even a triple-tube unilateral frame may be used. Such a frame is preferred for the fixation of femoral factures in massive or obese patients, each of the two main fragments being provided with three 6.0 mm Schanz screws. Each of these proximal and distal blocks is then connected using a universal joint or tube-to-tube clamp to two intermediate connecting tubes. Manual alignment and reduction is stabilized by tightening tube-tube clamps onto the connecting tubes.

Application of radiolucent carbon fiber rods to external fixation frames improves imaging control of fracture reposition and fixation and the radiological follow-up of the consolidation process. This is very useful in treating patients with complex intra-articular and periarticular fractures.

The stability of external fixators is determined by the diameter of the inserted screws, the configuration of the external frame, and the materials used in its components [32]. A pair of 5.0–6.0 mm threaded half-pins is introduced into each of the main bone fragments (proximal and distal). The bending stiffness of the 6 mm screw is almost twice that of the 5 mm screw [25]. Using 5 mm screws will raise the stability of their fixing in the bone by shortening their threaded part to such a degree that the more massive non-threaded part of the screw will settle in the nearest cortex. Performing this simple technique follows the rule where “the cross-sectional area of the screw in the proximal cortex should be as large as possible”, distributing the load over a larger area in the bone [25].

If necessary, and in patients with complex clinical conditions where other appropriate sites for the insertion are absent, emergency temporary fracture stabilization can be performed by introducing the Schanz screw, even to the uncovered bone. For maximal mechanical stability of the external bone fixation, the Schanz screws must be inserted across both cortices, with the point of the pin protruding from the opposite cortex.

In difficult and technically demanding situations of complex trauma, half-pins may be inserted into the bone under direct visual control. Each patient, especially after high-energy trauma with severe soft tissue damage, needs an individual approach in choosing the right placement and quantity of half-pins.

The site of the insertion of half-pins into the bone fragments close to the fracture zone is 3–4 cm from the ends of the main bone fragments. The most proximal and distal half-pins are introduced into the bone near the metaphyseal zone. The wider the base of the external fixation frame, the more stable it is, the less the danger of local pin-tract infection and pin loosening. To minimize post-fixation restriction of motion in adjacent joints, the half-pins must be inserted into the bone in functionally neutral zones and in places with the least soft tissue thickness, avoiding undesirable transfixation of the musculotendinous units.

Increasing the diameter of the half-pins and also their number in each of the fragments of fixed bone greatly helps to achieve stability of the fracture’s fixation. The introduction of three or more half-pins into the proximal and distal main fragments can benefit the treatment of a variety of complex scenarios, such as treating large and obese patients with an oblique configuration of fractures or severe comminution of bone fragments and the stabilization of femoral shaft fractures. The use of hydroxyapatite-coated tapered half-pins in external fixation frames has been associated with both a lower prevalence of pin-track infection and improved pullout strength [33].

Conclusion

Emergency response orthopedics must consider the unique conditions of a disaster: the paucity of supportive infrastructure, the patient’s immediate and non-acute needs treatment and rehabilitation, the available limited resources that are simultaneously under high demand, the availability and stability of transport methods, and the environmental conditions, and the accessibility of MEDEVAC. DCO promotes the use of expedient external fixation in the acute management of bone fractures in the complex or severely injured patient and has been proven successful in wartime and disaster situations [1–3]. The postponement of definitive surgical care procedures by employing external fixation for physiologically unstable patients is exercised in order to secure more severe orthopedic wounds, arrest continuing soft tissue injury, control internal bleeding, and allow the treatment of more patients in a mass casualty situation.

External fixation is an expeditious manner of delivering comparative bone stability in multi-fractured patients during mass casualty events. The modularity of modern external fixation sets allows for fixator assemblies suitable for each patient's specific situation. These combinations can be achieved with a modest quantity of construction elements, avoiding large, crude fixation constructions containing unnecessary components. These systems are relatively light and comfortable for patients. Moreover, they are more convenient in clinical practice. The least number of construction elements reduces the cost of treatment and shortens surgical time. The use of modular and custom-assembled hybrid frames results in better patient compliance and a wider range of motion than is obtained with standard classic all-wire constructs. External fixation and DCO processes allow responders to stabilize more victims in a shorter period of time, while maintaining therapeutic integrity for subsequent definitive care.

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22 Crush Injury and Crush Syndrome in an Earthquake Disaster Zone

N. Daniel Reis and Ori S. Better

22.1 Understanding Crush Injury and Crush Syndrome

The typical crush injury of a limb is the closed crush suffered by casualties crushed under masonry (earthquake victims) and vehicles or victims lying unconscious without movement for many hours (mechanical muscle-crush injury – MMCI). An extensive muscle-crush injury culminating in a crush syndrome is often lethal unless treated aggressively and promptly [1]. Prolonged crushing of the torso leads to death so that the injuries which present for treatment almost exclusively involve the limbs.

The systemic causes of morbidity and death in MMCI are hypovolemia (dehydration), hyperkalemia, hypocalcemia, metabolic acidosis, and acute myoglobinuric renal failure. This series of events begins with dehydration and is followed by the dangers of the reperfusion of the crushed tissues of the limb.

The local causes of morbidity and mortality are the acute muscle-crush compartment syndrome complicated by overwhelming sepsis, often after fasciotomy, and gas gangrene in neglected open crush wounds. A high-energy crush injury to a limb pulverizes, tears, and disrupts the soft tissues, concealing an occult dead muscle tissue mass.

22.2 Pathophysiology

External mechanical pressure destroys the volume regulation of myocytes, whose cytoplasm is negatively charged and is hyperosmotic compared with the extracellular fluid. By disrupting the impermeability of the sarcolemma, extracellular cations and fluid flow down the electrochemical gradient into sarcoplasm, overwhelming the capacity of the cationic extrusion pumps [2–6] and leading to swelling of the myocytes. Consequently, MMCI causes such gross edema that it may incarcerate much of the extracellular fluid and cause hypovolemic shock within hours of injury [1]. The local manifestation is acute muscle-crush compartment syndrome which develops rapidly in and around the crushed muscle as a reperfusion syndrome and which appears immediately after the extrication of a trapped victim and the consequent removal of the crushing force. An ominous chain of events then unfolds as the crushed vasculature allows the rapid seepage of fluid and plasma proteins into the dead muscle that is sheathed within its inelastic fascial compartment. A hyperperfusion rebound phenomenon in the dead muscle may also be involved [7]. We have always observed that crushed, dead

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_22

muscle bleeds profusely [8]. When victims are rescued, they may be dehydrated as the rapid loss of fluid into the compartment may tip the balance into profound, hypovolemic shock. In addition, intracellular potassium ions released through the incompetent sarcolemma of the dead muscle cells surge into the general circulation at this reperfusion stage and set the stage for sudden hyperkalemic cardiac arrest. This can occur very rapidly, as soon as 2 h after extrication [1]. Also, at this stage nephrotoxic myoglobin released from the disrupted muscle cells floods the circulation, creating the danger of acute renal failure.

22.3 Diagnosis [9]

The diagnosis is usually obvious if the history is known and the limb is inspected. MMCI is not usually painful immediately after extrication, and the limb is often numb with a peripheral pulse that is almost universally present if the patient is not in shock. Direct arterial injury is very rare in closed MMCI. Swelling appears rapidly, causing an acute compartment syndrome, and the limb can become turgid and brawny within hours without obstruction to the distal circulation. The crushed skin is bruised and discolored but remains intact. Pain develops gradually and may become excruciating. Intracompartmental pressure can be measured by intramuscular manometry as described by Whitesides et al. [10] and Hargens and Mubarak [11] (not usually possible or practical in a disaster zone). Although the clinical picture is clear-cut, we know of cases which have been diagnosed as thrombophlebitis or paraplegia [8]. Such patients were unable to give a history of being crushed, having been admitted in a confusional state.

22.3.1 Management

22.3.1.1 General

A nephrologist is not always immediately available when disaster strikes. Hence, the orthopedic surgeon should have knowledge of the fluid requirements which are indicated in the early, emergency situation. In order to counter both the life-threatening hyperkalemia and hypocalcemia and to prevent myoglobinemia from causing acute renal failure, massive fluid transfusion and alkalinization of the urine must be instituted as early as possible. Massive infusion is commenced as soon as intravenous access has been obtained, preferably while the victim is still trapped [12]. The sooner fluid replacement is established, the better the chance of avoiding renal failure [12]. Intraosseous transfusion (if available) must also be considered, should the intravenous route be inaccessible, particularly prior to extrication.

Recommended sequence of volume replacement during and after extrication of an otherwise healthy, adult crush victim (Adapted from Ron et al. [13]):

1. While the victim is being extricated, immediately start intravenous (or intraosseous) saline at a rate of 1 L/h (the extrication stage may last many hours). Monitor arterial pressure, central venous pressure, and urinary output as soon as possible.
2. After extrication, continue intravenous infusion with 500 mL normal saline alternating with 500 mL 5 % glucose at a rate of 1 L/h.
3. Add 50 mEq/L of sodium bicarbonate to each second or third bottle of glucose in order to maintain the urinary pH > 6.5.
4. Once the urine flow is established, add 20 % mannitol solution at a rate of 1–2 g/kg estimated body weight over about 4 h. Never exceed 200 g/day and never administer mannitol in the presence of established anuria.
5. Optimal urine flow is 8 L/day. This will require an infusion of 12 L/day. This positive balance is largely explained by the limb edema in the crush region and is permissible when the kidneys are at risk.
6. If bicarbonate has produced a metabolic alkalosis (arterial pH of 7.45), acetazolamide is given intravenously as a 500 mg bolus.
7. This regimen is continued until myoglobin has disappeared from the urine, usually by the third day.

22.3.1.2 Local

Open MMCI

When the skin is torn, laying open the MMCI, the treatment is the same as for any severe, open wound: radical debridement, repeated as often as necessary (performed under general anesthesia whenever possible); the opening of fascia and extension of the wound in order to remove all dead tissues and achieve adequate drainage is frequently necessary. Prophylactic intravenous antibiotics are commenced immediately (see Chap. 23). The surgeon must be constantly aware of the signs of sepsis (fever, mental obfuscation, tachycardia, plunging hemoglobin, hemolytic jaundice, and tachypnea), signaling stealthy clostridial infection arising in the wound. Hence, the wound is inspected regularly for swelling, subcutaneous crepitus, and malodorous "rotten apple" stench. Repeated bacterial swabs for direct microscopy and culture is taken at this time. Hyperbaric oxygen, if available, is specifically indicated in gas gangrene, as an adjuvant to radical excision of dead muscle, antibiotics, transfusion, and general intensive care support. If the sepsis fails to respond to aggressive treatment, amputation proximal enough to be performed through healthy muscle is indicated as a lifesaving measure. The only way to be certain that muscle is healthy is by its response to electrical stimulation. The appearance alone may be dangerously misleading.

Closed MMCI: Acute Mechanical Muscle-Crush Compartment Syndrome

The classical management of an acute compartment syndrome has recently been reviewed [11]; an immediate fasciotomy is performed in order to achieve decompression, thereby improving both local and distal blood supply. The purpose of the fasciotomy is to prevent ischemic muscle death. This classical treatment is not relevant to a closed MMCI, because in MMCI at least part of the muscle in the compartment is already dead. By converting the closed crushed limb segment into an open wound, profuse bleeding may occur, aggravating coagulopathy and complicating dialysis for myoglobinuric acute renal failure. Also, life- or limb-threatening sepsis now becomes a risk [8, 14]. Dead, crushed muscle bleeds abundantly, is deceptively normal in appearance, and can only be differentiated from healthy muscle by its lack of contractility on electrical stimulation [8]. Excision of necrotic muscle is inevitably incomplete and must be repeated, often several times, under general anesthesia. Acute mechanical muscle-crush compartment syndrome differs from other forms of compartment syndrome, in which at-risk muscle can be saved by fasciotomy because, in acute muscle-crush compartment syndrome, the muscle is already dead. Worldwide experience has shown that the theoretical benefits of a fasciotomy in these circumstances are far outweighed by its hazards [8, 15, 16]. Three hundred and seventy-nine fasciotomies performed during the Turkish Marmara earthquake showed that the rate of fasciotomy was related to sepsis and sepsis to mortality [15]. (The authors concluded that fasciotomy was usually contraindicated.) Unfortunately, the lesson was not learned. Following a further, catastrophic earthquake at Bingol, Turkey, in 2003, routine fasciotomies were performed in almost 70 % of the patients with acute muscle-crush compartment syndrome, 81 % of whom subsequently developed wound sepsis [17]. Tetsuya et al. [16] reviewed the results of the treatment of crushing injuries in the 1995 Hanshin-Awaji earthquake and concluded that there was no evidence that fasciotomy improved the late outcome. Huang et al. [18], describing patients who were injured in the earthquake at Chi-Chi in China, and Nadjafi et al. [19] those injured in Iran in 1977 came to similar conclusions. Reis et al. compared two similar groups of crush injuries. One had undergone a routine fasciotomy with a high rate of sepsis and amputation, while the other had been treated conservatively with no sepsis and no amputations [8]. In the past 35 years, they have treated 31 cases of acute muscle-crush compartment syndrome. Since adopting a conservative protocol in 1982, no closed crush injury developed life-threatening sepsis and no urgent amputations have been required. A patient with a poor functional result following acute compartment syndrome in a crushed limb will require subsequent reconstructive procedures such as tendon lengthening, osteotomy, arthrodesis, or even a late definitive amputation, in order to improve function. In view of the accumulated evidence, it can now be categorically stated that fasciotomy is contraindicated in patients with closed acute mechanical muscle-crush compartment syndrome. It does not improve the outcome for the limb, nor for the kidneys. Fasciotomy under these circumstances endangers life and limb. The only indication for fasciotomy is when the distal pulse is absent and when both direct local major arterial injury and systemic hypotension have been excluded. Pressure can be reduced without invading the compartment and risking infection, by the use of the intravenous hypertonic mannitol [20, 21], although this is strictly contraindicated in the presence of renal failure. Mannitol has important favorable systemic effects, particularly in hypotensive, hypovolemic casualties. Intravenous hypertonic mannitol expands the depleted extracellular volume and enhances cardiac contractility, as shown in our laboratory. Furthermore, mannitol actively redistributes fluids from edematous tissues and muscles and is thus able to reproducibly decompress clinical compartment syndrome in man as well as in experimental canine models [12, 22]. To be on the safe side, mannitol is contraindicated in patients with anuria or in those whose blood creatinine is higher than 3 mg% [12, 22].

A further form of conservative treatment is hyperbaric oxygenation (HBO). This specifically reduces edema and floods the tissues with oxygen dissolved in the extracellular fluid. This oxygen is available to the compromised cells without the energy expenditure otherwise required for its transfer from hemoglobin [23]. In a series of patients with compartment syndrome who were treated with HBO, Strauss and Hart [24] noted that none progressed and none required a fasciotomy. Our experience with hyperbaric oxygenation has been similar, but, in common with Strauss and Hart [25], we have no specific experience with HBO in the treatment of acute muscle-crush compartment syndrome. However, the rationale for using hyperbaric oxygenation is overwhelmingly persuasive [13]. Based on the clinical evidence and cost analysis, medical institutions that treat open fractures and crush injuries are justified in incorporating HBO as a standard of care. Both Medicare and Undersea and Hyperbaric Medical Society guidelines list crush injuries as an approved indication for HBO. Military surgeons should familiarize themselves with this emerging treatment modality because of their role in the early management of these injuries [26–29].

Orthopedic treatment should be primarily conservative. Joints are splinted in a functional position, while active and passive movements are encouraged as soon as pain allows. Finally, ischemic muscle contractures and paralysis caused by the destruction of muscle are corrected by late reconstructive surgery.

22.3.1.3 Special Aspects of Management in an Earthquake Disaster Zone

Following an earthquake, the medical services are overwhelmed. Therefore, the management of crush injuries must use minimal resources but still be effective. As explained the urgent treatment is massive fluid transfusion and analgesia for severe pain. A crush victim need not take up an acute hospital bed: he is satisfactorily managed in any protected environment. Fasciotomy for closed crushes is absolutely contraindicated not only because it is not effective but also because it burdens the overwhelmed system with unnecessary repetitive surgeries. Every medical system must have a pre-planned program for the evacuation of cases with acute renal failure to appropriate dialysis units. Similarly plans to make hyperbaric oxygen treatment available at a regional center are desirable.

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23 Wound Care: From Primary Debridement to Final Reconstruction

Brian M. Parrett and Michael C. Laliberte

Abbreviation

VAC® Vacuum-assisted closure

23.1 Extremity Evaluation

23.1.1 Anatomy

Knowledge of upper and lower extremity anatomy is crucial for the reconstructive surgeon when assessing and managing complex traumatic wounds. Limb salvage reconstruction is dependent on the surgeons' ability to recognize and inventory the level of injury to each of the major tissue types in the extremity: bone, major vessel, nerve, musculotendinous units, and soft tissue [1, 2].

23.1.1.1 Upper Extremity

The forearm is composed of two long bones arranged in parallel, the radius and ulna. The radius and ulna are connected along their length by a fibrous interosseus membrane dividing the forearm into two compartments: the ventromedial or flexor compartment and the dorsolateral or extensor compartment. The hand is composed of eight carpal bones proximally that are divided into the proximal and distal row. The proximal row articulates with the radius and ulna to form the wrist joint. The distal row articulates with the five metacarpals that serve as a base for the phalanges.

The volar forearm is comprised of four superficial, one intermediate, and three deep muscles. The superficial group (pronator teres, flexor carpi radialis, palmaris longus, and flexor carpi ulnaris) arises mostly from a common flexor tendon that attaches to the anterior part of the medial epicondyle of the humerus and from the adjacent fascia. The intermediate muscle (flexor digitorum superficialis) also arises from this common tendon as well as the anterior surface of the ulna and radius. The muscles of the superficial and intermediate groups are supplied by the median nerve. The deep muscle group (flexor pollicis longus, flexor digitorum profundus, and pronator quadratus) are supplied mainly by the anterior interosseous nerve, a branch of the median. The muscles in the superficial and deep groups that are not innervated by the median nerve (the flexor carpi ulnaris and the flexor digitorum profundus to ring and small fingers) are supplied by the ulnar nerve.

The dorsal forearm is comprised of seven superficial (brachioradialis, extensor carpi radialis

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_23

and brevis, extensor digitorum communis, extensor digiti minimi, extensor carpi ulnaris, anconeus) and five deep muscles (supinator, abductor pollicis longus, extensor pollicis brevis, extensor pollicis longus, extensor indicis proprius). The superficial group arises mostly from the posterior aspect of the lateral epicondyle of the humerus by a common tendon. These muscles are supplied by the radial nerve proper or its deep branch which continues as the posterior interosseous nerve.

The radial and ulnar arteries are terminal branches of the brachial artery and supply the muscles of the dorsal and volar forearm. The radial artery begins in the cubital fossa, opposite the neck of the radius, and travels the forearm deep to the brachioradialis. In the distal forearm, the radial artery lies radial to the flexor carpi radialis tendon, which serves as a guide to it. The radial artery leaves the forearm by winding dorsally across the carpus. The ulnar artery begins in the cubital fossa, opposite the neck of the ulna. The common interosseous artery branches here and divides almost immediately into anterior and posterior interosseous arteries, which descend on the anterior and posterior aspect of the interosseous membrane, respectively, and end dorsally on the carpus. The ulnar artery travels the forearm deep to the flexor carpi ulnaris and leaves the forearm by passing anterior to the flexor retinaculum on the radial side of the pisiform bone. After it gives off its deep palmar branch, it continues as the superficial palmar arch.

The intrinsic musculature of the hand is divided into ten compartments. The four dorsal and three palmar interossei, hypothenar muscles, adductor pollicis, and lumbricals of the ring and small fingers are innervated by the ulnar nerve. The thenar musculature and lumbrical of the index and middle are innervated by the median nerve. The ulnar and radial arteries enter the hand and anastomose to form the ulnar dominant superficial palmar arch and radial dominant deep palmar arch which vascularize the fingers.

23.1.1.2 Lower Extremity

The lower leg is composed of two long bones arranged in parallel, the fibula and tibia. The fibula is thin and long and provides insertion to many of the muscles of the leg. The tibia is a long and thick bone responsible for over 80 % of the weight-bearing capacity of the lower leg. The tibia and fibula are connected along their length by a fibrous interosseus membrane. These three structures together divide the leg into an anterior and posterior compartment.

The anterior compartment is further divided into anterior and lateral compartments by an intermuscular fascia. The anterior compartment has four muscles: the extensor digitorum longus, extensor hallucis longus, peroneus tertius, and the tibialis anterior. These muscles are vascularized by anterior tibial vessels and innervated by the deep peroneal nerve. The lateral compartment has two muscles, the peroneus brevis and longus. They are supplied by the peroneal artery and innervated by the superficial peroneal nerve.

The posterior compartment is divided into superficial and deep compartments by a thin intermuscular fascia. The superficial compartment contains the gastrocnemius, soleus, and plantaris muscles. The gastrocnemius and soleus join together to become the Achilles tendon that inserts into the calcaneal bone. They are vascularized by the popliteal artery and innervated by the tibial nerve.

The deep compartment has four muscles: the popliteus, flexor digitorum longus, flexor hallucis longus, and tibialis posterior. The blood supply is provided by two arteries, the posterior tibial and the peroneal. The tibial nerve innervates the compartment.

23.1.2 Wound Inventory

The bedside evaluation of the mangled extremity by the reconstructive surgeon is of critical importance to evaluate the acuity of surgical intervention and to inventory the structural damage that will need to be examined intraoperatively (Fig. 23.1a, b). This examination should be carried out following or concurrently during the advanced trauma life support protocol with the multidisciplinary trauma team on a case-by-case basis. If a threat to life or limb is expected, this inventory should be deferred for the controlled setting of the operative theater; however, the ability to examine function requiring

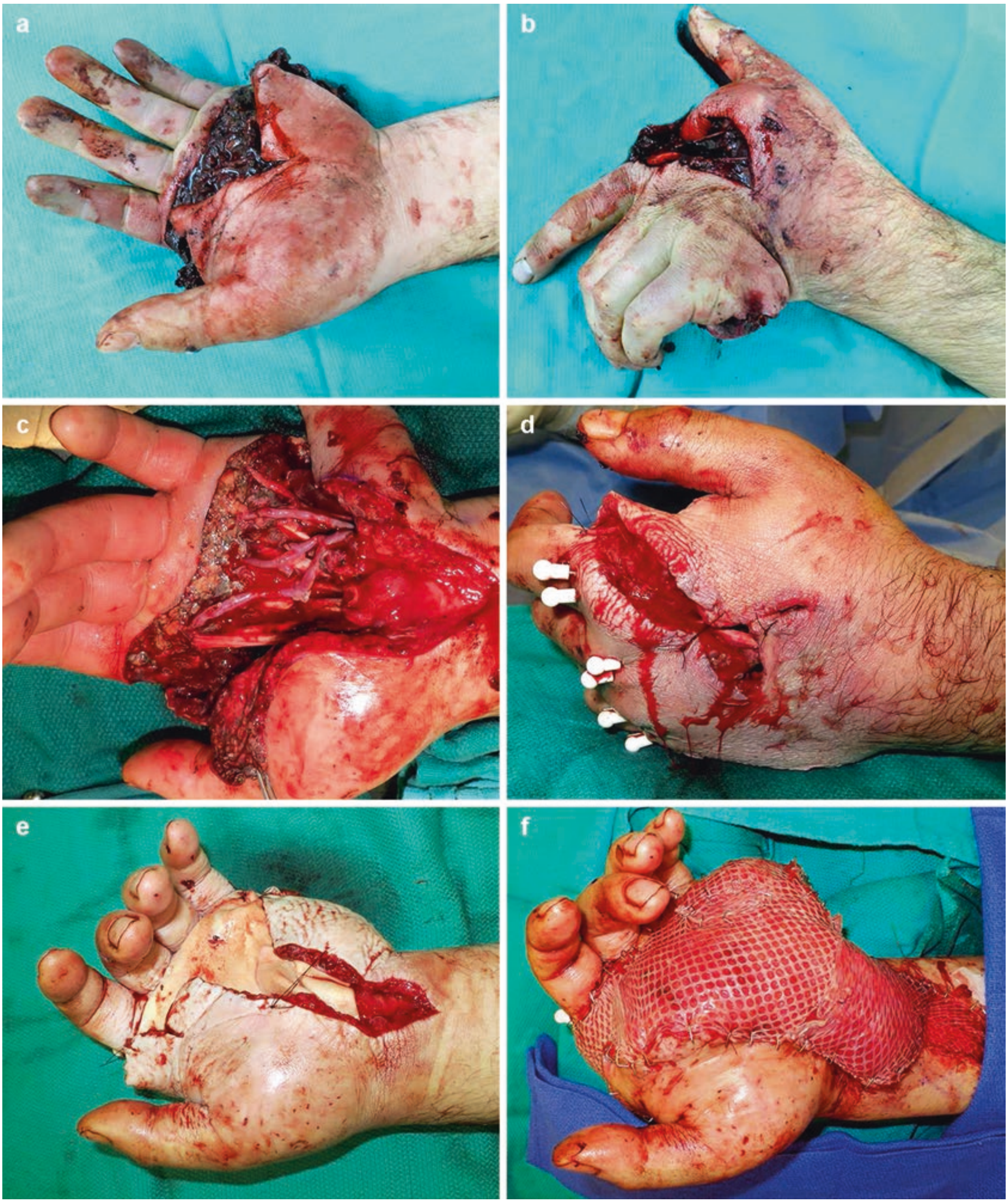

Fig. 23.1 Partial hand amputation. (**a**, **b**) Initial evaluation demonstrating gross soil contamination and ischemia of the index, middle, ring, and small fingers with disruption of the palmar arches. Flexor and extensor tendon injuries and metacarpal fractures to all four fingers also noted. (**c**, **d**) Extensive debridement, bony stabilization, tendon repair, and revascularization with multiple vein grafts to the ulnar artery and wounds loosely approximated. (**e**) Secondary debridement on day 2 demonstrating significant swelling, preventing wound closure with AlloDerm® artificial dermis placed over vein grafts to keep it moist. (**f**) Microvascular free latissimus dorsi muscle transplant for primary reconstruction on day 5

patient cooperation such as distal sensation and active muscle contraction will be lost.

Once the patient is stabilized, the extremity should be exposed, with dressings carefully removed to evaluate any interventions applied in the field and to determine if the limb is salvageable.

> Does the extremity require revascularization and is this technically possible? Is the wound contaminated? Is the soft-tissue defect treatable with local or free tissue transfer? Is any bone loss reconstructible? Is there nerve injury and is this repairable or does the nerve injury preclude a functional limb?

A complete disruption of the tibial nerve of the lower extremity may be a contraindication for extremity salvage, as nerve repair in the lower extremity has poor functional results and a below-knee amputation may be preferable to an insensate foot. This is dependent on multiple factors including patient age, patient motivation, type of nerve injury, and location of injury. Conversely, a complete nerve injury of the upper extremity often does reasonably well, and amputation is reserved as a last resort especially since prosthetics in the upper limb are not as functional as the lower limb.

A careful inspection for tourniquets applied proximally is vital to determine limb perfusion. Ischemia time of greater than 6 h due to tourniquet use or vascular damage will irreversibly damage the larger musculature in the limb, and aggressive debridement should be expected on reperfusion. After tourniquet removal, if applicable, acute hemorrhage should be evaluated for expected level of injury and vessel involved. Ischemia of distal parts should be noted. The majority of bleeding from the distal upper and lower extremity will be controlled by intrinsic vascular spasm and by applying direct pressure; therefore, tourniquet use should be strictly reserved for cases in which direct pressure cannot control bleeding.

Physical examination at this time, with patient cooperation if possible, can determine the extent of injury. Gross sensation in the distributions of the median, radial, and ulnar nerves of the hand and posterior tibial, superficial peroneal, and deep peroneal nerves of the foot should be examined. Pulsation of the radial and ulnar artery at the wrist and posterior tibial artery and dorsalis pedis of the ankle and foot should be palpated. A handheld Doppler ultrasound can be used to listen for flow in these vessels and the digits. If a hand, finger, leg, or foot is thought to have arterial insufficiency, a digital oxygen saturation monitor can be attached to the finger or toes to aid in the diagnosis. Intrinsic and extrinsic muscle function should be individually examined, assessing for structural damage or dermatomal patterns suggestive of complete nerve dysfunction.

23.1.2.1 Contamination

The gross appearance of the wound and history of the trauma will guide the surgeon's determination of the level of contamination (Fig. 23.1a, b). In a soil-contaminated wound, pathogenic fungi or bacteria may enter humans via direct inoculation. Soil minerals introduced simultaneously may promote infection by suppressing local host defenses. Several species of *Clostridium* including *C. perfringens* (gas gangrene), *C. tetani* (tetanus), and *C. botulinum* (botulism) are present in soil and should be empirically covered for by broad-spectrum antibiotics and debridement. Most commonly, soil-related endemic fungi cause primary pulmonary disease; however, grossly contaminated wounds in an immunocompromised host can lead to a significant infection such as *Rhizopus* or *Mucor* [3, 4]. Aquatic contamination should raise concern for the possibility of *Aeromonas* or *Mycobacterium marinum* contamination, and empiric antibiotic coverage should be adjusted accordingly. An infectious disease consult is often appropriate in heavily contaminated or infected wounds to determine antibiotic choice and duration.

23.2 Debridement

23.2.1 Primary Wound Debridement

Initial wound debridement should be performed within 12 h of the injury. *The goal is to remove all foreign bodies and clearly nonviable tissue including the skin, fascia, muscle, and bone.* The major neurovascular structures should be identified first, often with tourniquet control, and then debridement should proceed, protecting these structures. Often the tourniquet is released to assess bleeding from the edges of questionably viable tissue. The wound is irrigated with large volumes of saline irrigation using cystoscopy tubing or the equivalent (Fig. 23.1c).

23.2.1.1 Revascularization

Devascularized limbs require reestablishment of arterial inflow within 6 hours to prevent muscle necrosis. A vascular surgeon or hand/microsurgeon will often first place a vascular shunt to allow arterial blood flow while the orthopedic fixation is performed. After fixation is performed, the artery can be repaired directly, or more frequently, with a vein graft (Fig. 23.1c).

23.2.1.2 Temporary Fixation

Initial bone fixation is applied during the primary debridement, and whether an external fixator or internal hardware is placed is dependent on the wound contamination. Any concern for infection or contamination warrants external fixation (Fig. 23.1d).

23.2.1.3 Wound Coverage and Dressing

Exposed vessels or nerves should be temporarily covered with local tissue. If not possible, non-adherent dressings can be placed over exposed vessels/nerves with moist gauze over these (Fig. 23.1e). Non-adherent dressing should also be placed over exposed periosteum or paratenon. The remaining wounds can either have a VAC device placed or moist gauze and a gauze wrap. The dressings are changed multiple times a day in dirty wounds or less so on clean wounds. A negative pressure wound device is useful in clean wounds as it can be changed every 2–3 days instead of daily. *Areas that can be closed primarily should be done so loosely with minimal, nonabsorbable tacking sutures.* This will allow for expected post-operative swelling to occur without compromising soft tissue vascularity and fragile underlying vascular reconstructions.

23.2.1.4 Antibiotics

Broad-spectrum antibiotics are started initially and then tapered, directed by wound cultures or type of contamination.

23.2.2 Secondary Wound Debridement

Depending on the level of contamination, secondary wound debridement should be performed within 24–48 h. The dressings are removed, neurovascular structures are protected, and further necrotic tissue is excised. It is important to check for any remaining fluid collections and to send cultures of any tissue or fluid that appears infected. *Debridement should be performed until the wound is clean, devoid of necrotic tissue, and does not have an abnormal odor.* Necrotic muscle will often liquefy, become malodorous, and will often become superinfected; therefore, removal of dead muscle is critical. Further debridements are then performed every 24–72 h, depending on wound cleanliness. Debridements are continued until there is no further necrotic tissue, there is no malodor, and the patient is afebrile without any signs or symptoms of infection. At this point, a plan is made for wound reconstruction.

23.3 Reconstruction

23.3.1 The Reconstructive Ladder

Reconstruction of a traumatized extremity can be performed only after vascular injury has been addressed and repaired, bony fixation has been accomplished, and all contaminated and devitalized tissue has been debrided. The basic principle of debridement of all devitalized tissue is crucial to the final success of any reconstruction and often requires serial operative debridements prior to final wound coverage. Reconstruction failures are often due to inadequate wound debridement and subsequent infection. The reconstructive ladder guides our efforts in lower extremity reconstruction and describes levels of increasingly complex management of wounds [5] (Fig. 23.2).

23.3.1.1 Secondary Intention Closure

Closure by secondary intention is the simplest method of reconstruction and focuses on allowing the wound to naturally granulate and contract by the use of good local wound care. This can be performed with simple wet-to-dry gauze dressing changes or any number of advanced wound care dressings. The vacuum-assisted closure (VAC®; KCI, San Antonio, Texas) device has been useful in promoting wound granulation and closure by using subatmospheric negative pressure. This has been shown to cause decreased tissue edema, decreased wound circumference, and increased granulation tissue. The VAC® device is especially useful in patients who are too ill to undergo more complex reconstructions. DeFranzo et al. demonstrated that the VAC sponge successfully stimulated profuse granulation tissue over exposed bone, often allowing open fractures to be closed primarily or with skin grafts, thus avoiding more complex reconstructions [6]. However, in most cases of open fractures, especially Gustilo IIIB/C, the VAC® device is used as a temporary wound dressing prior to definitive reconstruction.

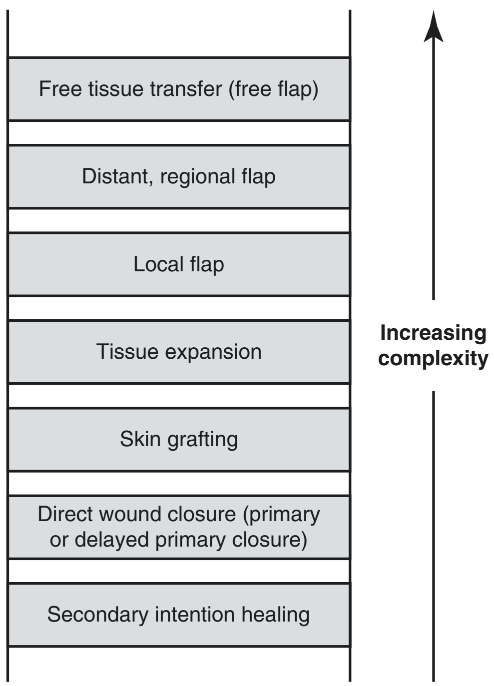

Fig. 23.2 The reconstructive ladder from the simplest closure method at the bottom rung to the most complex closure method at the top rung

23.3.1.2 Direct Closure (Primary or Delayed Primary)

Many wounds can be closed by directly opposing the skin edges as long as there is minimal tension on the wound and the skin edges are non-traumatized and have good blood supply. This can be performed either immediately after the injury or defect creation (primary closure) or some time afterwards (delayed primary closure). Occasionally this requires undermining the edges of the wound deep to the subcutaneous tissue to allow for greater laxity. Often direct closure is not an option in the open, traumatized extremity.

23.3.1.3 Skin Grafts

Full-thickness or split-thickness skin grafts can be used for lower extremity reconstruction. Skin grafts are best used to cover exposed muscle or soft tissue (fascia or subcutaneous tissue), but occasionally they can be used to cover bone with healthy periosteum or tendon with healthy paratenon. *Skin grafts will not survive on bone devoid of periosteum or tendon devoid of an outer layer of paratenon, which is often the case in traumatic wounds.*

23.3.1.4 Local and Regional Flaps

Local flaps use tissue adjacent to the wound, and regional flaps use tissue nearby in the arm and leg based on a named or random blood supply. Local and regional flaps are useful to cover small to moderate defects and can cover bone or exposed vessels or tendons. In the lower extremity, local and regional flaps can more easily cover defects of the proximal or middle third of the leg, while defects in the lower third of the leg have more limited local flap options [7]. Local flaps can be fasciocutaneous or muscle flaps and can be based on a proximal or distal blood supply. The flap is advanced, rotated, or transposed into the defect.

23.3.1.5 Free-Tissue Transfer

Microvascular free tissue transfer has revolutionized the treatment of extremity injuries with associated bone, soft tissue, and muscle loss and with exposure of bone and vital structures. Free tissue transfer is a complex procedure that involves removing a piece of tissue with its blood supply (free flap) from a distal part of the body and placing it over a defect, reconnecting the artery and vein to vessels at the recipient site under the microscope. The new tissue acts as an autotransplant, providing skin or muscle for coverage of otherwise exposed vital structures, thus avoiding amputation. The most commonly employed free flaps in upper and lower extremity reconstruction are listed in Table 23.1 [8].

23.3.2 Preoperative Preparation

Prior to reconstruction of complex defects of the upper or lower extremity, it is crucial to know the intact blood supply perfusing the limb. Often, especially in the lower extremity, physical exam alone is unreliable in assessing which arteries are still intact after a traumatic injury. It is also important for the reconstructive surgeon to determine preoperatively which artery and vein can be used for free flap reconstruction and which artery/arteries need to be preserved to perfuse the limb. Therefore, in all lower limb reconstructions, preoperative imaging with arteriography or a high-quality CT angiogram/MR angiogram is required (Fig. 23.3). Often in the upper limb, the patency of the radial or ulnar artery can be determined on physical exam, noting the location of injury and performing an Allen's test.

Table 23.1 The most common free flaps used for upper and lower extremity reconstruction

Flap	Flap type	Arterial supply
Rectus abdominis flap	Muscle flap from the abdomen	Deep inferior epigastric artery
Gracilis flap	Muscle flap from the inner thigh	Medial femoral circumflex vessels from the profunda femoral artery
Latissimus dorsi flap	Muscle flap from the back	Thoracodorsal artery
Anterolateral thigh flap	Skin and fascia from the thigh	Descending branch lateral femoral circumflex artery
Radial forearm flap	Skin and fascia flap from the forearm	Radial artery

23.3.3 Primary Reconstruction

Early soft tissue coverage is associated with a lower complication rate. The goal is to close wounds within 5–10 days if possible to decrease the risk of infection, osteomyelitis, nonunion, and further tissue loss. Byrd found that the overall complication rate of wounds closed within the first week of injury was 18 % compared to a 50 % complication rate for wounds closed in the subacute phase of 1–6 weeks [9, 10]. Wounds that cannot be reconstructed within this time frame should be kept clean with appropriate dressing changes and with exposed critical structures kept from desiccating; this is often done with nonadherent materials over exposed paratenon or periosteum. The reconstructive ladder guides soft tissue reconstruction [11].

23.3.3.1 Soft Tissue

Any wounds that can be closed by primary closure with minimal tension should be reconstructed by this method. This is an uncommon situation in significant extremity trauma.

Small areas of exposed bone or tendon can be treated successfully with secondary intention healing. This requires daily dressing changes or treatment with the VAC® device. The advantage of this method is that it does not require additional operations, is simple, and is especially useful in ill patients who cannot undergo more complex reconstructions [11]. The disadvantage

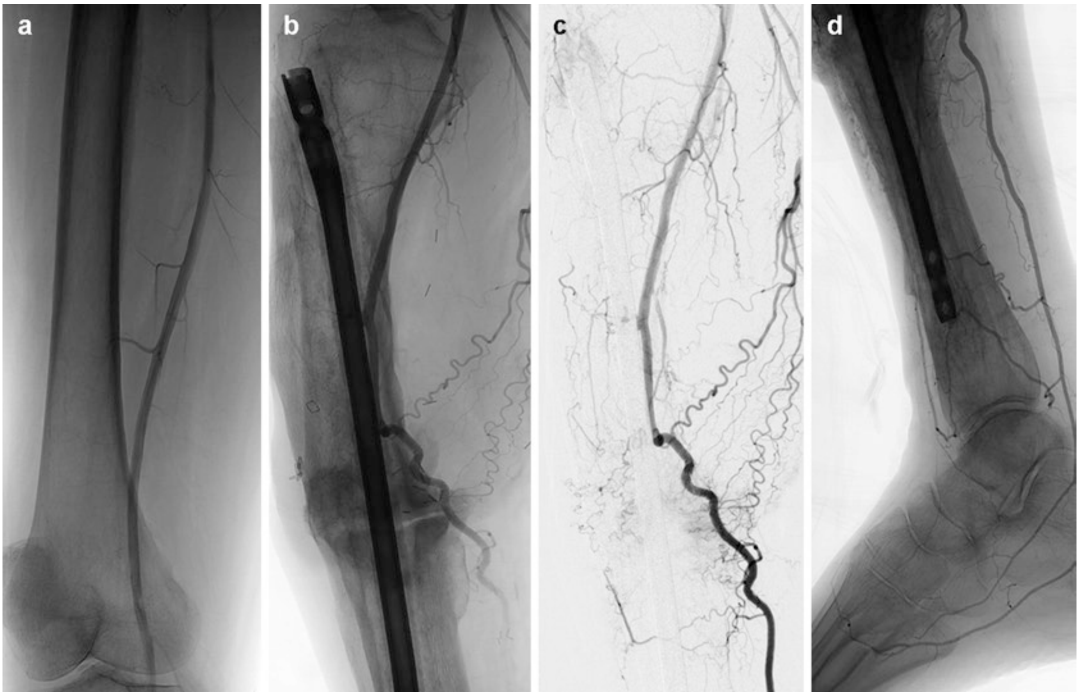

Fig. 23.3 Lower extremity angiogram after high-energy trauma and orthopedic fixation. (**a**) Patent superficial femoral and popliteal arteries. (**b**, **c**) Tibial fixation with intramedullary nail and occluded anterior tibial and peroneal arteries at their take-off points excluding their use for reconstruction. (**d**) Patent posterior tibial artery as singular arterial inflow to the foot that must be preserved

is that it often requires many weeks to months before definitive wound coverage.

Areas of exposed muscle, fascia, or periosteum can be reconstructed with a skin graft (Fig. 23.4). The skin graft must be placed on clean and viable tissue and bolstered in place for at least five days, and the patient must be kept non-weight bearing with the leg elevated. Skin grafts will not take on actively moving joints; therefore, joint immobilization is crucial. Skin grafts cannot be used over exposed tendon, bone, or neurovascular structures. The VAC® device is useful as a bolster device for extremity grafts and may improve graft take.

Local and regional flaps using muscle or skin and fascia are the first choice in the coverage of areas of exposed bone, tendon, nerves, or vessels. These flaps are limited to small- to medium-sized defects, and the blood supply of the local tissue must be intact.

Free tissue transfer is often needed when there is significant soft tissue loss in the upper and lower extremities with exposed bone, hardware, or tendon [12] (Gustilo Grade 3B/C injuries) (Figs. 23.1f and 23.5). Prior to the advent of free tissue transfer, such wounds required amputation. Now, free flaps from distant body regions allow coverage and reconstruction of such wounds, preventing amputation.

> It is crucial in the upper and lower extremity to have a proper pre-operative physical exam and angiogram to assess blood supply and to determine where you will anastomose the flap vessels to allow blood to flow.

Table 23.1 shows the most common free flaps for upper and lower extremity reconstruction. The current success rate for free flaps in lower extremity trauma is approximately 95–98 % [11, 13, 14].

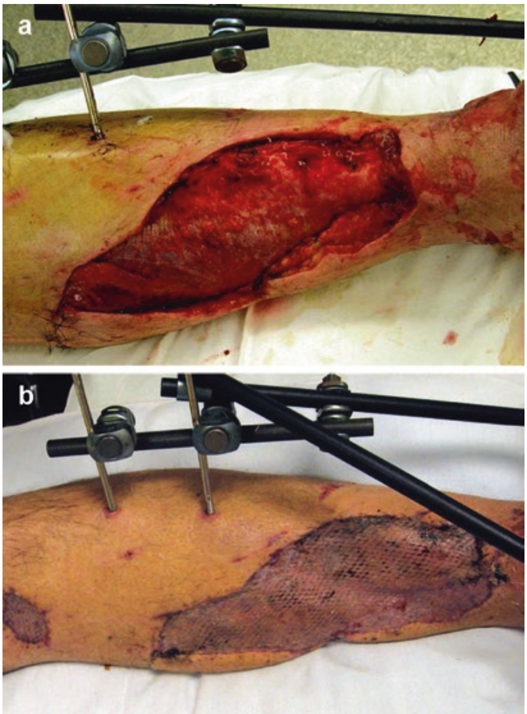

Fig. 23.4 (**a**) Open wound of the medial leg after crush injury with exposed muscle and bone that is covered by well-vascularized periosteum. (**b**) The wound was grafted with a meshed split-thickness skin graft and is shown at 2-month follow-up fully healed

23.3.4 Secondary Reconstruction

In contaminated open wounds, reconstruction of nerve, tendon, and bone defects with autologous tissue should not be performed until wound coverage has been completed and there is no evidence of infection. Therefore, nerve grafts, tendon grafts or transfers, and bone grafts are not performed until the soft tissue has healed. In our practice, these secondary procedures are performed approximately 8–12 weeks after flap transfer when all incisions, flap tissue, and grafts are healed and sturdy. The flap is then partially lifted, protecting its blood supply, to allow access to the surgical site for bone, tendon, or nerve grafting.

23.3.4.1 Bone Defects

There are three ways of managing bone gaps: nonvascularized cancellous bone grafts, Ilizarov

Fig. 23.5 (**a**) Open fracture of the lower leg with exposed tibia and antibiotic spacer. (**b**) The wound was reconstructed with a partial latissimus muscle flap connected to the posterior tibial artery and vein and covered with a skin graft. It is shown at 8 weeks' follow-up just prior to flap elevation, removal of spacer, and iliac crest bone grafting

bone lengthening, and vascularized bone grafts. Nonvascularized cancellous bone grafts are best used for nonunions or small bone gaps of less than 5 cm. We believe it is best to get wound control prior to bone grafting, avoiding the risk of losing valuable limited bone; we postpone bone grafting until 8–10 weeks after soft tissue wound coverage. With larger bone gaps, the success of nonvascularized bone grafts decreases, and the need for vascularized bone grafts or Ilizarov bone lengthening is indicated. The Ilizarov technique uses the concept of distraction osteogenesis to lengthen bone segments and is used for gaps of 4–8 cm. Alternatively, vascularized fibular grafts (fibula free flaps) are used for defects greater than 6 cm.

23.3.4.2 Nerve Defects

Injuries to the lower extremity often have associated nerve injuries; however, the results of nerve repair and grafting in the lower extremity have been poor. Disruption of the peroneal nerve results in foot drop and loss of sensation of the dorsum of the foot. Although not crippling, lifelong foot splinting or tendon transfers are required to offset the foot drop. The loss of the posterior tibial nerve is more devastating. It results in the loss in plantar flexion of the foot and the loss of sensation of the plantar aspect of the foot. This causes loss of position sense and chronic injury and wounding of the plantar foot. Atrophy and vasomotor changes complicate the injury. Therefore, posterior tibial nerve injury is often an indication for amputation [15]. In contrast, the upper extremity is more tolerant to nerve loss and can have good functional outcomes in severe injuries. Thus, upper extremity nerve injury alone should not be considered an indication for amputation.

Conclusion

Caring for the severely traumatized extremity can be a reconstructive challenge [1, 2]. With appropriate use of meticulous wound debridement, careful preoperative planning, and a suitable reconstruction for the type of defect, an excellent functional result can be obtained. It is critical that one avoids the pitfall of inadequate debridement before reconstruction to avoid serious complications. Amputations can be avoided by following a logical, step-by-step approach to these difficult problems (Fig. 23.6). Extremity salvage is a rewarding endeavor that allows patients to return to their day-to-day life, ambulate, and often return to work with a high functional capacity.

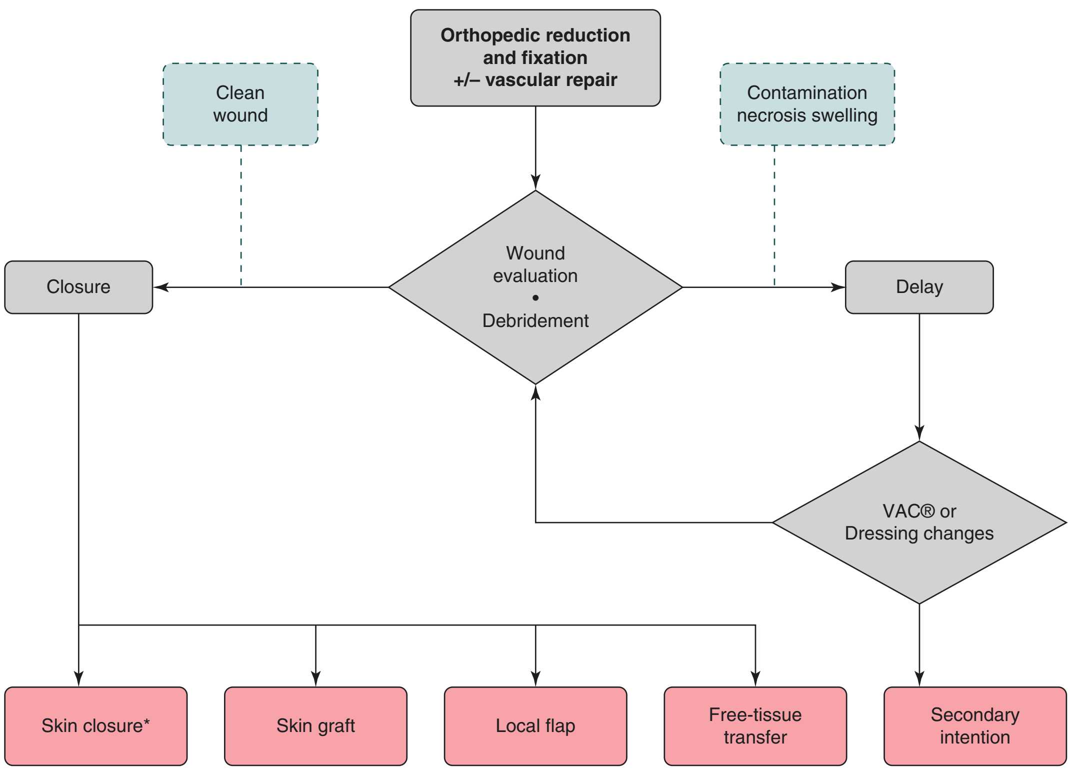

Fig. 23.6 Treatment flow chart for complex extremity traumatic wounds. Initially the traumatic wounds are taken emergently to the operating room; they are debrided, and orthopedic fixation is applied and vascular repair performed if needed. The wound is then assessed for contamination, swelling, and necrosis, and the timing of closure is determined. Frequently, VAC® sponges are placed until swelling has resolved; often at that point, delayed primary closure, local flaps, and skin grafts can be used for wound closure, and if not, a free flap is indicated. *Primary or delayed primary closure

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24 Vascular Injuries and Replantation

David S. Kauvar

24.1 Overview and Significance

This chapter covers the diagnosis and management of blood vessel injuries likely to be encountered when dealing with disaster-related orthopedic trauma. The focus is primarily on the expedient diagnosis and management of arterial injuries to the extremities. While the intricacies of definitive arterial and venous diagnosis and repair are beyond the scope of this chapter, we will outline the diagnosis of vascular injuries with emphasis on the physical examination and discuss the field management of hemorrhage and ischemia. We will cover vascular injury management techniques primarily constituting "vascular damage control," consisting of initial life and limb salvage maneuvers. A basic vascular surgical anatomy and technique reference can be invaluable when planning emergency surgery and will help to clarify the exposures and techniques mentioned below. Finally, attention is given to the identification and management of the physiologic consequences of Ischemia-Reperfusion (I-R) and a discussion of the vascular issues encountered in the evaluation and treatment of mangled or traumatically amputated extremities.

Extremity vascular injuries are clinically significant for three distinct reasons. First and most importantly, they can be a source of life-threatening hemorrhage, bringing to bear the prioritization of extremity injury in the context of the multiply injured patient. When faced with significant hemorrhage from an extremity with a complex vascular injury, measures to preserve the patient's life must take precedence over those taken to salvage the injured limb, even if the result is an amputation. A second significant aspect of extremity vascular injury is the ischemia resulting from major arterial occlusion or disruption. Prolonged ischemia can lead to cellular death and irreversible tissue destruction resulting in the need for amputation. This makes restoring arterial perfusion to a dysvascular extremity a high priority in the early management of limb trauma. Shorter periods of ischemia can result in serious but reversible tissue changes which can lead to the third significant consequence of extremity vascular injury, the ischemia-reperfusion syndrome (I-R). The physical consequence of I-R, compartment syndrome, is discussed elsewhere in this book, but herein we address the physiologic consequences and their urgent management below.

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_24

24.2 Epidemiology, Consequences, and Pattern of Injuries

24.2.1 Epidemiology

Civilian arterial and venous injuries are present in up to 2 % of injured patients, and affected patients account for a disproportionate share of trauma-related morbidity and resource utilization [32, 39]. Injuries to extremity vessels comprise 20–50 % of all vascular injuries [1, 32, 34, 39]. No specific data is available on the epidemiology of vascular injuries in civilian disasters and mass casualty events, but in recent military experience which may be more relevant to the study of civilian disaster and mass casualty events, vascular injuries are much more common than in the civilian experience. The combined incidence of such injuries in the Iraq and Afghan wars is over 10 %, with extremity vessels representing 80 % of injuries [57].

24.2.2 Mortality and Amputation

Hemorrhage is a source of a great deal of trauma-related morbidity and mortality [23, 24]. Extremity arterial injuries can result in catastrophic bleeding and exsanguination if hemorrhage is not controlled quickly. Mortality resulting from such injuries is most common in proximal lower extremity vessel injury, particularly to the common femoral artery [3, 10, 25]. In the modern military experience, hemorrhage from extremity vascular injuries is a leading source of potentially preventable mortality, accounting for 15–30 % of such deaths [11, 12]. This emphasizes the necessity for early hemorrhage control in managing patients with vascular injuries.

Amputation is the other catastrophic consequence of extremity vascular injury. In civilian trauma, it is much more frequently performed in blunt than in penetrating trauma owing to the high incidence of concomitant injury to skin, nerve, muscle, and bone with this mechanism of injury [21, 25, 35, 39, 46]. In contrast to mortality, amputation is more frequently performed for more distal vascular injuries, most commonly at the forearm (radial/ulnar) level in the upper extremity and the popliteal level in the lower extremity [1, 25, 44]. Traumatic amputation, which by necessity involves at least one major vascular injury, is exceedingly common in modern military trauma, accounting in one report for 20 % of patients with arterial injuries and 10 % of all combat trauma admissions [15, 27]. Over 80 % of amputations in recent combat experience are in the lower extremity, approximately equally divided between the transtibial and transfemoral levels. Of significant note, in modern combat trauma, 30 % of amputees sustain multiple amputations [27].

24.2.3 Vascular Injury Pattern

In disasters and mass casualty events, it is reasonable to expect that blunt mechanisms of injury will predominate. Further, one can expect complex limb injuries including significant trauma to multiple tissue types. The treating surgeon should be prepared for the initial decision-making and management of vascular injuries in the setting of a number of multiply injured patients with extensive trauma to skin, muscle, nerve, and bone [53]. A comprehensive review of recent military combat trauma data revealed that extremity vascular injuries distal to the elbow and knee predominate, but that femoral, popliteal, and axillary artery incidences were not insignificant [11].

24.2.4 Associated Tissue Injuries

Concomitant fractures are frequently present in limbs that have sustained blunt arterial injuries [36, 54]. The presence of a fracture, especially when comminuted, has been shown to be a consistent and strong predictor of eventual amputation [16, 20, 36]. Named venous injuries have an incidence ranging from 15 to 35 % when an arterial injury is present. There is no consensus regarding the necessity to repair such injuries, and they do not consistently predict amputation or long-term morbidity [54]. Injuries to peripheral nerves are likely under-reported in association with extremity arterial injuries because they are difficult to detect in the acute setting. The reported incidence is about 10 % in the lower extremity and about 40–50 % in the upper extremity. Identified nerve injuries do not predict acute or eventual amputation, even in severely injured limbs [5]. The presence of significant soft tissue disruption (skin and/or muscle) consistently predicts amputation when associated with arterial injury and is more commonly reported in injuries to the upper extremity (40–70 %) than to the lower extremity (about 30 %).

24.3 Field Management of Arterial Ischemia and Hemorrhage

Major extremity arterial injury may be associated with limb-threatening ischemia or life-threatening hemorrhage, both of which must be immediately addressed prior to transfer of the patient to initial surgical care. In disaster and mass casualty situations, resources may be limited, but some relatively simple techniques can be applied to salvage life and limb.

24.3.1 Field Management of Ischemia

Minimizing the time that a limb is ischemic is important to avoid the downstream consequences of ischemia and reperfusion. In the field, surgical management of arterial disruption is not feasible, but if a partial arterial disruption such as a kink, focal dissection, or partial thrombosis is present, then closed reduction of a fracture or dislocation may result in restoration of adequate distal perfusion. Sometimes, reduction maneuvers bringing a foreshortened limb out to length will result in restoration of a distal pulse and may be the only vascular intervention necessary. Even if a state of normal perfusion is not restored, field reduction may allow for increased collateral perfusion, preserving limb viability. In a traumatized extremity with a fracture and/or dislocation and evidence of distal ischemia, closed reduction and splinting (perhaps with a traction splint) should be one of the first maneuvers performed once immediate threats to life have been addressed.

24.3.2 Field Management of Hemorrhage

Hemorrhage from extremity arterial injuries may be catastrophic and refractory to conventional methods of control such as gauze packing and pressure dressings. Though controversial in civilian practice, the placement of an arterial tourniquet has proven lifesaving in recent military experience, especially in severe limb injuries or where a traumatic amputation is present [2, 29, 31, 38]. In the early stages of the wars in Iraq and Afghanistan, the US Department of Defense sponsored a program to develop and field a compact, lightweight, and easy-to-use tourniquet for expedient extremity hemorrhage control [55]. These devices have proven effective in both the upper and the lower extremities, and their wide availability and frequent use has been associated with an 85 % improvement in survival following severe extremity injury [12] (Fig. 24.1). Importantly, despite the ubiquitous availability and frequent use of extremity tourniquets in modern combat casualties, the amputation of a potentially salvageable limb has not once been attributed to tourniquet use [2, 30].

The application of a tourniquet designed to control extremity arterial hemorrhage should be considered in cases of severe extremity arterial hemorrhage refractory to conventional packing or pressure dressings. Tourniquets will be most effective when placed proximal to the knee or elbow and should be tightened sufficiently to eliminate distal arterial flow. In larger-diameter limbs (especially the thigh), multiple tourniquets placed in series may be required. Once tightened, a tourniquet should not be loosened until surgical control can be achieved rapidly.

The source of some extremity arterial hemorrhage is too proximal to allow for the placement of a tourniquet for control. Such “junctional”

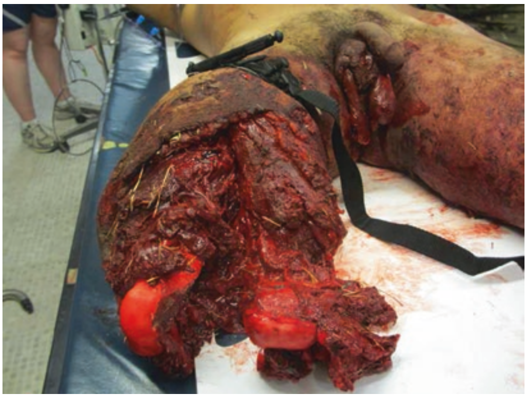

Fig. 24.1 Military tourniquet used for field hemorrhage control following a traumatic right lower extremity amputation sustained following the detonation of an improvised explosive device in Afghanistan

Fig. 24.2 Left groin pressure dressing controlling junctional hemorrhage from a gunshot wound to the proximal profunda femoris artery. Dressing consisted of multiple layers of wrapped noncompliant cotton gauze over a firm mass of gauze directly over the wound. This approximated as much as possible the ideal method of control, direct manual pressure, which was not possible in this case

injuries to the proximal femoral or axillary arteries require the constant application of direct pressure to staunch bleeding. This is best accomplished with manual compression, but occasionally a pressure dressing can be devised to control junctional hemorrhage (Fig. 24.2). Tourniquet-type devices designed specifically for junctional hemorrhage are being developed, but their availability is not commonplace [30].

24.4 Diagnosis of Arterial Injury

The rapid identification of extremity arterial injuries is key to preventing their life- and limb-threatening consequences. A high index of suspicion for arterial disruption should be maintained in all cases of severe extremity injury, especially when multiple tissue types are traumatized. This is particularly true in cases with severely comminuted fractures, extensive soft tissue disruption (including skin, muscle), neurologic deficit, and crush injuries. Attention to specific historical and physical examination features is key to the efficient diagnosis of extremity arterial injuries. The probability of an injury being present and the subsequent need for workup and/or intervention are guided by the presence or absence of "hard" and "soft" signs of arterial injury.

Box 24.1 Clinical Signs of Extremity Arterial Injury

"Hard Signs"

- Absent distal pulse
- Palpable thrill/audible bruit
- Actively expanding hematoma
- Active pulsatile bleeding

"Soft Signs"

- Diminished distal pulse
- History of significant hemorrhage
- Neurologic deficit
- Proximity of wound to named vessel

If one or more "hard signs" are present, then an arterial injury is likely and expeditious operative exploration is mandatory. If one or more "soft signs" are present, then an arterial injury is possible and further specific diagnostic investigation is warranted.

24.4.1 History and Physical Examination

In the austere conditions that might be encountered while caring for victims of disasters and mass casualty events, the history and physical examination may be the only diagnostic modalities available. In blunt extremity trauma with arterial injury, diminished or absent pulses may be present in up to 95 % of patients [44, 54]. The ankle-brachial index (ABI) is a simple, noninvasive test that can be performed in the field and is a good supplement to the pulse exam. The Doppler-derived blood pressure is taken at the bilateral brachial arteries (with a manual cuff at the humeral level) and at the posterior tibial and dorsalis pedis arteries (with the cuff at the ankle). The ABI is calculated as follows:

$$\frac{\text{Highest ankle pressure distal to presumed arterial injury}}{\text{Higher brachial pressure}} = \text{ABI}$$

An ABI ≥ 1.0 is normal, while an ABI ≤ 0.9 is suggestive of an arterial injury and, if accompanied by one or more "soft signs" of arterial injury, mandates radiologic or operative investigation. A number of clinical studies in patients sustaining extremity trauma have confirmed that a pulse examination supplemented by a determination of the ABI has excellent predictive value, sensitivity, and specificity for the detection of arterial injury [17, 49, 56].

24.4.2 CT Angiography

In cases where an arterial injury is suspected but initial operative exploration is not mandated (such as in the presence of isolated "soft signs"), additional diagnostic imaging should be performed if appropriate facilities and equipment are available. The modern-day standard of care for vascular diagnostic imaging in trauma is computed tomography angiography (CTA), which has largely replaced conventional catheter-based angiography. CTA is noninvasive and provides additional imaging of the bone and soft tissues of an injured extremity. Additionally, it can help in diagnosing major venous injuries if an appropriately delayed venous phase scan is performed. The sensitivity and specificity of modern CTA for the detection of arterial injuries are over 90 % [41].

24.4.3 Intraoperative Angiography

In cases where an arterial injury is suspected and the patient is in the operating room, intraoperative angiography may be performed to identify and/or localize an arterial injury. This is typically performed following surgical exposure of an artery proximal to the presumed area of injury (see below). The procedure requires the use of a radiolucent operative table, C-arm fluoroscopy with or without digital subtraction (DS) capability, intravenous contrast, an 18 gauge or larger over-the-needle angiocatheter, a segment of intravenous tubing, a three-way stopcock, and syringes for contrast and heparinized saline flush. The needle/catheter is inserted antegrade through the anterior surface of the vessel at about a 60° angle until pulsatile backflow is observed. The catheter is advanced over the needle, which is removed. The catheter is connected to the deaired and primed tubing/stopcock. The downstream area to be interrogated is placed in the center of the image field and contrast steadily injected under live fluoroscopy (or DS if available) and observed traversing the imaged field. If DS is used, then antegrade flow through the arterial system provides the driving pressure for the contrast. If the angiogram is performed with fluoroscopy, then the artery proximal to the contrast injection site should be clamped and the injection pressure should drive the contrast distally.

Significant potential angiographic findings include complete flow interruption indicating focal occlusion, free contrast extravasation indicating arterial disruption, and luminal irregularities which can represent nonocclusive thrombus, dissection flaps, or mural hematomas. Though a single plane of imaging can frequently be considered adequate to rule out an arterial injury if the angiogram is completely normal, if there is even an insignificant abnormality noted, an additional plane of imaging can help to determine if the abnormality represents an artifact or an actual arterial injury.

Following the procedure, a u-stitch of polypropylene suture is placed around the angiocatheter. As the catheter is removed, the suture is tied down, sealing the arteriotomy.

24.5 Extremity Arterial Anatomy and Exposures

24.5.1 Axillary Artery

The axillary artery is exposed through a horizontal incision beginning on the anterior chest wall inferior to the lateral third of the clavicle. The pectoralis major muscle fibers are split or divided, revealing the pectoralis minor. The artery lies just deep to this muscle. The incision is extended distally into the bicipital fossa as necessary. When exposing the axillary artery, care should be taken to avoid injury to branches of the brachial plexus, which are intimately associated with the proximal portion of the vessel.

24.5.2 Brachial Artery

The exposure of the brachial artery is via a longitudinal incision along the relatively straight course of the artery within the bicipital fossa. The vessel lies within the brachial sheath, closely associated with the median nerve (Fig. 24.3). If exposure of the brachial artery distal to the antecubitum is necessary, then a "lazy-S" skin incision should be used to traverse the joint. About 5–10 % of patients have a proximal division of the brachial artery, most frequently at the level of the mid-humerus. In these patients, the ulnar artery typically courses deep to the bicipital aponeurosis and the radial artery typically superficial to the biceps brachii muscle [26].

24.5.3 Radial and Ulnar Arteries

Both the radial and ulnar arteries are exposed via longitudinal incisions directly overlying their respective courses in the forearm. The vessels are deepest more proximally and become more superficial at the wrist. The ulnar artery is typically dominant, providing most of the perfusion to the digital branches of the palmar arch. This vessel should be given precedence in decisions regarding which vessel to repair if both are injured (Fig. 24.4).

24.5.4 Femoral Arteries in the Groin

A longitudinal inguinal incision directly overlying the femoral pulse should be used to expose the common femoral (CFA) and pro-

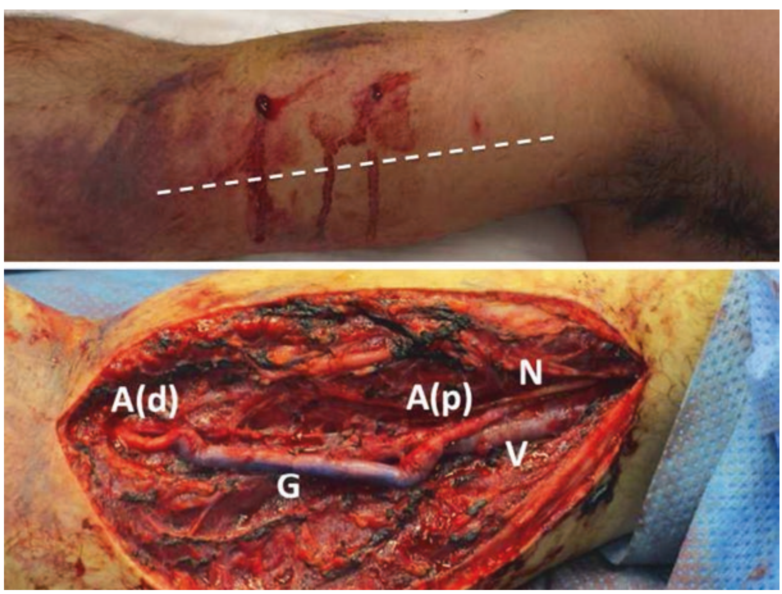

Fig. 24.3 Gunshot wounds to the brachial artery. The incision was made in the bicipital groove (*top panel*, *dashed line*). Visible following exposure in the bottom panel are the proximal (*Ap*) and distal (*Ad*) brachial arteries, one of the brachial veins (*V*), and the median nerve (*N*), all in close proximity. The artery could not be primarily repaired, so a brachial-brachial reversed saphenous interposition graft (*G*) was placed

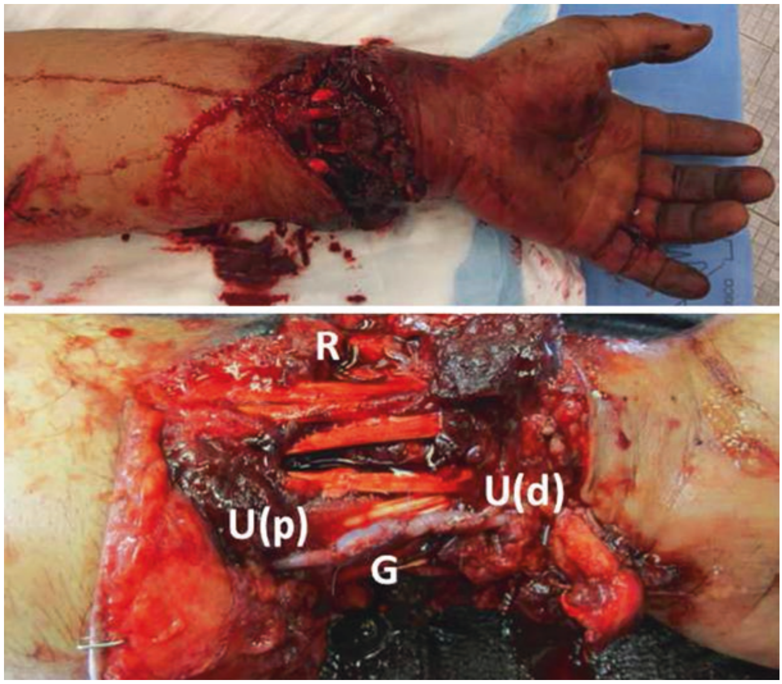

Fig. 24.4 Near-complete amputation at the level of the left wrist due to blunt trauma (*top panel*). The radial artery (*R*) was thrombosed and the ulnar artery transected between its proximal (*Up*) and distal (*Ud*) ends. A short ulnar-ulnar reversed saphenous interposition graft (*G*) was created (*bottom panel*)

funda femoral (PFA) arteries in the groin. This allows for simple proximal and distal extension if necessary. If there is no femoral pulse, then ultrasound can be used to localize the artery. If ultrasound is not available, then an incision two fingerbreadths medial to the pubic tubercle is usually in the vicinity of the CFA. The artery lies just deep to the inguinal ligament, and this structure's obliquely oriented fibers are a good landmark to identify the correct plane of dissection proximally. If more proximal exposure of the distal external iliac artery (EIA) is required for control, the inguinal ligament may be partially or even completely divided, but should be repaired if possible. Care should be taken to avoid injury to the lateral circumflex iliac veins overlying the distal EIA under the inguinal ligament and the circumflex femoral veins traversing the space between the PFA and superficial femoral artery. The PFA is a thin-walled vessel with a number of proximal branches, and it should be dissected carefully and only as much as is necessary to obtain loop or clamp control (Fig. 24.5).

24.5.5 Superficial Femoral Artery

The superficial femoral artery (SFA) courses down the medial thigh deep to the sartorius muscle. It is best exposed through a longitudinal incision overlying the anterior border of the muscle, followed by posterior reflection of the sartorius and anterior reflection of the vastus medialis.

24.5.6 Popliteal Artery

The popliteal artery has three distinct segments relative to the knee: above, behind, and below. In most circumstances, the most appropriate exposure of the above- and below-knee segments of the artery for vascular control is via the medial approach. Approaching the behind-knee popliteal from the medial approach requires division of the semimembranosus and semitendinosus tendons, inviting considerable morbidity. Most popliteal artery injuries can be controlled and excluded without exposing the segment of the artery behind the knee. An

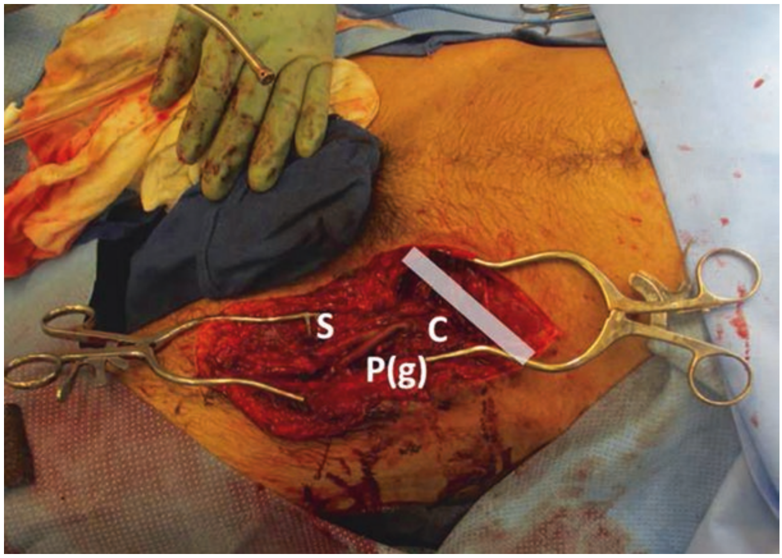

Fig. 24.5 Exposure and repair of the femoral arteries in the gunshot wound patient seen in Fig. 24.2. The femoral bifurcation was high, so the inguinal ligament (*white shaded box*) has been partially divided to obtain proximal control. Visible are the common femoral artery (*C*), superficial femoral artery (*S*), and a reversed saphenous common femoral-profunda femoris artery interposition graft (*Pg*)

isolated retrogeniculate injury may be approached posteriorly through a "lazy-S" incision directly overlying the popliteal fossa, but this requires the patient to be placed in the prone position, which is frequently contraindicated in a trauma patient due to associated injuries. The tibial nerve trunk above the knee and its branches below the knee are intimately associated with the popliteal artery, and injury to these structures should be avoided.

24.5.7 Tibial Arteries

The approach to the anterior tibial artery is through a longitudinal incision 1–2 cm lateral to the lateral border of the tibia. The vessel lies deep within the anterior compartment, just superficial to the intraosseous membrane. The posterior tibial and peroneal arteries are exposed via a medial calf longitudinal incision into the deep posterior compartment. The same incisions used for calf fasciotomies can be used to expose the tibial vessels. When performing the medial exposure, care should be taken to preserve the greater saphenous vein running up the medial calf.

24.6 Damage Control Vascular Surgery

24.6.1 Hemorrhage Associated with Pelvis Fractures

While a detailed description of the comprehensive management of fractures of the pelvis is beyond the scope of this chapter, it is important to keep in mind that such injuries can be a source of significant, even life-threatening retroperitoneal hemorrhage. The incidence and severity of bleeding in pelvis fractures correlate with the severity of the fracture and the degree of diastasis of the sacroiliac joints and pubic symphysis [52]. Anteroposterior compression fractures appear to have the greatest potential for catastrophic bleeding from branches of the hypogastric arteries [18]. In austere settings, the preferred initial management of displaced pelvis fractures with clinical evidence of hemorrhage is placement of an external pelvic binder or closed reduction and external fixation. These procedures may collapse the hematoma cavity enough to allow for temporary tamponade and slowing or cessation of active bleeding, especially from venous injuries. Following reduction and placement of a pelvic binder or external fixator, the patient should be closely monitored for signs of ongoing bleeding, and, if these are present, should be urgently referred for angiography with possible embolization or open preperitoneal packing [7].

24.6.2 Non-reconstructive Management: Ligation

In situations where time and surgical resources are limited or vascular surgical expertise is unavailable, arterial and venous ligation may be the best option for surgical treatment of an extremity vascular injury. Many extremity arterial injuries and most venous injuries can be acutely ligated without dooming the affected extremity to amputation. If a major arterial ligation is performed, the limb must undergo frequent clinical examination for viability loss and the patient should be referred to a surgeon with expertise in vascular reconstruction as promptly as possible. Some injuries noted on imaging do not require immediate reconstruction provided there is no clinically apparent distal ischemia or free extravasation of contrast in the setting of hemodynamic instability. Such injuries include small intimal tears or flaps, pseudoaneurysms, and arteriovenous fistulae [45]. When such injuries are not repaired, however, serial imaging is recommended because some of these injuries do progress to requiring surgical intervention [8].

In the upper extremity, the axillary artery is very well collateralized around the shoulder. If these collaterals are intact, the axillary artery can usually be ligated without producing a nonviable limb. The same is true for the brachial artery, especially its proximal portion. Most injuries to the radial and many to the ulnar artery can be safely treated with ligation as well, provided a preoperative Allen's test has confirmed codominance of these vessels in their contributions to the palmar arches and digital circulation.

In the lower extremity, the CFA can be ligated acutely, but this is likely to result in limb loss if the PFA is not patent to receive collateral from the hypogastric artery in the pelvis. Ligation of the PFA is typically well tolerated acutely, but this artery has a significant role in receiving iliac and donating geniculate collaterals, so it should be eventually reconstructed if possible, especially if other femoral arterial injuries are present. In general, either the PFA or the SFA must be patent in order for an injured extremity to avoid amputation. The popliteal artery does not collateralize distally to a great degree. Ligation generally produces significant limb ischemia and should be avoided unless absolutely necessary. Isolated tibial arterial injuries can be safely ligated without significant ischemic consequences. Complete disruption of two or more tibial vessels is uncommon, even in severe limb trauma, but at least one tibial artery must be patent to the foot in order to ensure limb salvage.

Most major deep venous injuries can be safely ligated in the acute setting without precluding limb salvage. This is especially true if collateral venous drainage is present through the superficial veins. One can expect significant limb edema following a major venous ligation, however, especially in the lower extremity. This is seen in up to 50 % of femoral and 90 % of popliteal vein ligations [51]. Significant edema is typically transient, however, lasting a few days to weeks [37, 51, 58]. If a major deep venous ligation is performed, the injured limb should be placed in a compliant compressive wrap and elevated if possible to reduce hydrostatic pressure and edema. Another complication of major venous ligation is deep venous thrombosis, which is twice as common in patients undergoing ligation versus those undergoing repair. This does not appear to be associated with an increased rate of pulmonary embolism, however [47].

When performing limb replantation following complete or near-complete traumatic amputation, flow through at least one major vein must be restored because most or all collateral drainage has been disrupted. The venous injury should be shunted or repaired prior to arterial shunting or repair because of the potential for rapid exsanguination when arterial flow is restored without a pathway for intravascular venous blood to return to the central circulation.

24.6.3 General Operative Principles and Techniques

The general operative sequence for the management of extremity arterial injuries involves first obtaining anatomic proximal vascular control, followed by distal control. Once clamp or vessel loop control is obtained, dissection from both directions can be most safely performed to expose the zone of injury. Proximal and distal control should be obtained close to the expected area of injury, and the traumatic wound can be itself extended in lieu of making discrete incisions over the target vessels. It is generally not recommended to explore the injured zone prior to at least obtaining proximal control because hematoma and active bleeding typically obscure the expected anatomy, increasing the likelihood of injuring nearby tissues and exacerbating blood loss.

Once the zone of injury is exposed, nonviable arterial tissue should be debrided and an initial assessment made of the resulting vessel defect. Proximal and distal balloon catheter thrombectomy should be performed through the defect with an appropriately sized embolectomy catheter. Inflow (i.e., proximal) arterial bleeding should be pulsatile and commensurate with the patient's systolic blood pressure. Backbleeding from the distal vessel should be present, though in cases of severe injury, may be minimal. Manual or Esmarch distal exsanguination can be performed to confirm backbleeding and distal vascular patency. Once this is completed, dilute heparin (10–100 units/mL unfractionated heparin in 0.9 % sodium chloride) should be injected directly into the proximal and distal vessels.

When performing vascular injury damage control, there are essentially three options for initial operative management: ligation, primary repair, or shunting. If ligation is selected, suture ligature with a nonabsorbable suture is recommended for veins and smaller arteries (generally distal to the knee or elbow) in order to secure the ligature in place. This prevents the suture from slipping free of the vessel. The proximal portion of larger vessels should be oversewn in two layers with an appropriately sized polypropylene suture. This involves placing a running horizontal mattress suture beneath the clamp, followed by clamp removal and placement of an overlying running suture. Both can be performed with the same needle and suture strand. The distal artery should be oversewn as well, and typically a simple suture ligature will suffice to control backbleeding from this vessel.

Primary suture repair of venous injuries is generally acceptable, especially for relatively clean longitudinal lacerations. This so-called "lateral suture" technique should be performed with an appropriately sized polypropylene suture in a continuous running fashion with one strand from each end of the laceration, each secured at the apex with knots. The two running strands are knotted together near the midpoint of the laceration. Small arterial injuries in vessels with a patulous lumen may also be primarily repaired, but care should be taken to avoid or minimize compromise of the luminal diameter. This is best facilitated by closing simple arteriotomies in a transverse fashion using interrupted sutures. Sutures should be placed from the inside of the vessel out in order to avoid dissection of the layers of the arterial wall. If the ends of the injured artery can be brought in close proximity without tension, then a minimally spatulated, end-to-end anastomosis with interrupted polypropylene sutures may be performed. In the setting of combined arterial injury and severe segmental fractures, it may be possible to shorten the limb to allow for a simpler, shorter-segment primary reanastomosis of the injured artery.

24.6.4 Shunting

If neither ligation nor primary repair of a vascular injury is immediately feasible, then placement of arterial and/or venous shunts can be used to restore antegrade flow prior to definitive surgical repair. Since the technique's initial military use in the Vietnam War [13], arterial shunting has gained widespread acceptance as a technique of vascular injury damage control. Reported arterial shunt dwell times have ranged from a few hours to over a day, with near 100 % patency maintained despite the absence of systemic anticoagulation [9, 19, 43]. Shunts placed in the axillobrachial and femoropopliteal arteries fare much better than those placed in the radial, ulnar, or tibial arteries [42]. Despite low flow, venous shunts fare surprisingly well and should be considered for non-immediately reconstructible major proximal venous injuries [42, 50].

If no commercially produced vascular shunt is available for use, a shunt can be improvised from any available noncollapsible, sterile tube of appropriate diameter such as a feeding tube or Robinson catheter. Shunts should be of a length determined to lie between the ends of the vessel without kinking. The shunt should be inserted into an uninjured segment of a vessel in an end-to-end fashion. The author prefers to place the distal end of the shunt first and to allow back-bleeding to passively fill the tubing, then place the proximal end, and release the proximal clamp. This minimizes the chance of a large air embolus progressing distally. Both ends of the shunt should be fastened securely with heavy silk ties placed around the shunted portion of the vessel. Following shunt placement, Doppler signals should be obtained from the shunt itself and from the vessel downstream of the shunt to confirm flow through the device. Frequent distal pulse checks should then be performed to rapidly identify shunt thrombosis if it occurs. If a shunt thrombosis occurs, then re-exposure of the injured segment, removal and thrombectomy of the shunt, repeat local heparinization, and re-shunting can be performed.

24.7 Physiologic Consequences of Ischemia and Reperfusion

Limb ischemia produces a number of significant consequences affecting the injured extremity. The progressive cell death that occurs during long periods of ischemia can lead to tissue destruction resulting in limb unsalvageability. Muscle is the extremity tissue most susceptible to ischemia, followed by skin, nerve, and bone. In general, 6 h of ischemia is considered to be the threshold at which limb salvageability is questioned due to the likely severity of muscle necrosis and nerve dysfunction. Extremity ischemia itself is not responsible for any significant general physiologic consequences, nor is it responsible for compartment syndrome. These derangements occur following the reperfusion of a previously ischemic extremity.

Upon limb reperfusion, there is a significant increase in microvascular permeability, resulting in fluid and protein extravasation into the interstitium. This can lead to significant intracompartmental edema and its clinical consequence, compartment syndrome. The details of the diagnosis and management of compartment syndrome are discussed elsewhere in this book, but are important to remember in the context of arterial injuries because approximately 40 % of patients with an arterial injury to the lower extremity will undergo a fasciotomy and the procedure is associated with a fourfold reduction in amputation and other complications [14]. Fasciotomy is increasingly common as the degree of limb tissue injury increases, especially when arterial injury is accompanied by an orthopedic injury, vein, or nerve injuries [6, 14, 28]. A high index of suspicion for the development of compartment syndrome must therefore be maintained in limbs sustaining multiple tissue injuries, especially crush injuries.

The physiologic consequences of I-R are the result of the release into the circulation of mediators produced during ischemia and during the early reperfusion period. Such mediators include reactive oxygen species, calcium, potassium, and a number of inflammatory cytokines. As the process progresses, inflammatory cells congregate within the reperfused tissue, releasing more mediators and setting up a cycle of inflammation which quickly reaches beyond the affected extremity. The clinical manifestations of this process develop in the minutes to hours following reperfusion and include acidosis, coagulopathy, myoglobinuria/renal failure, pulmonary edema and adult respiratory distress syndrome, cardiac arrhythmias, and, in severe cases, multiple organ failure.

There is no universally effective method to prevent the systemic physiologic derangements associated with severe reperfusion injury. Having a high index of suspicion and providing necessary supportive care as necessary are instrumental in managing these patients. Administration of free radical scavengers such as mannitol can reduce some of the inflammatory effects of I-R. Intravenous sodium bicarbonate can be used to alkalinize the urine and mitigate severe acidosis. Hyperkalemia can be treated by the administration of dextrose and insulin along with intravenous hydration.

24.8 Vascular Decision-Making in Traumatic Amputation and the Mangled Extremity

Traumatic amputations and near amputations can be seen as representing the severest form of mangled extremity, so the vascular considerations in managing these two related clinical entities will be discussed together. Ischemia resulting from arterial disruption is frequently a component of the injury complex in mangled extremities and plays a role in estimating limb salvageability using the Mangled Extremity Severity Score (MESS). The MESS is the most reliable prediction score for the eventual amputation of severely injured upper and lower extremities [4, 22, 40, 48].

Though ischemia plays a role in the estimation of limb salvageability, the degree of bone and soft tissue disruption has greater bearing on the decision of whether or not to attempt limb salvage [21, 33]. Even in the case of traumatic amputation and near amputation, arterial perfusion and venous drainage can almost always be reestablished to facilitate an initial attempt at limb salvage or replantation. In general, the need for vascular reconstruction should not be considered a sole indication for a primary amputation or foregoing attempted limb replantation. Exceptions are made in cases of very long arterial and/or venous disruptions requiring extensive vascular reconstruction, especially when available vein conduit is limited or the patient's physiologic status or available resources will not permit a long, complicated procedure with a large volume of blood loss. Multidisciplinary participation is crucial to making the best determination of the value of attempted limb salvage.

Embolectomy and shunting of arterial and venous injuries can be performed to allow time for closer examination, orthopedic fixation, and further decision-making. If the decision is made to attempt limb salvage, then formal vascular reconstruction can be performed, even in a delayed fashion if necessary. An important technical point in the surgical treatment of arteriovenous injuries in mangled extremities and traumatic amputations is that some major venous outflow must be established and should be established prior to arterial reperfusion. This will help to minimize the massive bleeding from injured tissue that can occur in severe limb injuries if no intravascular outflow is established.

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Blast and Fragment Injuries of the Musculoskeletal System

25

D.C. Covey and James R. Ficke

25.1 Introduction

Injuries to the musculoskeletal system are the most common type seen on the battlefield today. Most of these injuries are due to explosive munitions or improvised explosive devices (IED). However, due to terrorist attacks, blast-related injuries are those that both civilian and military medical personnel should be prepared to treat [1]. Explosive devices are often preferred by today's terrorists, because they are not only relatively inexpensive, but readily designed, assembled, transported, and detonated. As of 2012, bomb blasts accounted for the vast majority of all of terrorist attacks worldwide, and the trend continues upward [2].In addition, devastating explosions can occur outside the military and political environment [3].

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25.2 Pathomechanics and Pathophysiology

25.2.1 Blast Physics

Detonation is the rapid chemical decomposition of an explosive into a gas [4]. When an explosion occurs, space previously occupied by the explosive material is filled with gas under high pressure and temperature, which expands radially outward as a blast wave moving at supersonic speed. Air is highly compressed on its leading edge ("overpressure") creating a shock front. The body of the wave, including the associated mass outward movement of air, called the blast wind, follows this front. The blast wind, which travels slower than the blast wave, can propel people and objects considerable distances and may be as damaging as the original explosion [5, 6]. In an open area, the overpressure that results from the blast generally follows a well-defined pressure/time curve, called a Friedlander wave, which has an initial, near-instantaneous spike in the ambient air pressure (Fig. 25.1) [7]. This pressure quickly declines and is followed by a negative pressure wave that sucks debris back into the area. A pressure/time curve can vary depending on the local topography, presence of walls or other solid objects, and whether the blast is detonated indoors or outside. The blast wave can reflect off, and flow around, solid surfaces. Reflected waves can be magnified eight to

N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_25

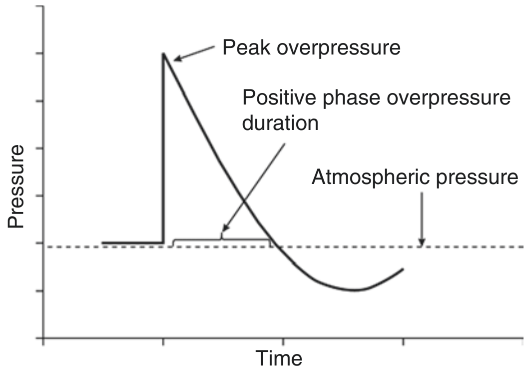

Fig. 25.1 This graphical depiction of a Friedlander wave shows the initial, near-instantaneous spike in the ambient air pressure that quickly declines, and is then followed by a negative pressure wave

nine times and cause substantially greater injury [8, 9]. Blasts that occur in buildings and other confined spaces can be more lethal because of the increased energy of the complex and reflected waves [10, 11]. The medium through which the blast wave moves is also a factor in blast intensity. Owing to its increased density, water allows for faster propagation and a longer duration of positive pressure, accounting for the increased severity in that environment. The distance from the explosion's epicenter also factors in, with pressure wave decay occurring roughly as the inverse cube of the distance.

The velocity, duration, and magnitude of the overpressure from the blast wave are dependent on several issues, including the physical size and the type of explosive in the charge being detonated [13]. Explosives can be categorized as either high or ordinary [14]. In high explosives, the chemical reaction is triggered by a mechanical shock wave that travels at a high speed causing the explosive to detonate rapidly [4]. High explosives further possess a shattering power, or so-called brisance. In contrast, ordinary explosives, such as gunpowder, release energy more slowly by deflagration, a process involving rapid chemical burning.

25.2.2 Blast Injury Classification

Blast injuries are categorized as primary, secondary, tertiary, or miscellaneous [4, 10].Primary blast injuries are caused by the sudden change in environmental pressure by the blast wave [5].The organs most commonly affected are the lungs, ears, bowel, central nervous system, and cardiovascular system. Severe primary blast injuries are rarely seen in survivors because one who is close enough to sustain such injury is usually killed immediately by fragments [15]. Secondary blast injuries occur from objects that have been energized by the explosion to become projectiles. Tertiary blast injuries result when a victim is thrown against the ground or an object or is injured by the collapse of a structure. Miscellaneous blast injuries include exposure to dust, thermal burns from an explosion, or burns from fires started by the blast. Any of these categories of blast injury may affect the musculoskeletal system.

25.2.3 Mechanisms of Orthopedic Injury

Musculoskeletal trauma resulting from an explosive blast is manifested as a primary, secondary, tertiary, or miscellaneous blast injury, in isolation or in combination. Although relatively uncommon in survivors, with primary blast injury, the direct effects of changes in atmospheric pressure caused by the blast wave can cause fractures and are probably responsible for limb avulsions in those exposed to stress waves of high intensity [16, 17]. Mellor and Cooper showed that limb amputation had a grave prognosis, in that only 9 of 52 servicemen who sustained amputations from explosive blasts survived [18]. Hull analyzed 41 blast amputations in 29 servicemen who survived to reach medical care, and noted in the lower limb, the prevalence of traumatic amputation was significantly higher ($p<0.001$) at the level of the tibial tuberosity than at other sites [19]. In the upper limb, the tendency was for the traumatic amputation to occur through its distal portion, but this was not statistically significant. The pattern and mechanism of traumatic limb amputation by explosive blasts were studied by Hull and Cooper [20]. They reviewed the cases of 100 consecutive individuals who had died in bomb blasts (34 of whom had one or more major traumatic amputations), subsequently performed computer modeling with finite element analysis, and then carried out explosive trials using goat hind limb bones. Of 73 upper and lower limb amputations in their study, only one occurred through a joint (the knee). They determined that major limb amputation by an explosive blast is a combination of blast-wave–induced fracture, due predominantly to coaxial forces, followed by limb avulsion through the fracture site by dynamic forces (the blast wind) acting on the whole limb.

Secondary blast injuries caused by flying casing fragments or other debris are the blast injuries that most often involve the musculoskeletal system [21]. Sufficiently large fragments can cause direct limb amputation [20]. Although conventional military explosives may create multiple fragments with initial velocities of up to 1800 m/s [22], Bowyer et al. [23] indicated that most casualties who survived to reach surgical facilities had been struck by fragments with a velocity of <600 m/s. The aerodynamic drag on these irregularly shaped projectiles also results in rapid deceleration outward from the point of detonation [24, 25]. Therefore, depending on the distance from the blast, fragments that strike the body can range from high to low velocity, without the streamlining seen with bullets. There are other ways in which low-velocity fragments from explosive munitions behave differently from low-velocity bullets. Upon striking a tissue, even at a low velocity, these fragments may exhibit a tumbling or so-called shimmy effect that can increase the amount of tissue damage [26, 27]. Also, blast fragments often carry environmental debris into the wound, and they frequently cause more severe tissue injury than do low-velocity bullets [22, 28–30]. Furthermore, a large, slow projectile can crush a large amount of tissue, and fragmentation may occur within the body greatly increasing temporary cavity effects [31]. One or a combination of the above factors likely account for the qualitative differences often seen between the tissue damage caused by explosive fragments and the damage caused by low-velocity gunshot wounds. Huang et al. showed in an animal study that extremity injury from a high-velocity fragment can aggravate blast injury to the lung [32]. The use of modern body armor that gives some protection to the thorax and abdomen from secondary blast injury has led to a relatively greater percentage of fragment wounds to extremities including brachial plexus injuries [33–35].

Tertiary blast injuries are caused by the blast wind which can accelerate bodies in its path and cause wounds of varying severity at a lesser distance from the point of detonation than that reached by secondary missiles [5, 25]. Often, victims tumble along the ground, sustaining multiple injuries, or are hurled through the air until they strike or are impaled on objects [25]. Fractures, crush injuries, amputations, and severe soft tissue lacerations and contusions are all possible [36]. Miscellaneous orthopedic quaternary blast injuries are much less common than secondary blast injuries and may include burns from the thermal effects of explosions or from secondary fires [37].

25.3 Treatment Principles

25.3.1 Nonoperative Treatment

In the field, the primary survey should follow the paradigm, control of catastrophic hemorrhage, airway, bleeding, and circulation (<C>ABC), in that priority during the initial resuscitation [38]. Open wounds should be covered with sterile dressings and any fractures should be gently aligned and splinted before transport. Bleeding from blast and fragment injuries can often be controlled by direct compression, and those extremity wounds that have severe or uncontrolled bleeding should have immediate tourniquet placement [39]. The time of tourniquet application should be clearly noted and communicated to all personnel directly involved in the care of the patient. In the casualty receiving area of a field hospital or in an emergency room, the patient's vital signs should be reassessed; large-bore venous access should be established if not established already, and appropriate resuscitation should be carried out [40]. Intraosseous access is an alternative if intravenous access is difficult. For major hemorrhage, a transfusion ratio of 1:1:1 for packed red blood cells, fresh frozen plasma, and platelets is used. Tranexamic acid, an antifibrinolytic, has been shown to be efficacious in reducing blood loss after trauma [41] and is often used in treatment of battlefield blast casualties.

A secondary survey is performed to include a thorough examination of the musculoskeletal system. Dressings and splints are removed as necessary to check the status of soft tissues, fractures, and neurovascular functions. Although fractures or dislocations may have been treated with splints in the field, they should be reassessed to ensure that there is no skin or neurovascular compromise and then re-splinted as indicated [42].

25.3.2 Antibiotic Prophylaxis

Musculoskeletal wounds caused by explosive munitions are contaminated with bacteria and associated with a high risk of infection, and antibiotics are important adjuncts to the surgical treatment of these injuries [43]. Ideally, antibiotic treatment should begin within 3 h of wounding [44, 45]. Early use of cefazolin or another intravenous first-generation cephalosporin should be given for all extremity injuries [46]. To provide protection against *Clostridium tetani*, the cause of tetanus, all patients should receive tetanus toxoid, and those who have not been immunized should receive anti-tetanus immunoglobulin as well [47–49]. For additional protection, patients with severe injuries with soil contamination and tissue damage with areas of ischemia, a penicillin should be added to provide coverage against anaerobes, particularly *Clostridia* species, or, alternatively, erythromycin, chloramphenicol, or a cephalosporin [50, 51]. When a blast injury includes severe contamination and high-grade open fractures, coverage for gram-negative organisms with an aminoglycoside antibiotic has traditionally been added [50, 52, 53]. However, its use has been questioned because it may lead to the development of resistance. Injured US service members from the Iraq and Afghanistan wars often had wounds that were colonized or infected with multidrug-resistant strains of *Staphylococcus aureus*, *Acinetobacter calcoaceticus-baumannii* complex, *Pseudomonas aeruginosa*, and *Klebsiella pneumonia* [46]. It is uncertain if additional gram-negative coverage is necessary or if it would potentially complicate wound care.

Although not adequately studied for the treatment of war wounds, a polymethyl methacrylate antibiotic bead pouch may be an efficacious means of dealing with high-grade open fractures caused by explosive devices [54, 55]. In wounds involving severe osseous and soft tissue injury, this technique can deliver high local concentrations of an aminoglycoside antibiotic, decrease wound dead space, and reduce bone desiccation until coverage is achieved.

25.3.3 Treatment of Selected Small Fragment Wounds

Nonoperative treatment of selected small fragment wounds can be successful [46, 56, 57], but not all surgeons follow this approach because these injuries usually occur under battlefield conditions, where wounds often have heavy contamination, and there can be delays in medical evacuation [58]. Coupland reported a case series of 68 survivors who had sustained a total of 89 wounds from hand grenades [59]. Twenty-four of these wounds were treated with dressings and intravenous antibiotics without primary surgery, and the only complication was a wound hematoma. It was recommended that soft tissue fragment wounds <1 cm in size without evidence of hematoma or injury to a vital structure be initially managed nonoperatively. Bowyer reported on the treatment of 1222 small fragment wounds sustained by 83 patients during the 1979–1989 Soviet-Afghan War [24]. Of these wounds, 866 met the following prerequisites for nonoperative treatment: (1) involvement of soft tissue only with no breach of pleura or peritoneum and no major vascular involvement, (2) an entry or exit wound <2 cm in maximum dimension, (3) not frankly infected, and (4) not caused by a mine blast because these wounds tended to have extensive contamination. Nonoperative management consisted of cleaning and dressing the wound, tetanus prophylaxis, and parenteral administration of benzylpenicillin for 1 day followed by oral administration of penicillin V for the next four days. The only complications were superficial abscesses involving two wounds (0.23 % infection rate). Performing surgery merely to remove small metal fragments in soft tissue is usually unnecessary [60–62].

25.3.4 Surgical Treatment

25.3.4.1 General Principles

Although the war surgery literature stresses the need for complete wound debridement, this is not always easy to accomplish and is not uncommonly performed inadequately [28]. The key to success is meticulous wound debridement with excision of nonviable tissue and foreign material likely to cause infection [63]. Authors in North America and Sweden use the term *debridement* to describe the entire surgical procedure in war wound treatment, but in the United Kingdom and France, the term has typically referred only to the first stage of the operation, in which the wound is unbridled (laid open) in preparation for formal wound excision [64].

There are a number of important technical points to consider during the actual wound surgery, many of which are similar to those used in the treatment of high-grade open fractures in civilian practice [42]. A tourniquet may be applied (if available), depending on the site of injury, and inflated if there is uncontrollable bleeding. Before the surgery is begun, the wound is cleaned of gross contamination, with a brush if needed (Fig. 25.2). Appropriate extending incisions, usually in the axis of the limb, should be used to enable exposure of the missile track, nonviable tissue, and foreign material [64]. The wound should be copiously irrigated under low pressure [65] using 3–9 l of normal saline or lactated Ringer's solution to help remove bacteria and foreign material. Fasciotomy for compartment syndrome, a diagnosis that is usually made clinically at the time of the secondary survey, may be required at the time of debridement [42].

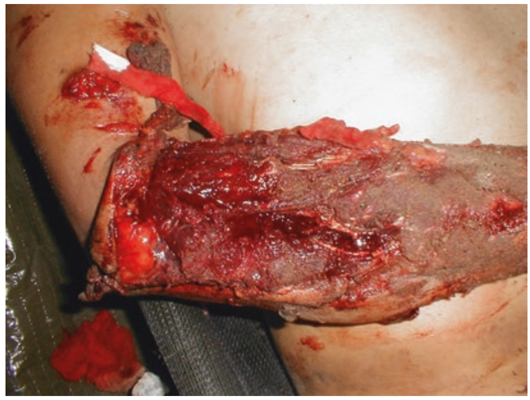

Fig. 25.2 This 20-year-old Marine sustained severe injury to his right upper extremity from an Improvised Explosive Device (IED) detonation in Iraq. In addition to the magnitude of injury, note the extensive soil contamination and muscle devitalization

Debridement of skin should be conservative because of skin's inherent resiliency and to facilitate delayed wound closure; and only grossly damaged skin should be excised, usually in an elliptical fashion for smaller wounds [29]. The cornerstone of war wound surgery is removal of all nonmetallic foreign material and excision of nonviable fat, muscle, and fascia back to healthy tissue. Viable tissue can be differentiated from nonviable tissue on the basis of its color, consistency, contractility, and ability to bleed [66, 68], although these are imperfect guidelines at best [63]. Of these tissue features, active bleeding from muscle and/or bone fragments is the one most consistently predictive. Removal of metallic fragments is not specifically the goal of debridement unless they are intra-articular or compromising neurovascular structures [69]. When there is osseous involvement, as much bone as possible is saved to provide stability, but small fragments detached from their vascular supply are removed. Contaminated bone ends should undergo curettage to remove foreign material. If repair of damaged tendons and nerves is deemed possible, they may be tagged with suture [47, 67] or left untagged *in situ* [68] for secondary surgery. Wounds should be dressed open, with enough bulky gauze to absorb the wound drainage, and should not be closed until they are clean and granulation tissue has appeared. Unless infection supervenes or additional debridement is needed, the wound should be ready for delayed primary closure, skin grafting, or other coverage four to six days after the primary surgery [28, 70].

The injured part can be immobilized with a bulky dressing, plaster of Paris, traction, or external fixation [28, 71, 72]. Has et al. employed external fixation to treat 215 (16.3 %) of 1320 open upper and lower limb fractures, mostly from exploding devices and reported that twenty fractures (9.3 %) were complicated by osteomyelitis and another twenty-one (9.8 %) had nonunion requiring secondary surgery [73]. Although they did not grade the fractures or indicate the criteria for use of external fixation, they concluded that proper wound treatment combined with external fixation was the treatment of choice for open fractures caused by exploding ordnance. Other authors have used external fixation for open fractures associated with blast and fragment wounds [62, 74].

In our experience and that of others, repeat debridement may be necessary for high-energy blast injuries because the zone of tissue ischemia tends to evolve over several days, and serial debridements should be performed every 24–48 h as indicated to remove necrotic soft tissue to decrease the risk of infection [42, 60, 75]. Although inadequate wound debridement is the most common technical error in treating blast and fragment injuries, some authors have also pointed out the pitfalls of excessive excision of war wounds [76–78].

One should have a low threshold of suspicion for compartment syndrome in patients with extremity injuries due to exploding ordnance. In addition to the acute onset of compartment syndrome after injury, it can also develop or evolve occultly in those patients that have a combination of extremity blast trauma, resuscitation with 5 or more liters of crystalloid, and/or more than 5 units of fresh frozen plasma in conjunction with medical evacuation by air [79]. If there is any concern about possible compartment syndrome, appropriate fasciotomies should be performed before aeromedical evacuation.

25.3.4.2 Extremity Amputations

Limbs beyond salvage should be amputated – in essence, a category of debridement – at the most distal possible level through healthy, uninjured tissues leaving the residual limb open (Fig. 25.3) [28, 42, 81]. Careful and thorough debridement should be carried out to remove all devitalized or contaminated tissues, and special emphasis should be placed on removing dirt, cloth, organic matter, and other nonmetallic foreign bodies. In cases of injuries due to land mines or IEDs, the blast often propels dirt and other debris proximally along tissue planes of the leg so that the extent of injury and contamination is often more proximal than initially appreciated [82]. Inadequate exploration or excision of these wounds and poor amputation technique can cause serious early and late postoperative complications, including sepsis, osteomyelitis, painful scar tethering, and chronic bone exposure, often necessitating revision surgery [82, 83]. Amputation bone ends should be trimmed or shortened as appropriate, and the residual limb should be left open and covered with a bulky absorbent dressing which can be secured to the residual limb with Ioban Steri-Drape™ or similar material, which also helps to decrease external drainage. A posterior splint in cases of below-knee amputation will keep the knee extended during initial treatment to help prevent flexion

Fig. 25.3 The author (center) with his U.S. Marine Corps far-forward surgical team performs a transfemoral amputation through viable tissue in a 23-year-old Afghan National Army soldier who was injured in an IED blast

contracture. Repeat debridement in 24–48 h may be clinically indicated, and delayed primary closure may be accomplished when the wound is clean and granulating [42]. When the distal part of the tibia has been shattered by an antipersonnel mine, there is usually severe contusion and contamination of the muscles of the proximal anterior, lateral, and deep posterior compartments with relative sparing of the gastrocnemius [81]. Coupland described a medial gastrocnemius myoplasty technique as a means to maintain a tibial residual limb of acceptable length when a conventional below-the-knee amputation cannot be done because the soft tissue is insufficient but the gastrocnemius is intact [84]. In a series of 111 acute below-the-knee amputations performed for war injuries, Simper reported that 74 (67 %) required more than one debridement, and the mean time to delayed primary closure was 6.4 days (range, 3–35 days) [80]. Ninety-six residual limbs (86 %) healed without complications, 14 required revision, and one underwent above-the-knee amputation because of *Pseudomonas* infection.

25.3.4.3 Dismounted Complex Blast Injuries

Although orthopedic surgery performed on personnel severely wounded on the battlefield is treated according to the principles of damage control orthopedics [85], some injury patterns are much more difficult to treat than others. Among the constellation of battlefield blast and fragment injuries, the most challenging to successfully treat are those caused from buried improvised explosive devices (IEDs) that are detonated while a service member is on foot patrol. During such patrols, it is common for an IED to be triggered by the service member's lead foot resulting in an upward and backward blast that passes through the extremities, groin, and buttocks [86]. Personnel often carry their weapon in the "low ready" position in which their non-dominant hand and arm are more exposed to the effects of the explosion. Also, there is an associated four-fold increase in perineal and genito-urinary injuries. These injury patterns have been termed Dismounted Complex Blast Injuries (DCBI) [87]. Severe cases often involve bilateral proximal lower extremity amputations, upper extremity injuries or amputations, open pelvic fractures, genitourinary trauma, and abdominal wounds [88]. Early hemorrhage control is paramount, and resuscitation utilizing massive transfusion therapy including blood components is usually needed. High mortality is associated with DCBI, and caring for these patients is resource intensive and requires a team approach for the best chance of survival [89].

25.3.4.4 Junctional Injuries

The term junctional injury refers to damage to tissues spanning the root of an extremity and adjacent torso, pelvis, or abdomen and often involves vascular injury too proximal to be controlled by conventional tourniquets [90]. Junctional injuies in the military context usually result from explosive blast-associated high lower or upper extremity amputations, with or without intracorporeal vascular injury, pelvic bony and soft tissue trauma, and other high-energy–associated injuries (Fig. 25.4). Lower limb proximal traumatic amputations represent an extreme form of junctional zone injury, and are associated with profound hemorrhagic shock, which, if untreated, is rapidly fatal. Junctional injury was responsible for 6.5 %

Fig. 25.4 A 21-year-old Marine sustained this junctional trauma in a Dismounted Complex Blast Injury (DCBI) with penetrating wounds of the perineum, as well as extensive lower extremity injuries. The thigh-high tourniquet that is not effective in controlling intra-pelvic bleeding

($n=93$) of nonsurvivable injuries and 11.7 % ($n=104$) of potentially survivable injuries on the battlefield [91]. The difference between nonsurvivable and survivable injury was mostly related to an open pelvic fracture component with abdominopelvic exsanguination. Associated pelvic fractures are most commonly of the anterior-posterior compression type, possibly related to forced abduction of the femurs, but lateral compression and acetabular fractures can also occur and may be due to tertiary blast effects. Temporary reduction of pelvic volume with a circumferential compression sheet or pelvic binder may be indicated in unstable pelvic ring injury patterns. Patients can additionally sustain trauma to the upper limbs, including amputations, and retroperitoneal and intra-abdominal injuries. Survival from this injury pattern is possible, when prehospital hemorrhage is successfully controlled.

In severe junctional injuries with high amputations, a tourniquet is often not useful because there is no residual limb left for it to be applied to. A combination of direct pressure at the site of bleeding and topical hemostatic agents may be effective but can be difficult to maintain in place, particularly when casualties have to be moved. Passing the securing bandages over the patients' shoulders, rather than around the pelvis, may help to maintain pressure on the wound and keep hemostatic agents in place. Indirect pressure on the artery above the site of the injury may also be helpful if hemorrhage control cannot be obtained with direct pressure.

Improvements in personal protective gear that include tiered antiballistic paneled protective undergarments ("blast boxers") have helped mitigate proximal thigh and perineal soft tissue injury from a dismounted IED detonation. The concepts of Tactical Combat Casualty Care have improved outcomes in the prehospital phase of care [92]. New junctional hemorrhage control devices include the Combat Ready Clamp (CRoC; Combat Medical Systems), Abdominal Aortic Tourniquet (AAT; Speer Operational Technology), and the Junctional Emergency Treatment Tool (JETT; North American Rescue). The CRoC has recently been deployed to Afghanistan but has few documented uses and minimal data on efficacy. This device addresses junctional major vascular injury only and not pelvic stabilization.

Rapid medical evacuation is associated with increased survival [93]. Acute care is then optimized by the tenets of early surgical hemorrhage control and damage control resuscitation to concomitantly correct the coagulopathy of trauma [94]. In conjunction with trauma surgical interventions, orthopedic intervention is directed at pelvic ring stabilization and debridement of bony and soft tissue injuries of the lower extremities, according to the principles of extremity war surgery [95]. Sequential debridement at least every 24–48 h is vital to minimize contamination and infection. Particularly problematic with this mechanism of injury and contamination are multidrug-resistant and invasive fungal infections. There is a continuing need for improved prehospital care, including field junctional hemorrhage control devices/techniques that may extend the survival time window from point of injury to medical treatment facility. The development of intracorporeal hemostatic agents and the utilization of freeze-dried plasma and tranexamic acid may aid acute resuscitation.

25.3.5 Other Considerations

Injury to nerves and blood vessels can pose special problems in the context of war wound surgery. Large nerves are resilient and may often be the only structures left running through the wound cavity [96]. If contused, the nerve should be left intact and the wound should be excised around it to allow the potential for recovery; if the nerve is lacerated, repair may be appropriate as a secondary procedure [28]. Treatment of vascular injuries due to explosive blast can be challenging, and in the damage control situation, temporary vascular shunts can be a valuable adjunct and is preferable to attempted reconstruction in austere conditions. Shunts in proximal injuries including veins have higher patency rates compared with those placed in distal injuries [97]. Reconstruction of vessels across a large wound cavity is often difficult, and the reconstructed vessel will need to be covered with muscle tissue or flaps [98].

Blast and fragment injuries of the hand present special challenges. The basic principles of war wound care apply to hand wounds, but with some modification. On the basis of a series of 147 patients with war wounds of the hand and forearm, which were caused by blasts and fragments in 108 (73 %), Jabaley and Peterson advocated a two-stage method of wound management [99]. In the initial operation, they performed a fairly conservative debridement that included minimum skin excision, fasciotomies if indicated, removal of devascularized bone, minimal debridement of divided nerves, trimming of frayed tendons, hematoma evacuation, and any needed arterial repair. At repeat operation three to five days later, any additional required debridement was accomplished, fractures were stabilized (with Kirschner wires), and, if appropriate, wound coverage was obtained. An infection developed in only one patient (infection rate, 0.68 %).

Although the fundamentals of war wound surgery apply to foot injuries, overzealous debridement and wound excision of all damaged soft and osseous tissue could cause irreversible loss of function; thus, moderation has been recommended [78]. When tendons are torn or damaged, the excision should reach healthy tendon, which can be tagged for later repair or reconstruction. Although small bone fragments devoid of their blood supply should be removed, excision of bone should be sparing to preserve the architecture of the foot [100]. After a satisfactory I&D has been performed, one of the most effective and expeditious methods of skeletal stabilization is application of external fixation [78]. Kirschner wires can also be used as temporary spacers in cases involving bone loss. Battlefield orthopedic wounds tend to be highly exudative, and those of the foot and ankle are no exception. Stabilizing injured limbs with external splints may not only interfere with wound examination, but splints may lose their rigidity if saturated with exudate. Whether splinting or external fixation is initially used, the goal is delayed closure by suture, skin grafts, or flaps when the soft tissues are ready. Negative pressure wound therapy (NPWT) is often a valuable adjunct in preparing the wound for eventual closure [78, 95].

Suspected penetrating injuries of major joints should be treated immediately, and arthrotomy should be performed if there is high suspicion or confirmation that penetration occurred [42]. The joint should be copiously irrigated, debrided of foreign material and nonviable tissue, and drained, with primary closure of the synovial layer (if possible) and delayed primary closure of the skin or, alternatively, use of skin grafts or flaps. Nikolic et al. [67] presented their results of treatment of war injuries involving major joints in 339 patients, 176 (51.9 %) of whom were injured by high explosive fragments. Early complications occurred in 77 (22.7 %) of the patients; 32 (9.4 %) had either joint or soft tissue infection and 81 (23.9 %) required subsequent reconstructive surgery. Concomitant injury of a joint and bowel is associated with a very high prevalence of septic complications, and the entire missile track, including bone fragments, bone margins, and retained missiles, should be regarded as contaminated and undergo meticulous debridement. Penetrating fragments can cause spinal cord or cauda equina injury, and, if there is concomitant bowel injury, the risk of infection is high. These injuries should be treated surgically along with the use of antibiotics. Spinal cord injury can occur even if fragments do not enter the spinal canal or cause apparent vertebral damage [66].

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26 The Role of the Anesthesiologist in the Response to Mass Casualty Catastrophic Events

Jack M. Berger, Vladimir Zelman, and Rodolfo Amaya

Disasters are catastrophic events that overwhelm a community's emergency response capacity, threatening public health and the environment [1]. Although disaster medicine is rapidly developing as a distinct discipline, it lacks a commonly accepted definition. Initially, the focus of disaster medicine was centered on the response to a catastrophic event with the intent to provide the greatest good for the greatest number [2, 3]. Traditionally, disasters have been thought of as natural in cause. Disaster physicians then must be prepared to fulfill a number of critical professional roles – rapid assessment of the health needs of affected populations, logistic and communication concerns, prioritization of airlifted medical resources, and patient triage and medical care – and have the political skills necessary to successfully work with a variety of local, state, federal, and international relief agencies [4].

In the quest for an increase in the efficiency of relief operations, disaster response organizations are considering a variety of new technologies that can be rapidly adapted to disaster operations. Such technologies include telemedicine, health data transfer over electronic networks such as the Internet, geographic information systems, geographic positioning systems, and a number of other emergency data management systems [5]. It is clear that in the case of such disasters as a train derailment or multiple soldiers injured by a land mine, communication systems remain intact, transportation means and routes remain open, and receiving centers are ready, staffed, and prepared. In these cases, the first responders have the responsibility of extricating the injured as quickly as possible and transporting them to the definitive healthcare receiving centers. But during catastrophic events, either natural or man-caused, traditional response teams may not have access to the injured, the number of injured and/or dying may be overwhelming, communications may be down, roads may not be passable, hospitals may be damaged, power may be absent, and the mass

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_26

casualties may be multifactorial, e.g., toxic exposures combined with physical trauma.

In emergency medical care, response time is critical. Observations made during earthquakes in Tangshan, China (1976), Campania–Irpinia, Italy (1980), and Armenia (1988) indicate that 85–95 % of the victims who survived being trapped in damaged buildings were extricated within 24 h [6–9]. Unfortunately, current response plans that rely on local hospitals and disaster-medical-assistance teams may be insufficient to prevent high mortality [10]. And in the case of terrorism, first responders themselves must be protected from the infective, chemical, inhalation, or explosive agents. They must also be trained in rapid assessment of physical condition and offending agents, and make triage decisions rapidly for the most expeditious utilization of limited available resources. Treatment in the field will be necessary, since transport will be limited and mobile "hot zones" will require time to establish [11]. Reviews of proposed emergency medical response needs for earthquakes [10], for victims of combined conventional injuries and concomitant nerve agent intoxication [12], for management of crush-related injuries after disasters [13], and for other disasters have been published. But the role of anesthesiologists has rarely been addressed except for their roles in the hospital or in mobile acute care settings [11].

The estimates are that *220,000 people died* and over *300,000 were injured* in January 2010 following the devastating 7.0 magnitude earthquake *in Haiti* with a total *population* at that time of *10.2 million* (50 % living in the urban areas). Fifty healthcare facilities were destroyed and not available to treat the injured [14].

By comparison, the Northridge earthquake was an earthquake that occurred on January 17, 1994, at 04:31 Pacific Standard Time in Reseda, a neighborhood in Los Angeles, California, lasting for about 10–20 s. The earthquake had a "strong" moment magnitude (M_w) of 6.7, but the ground acceleration was one of the highest ever instrumentally recorded in an urban area in North America, measuring 1.7 *g* (16.7 m/s^2) [15], with strong ground motion felt as far away as Las Vegas, Nevada, about 220 miles (360 km) from the epicenter. The peak ground velocity in this earthquake at the Rinaldi Receiving Station was 183 cm/s (6.59 km/h or 4.09 mph), the fastest peak ground velocity ever recorded. In addition, two 6.0 M_w aftershocks occurred about 1 min after the initial event, and again 11 h later, the strongest of several thousand aftershocks in all. The *death toll came to a total of 57 people*, and there were over *8700 injured*. Eleven hospitals were damaged and had to transfer out their patients to other hospitals. The estimated *population* of Los Angeles County in 1994 was *9,100,000*.

How can a country, state, county, or city prepare for a catastrophic event that kills nearly a quarter million inhabitants and injures 300,000? There are 122 hospitals in Los Angeles County for a population in the catchment area estimated at possibly 15,000,000 people. What if the same magnitude earthquake that just struck Japan occurred on the US west coast? How much damage would there be and how many people would be killed? The damage and death toll from an offshore earthquake and tsunami near Seattle, Portland, San Francisco, Los Angeles, or San Diego of the same strength as the Japanese earthquake of March 2011 would depend on where the epicenter of the quake was located. However, it is safe to assume that if a 9.0 or larger shallow earthquake that hit 100 miles off the coastline of any of these cities, the damage would be incalculable, and the death toll could be more than one million [16].

In this chapter we will explore the *roles of anesthesiologists* in the initial response to various types of catastrophic events with mass casualties. The word "roles" is emphasized, since the function of an anesthesiologist in the initial response will change depending on the circumstances of the disaster. For example, following the earthquake in the Los Angeles area in 1994, there were many injured but relatively few fatalities. The roads were passable for the most part, and the trained first responders (firemen and EMTs) were responsible for rescuing the injured and transporting them to hospitals for resuscitation, surgery, etc. Anesthesiologists functioned by providing operating room anesthesia for emergency surgical intervention.

But in the case of a devastating earthquake such as in Haiti or the tsunami in Japan, the concept of multiple mobile (*on foot*) trained and equipped surgical response teams, which would

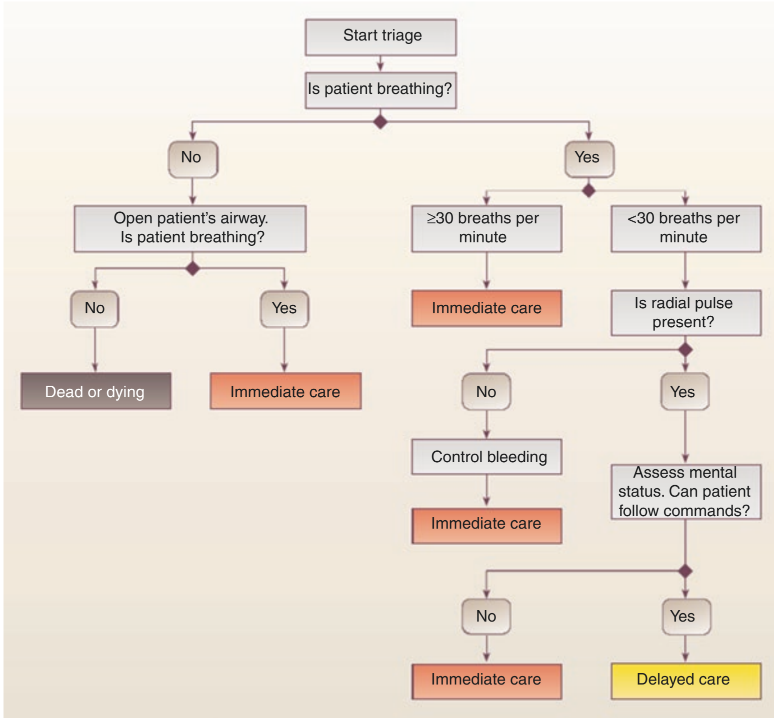

Fig. 26.1 The Modified Simple Triage and Rapid Treatment system. Victims who can walk are identified first and receive first-aid measures only. The remaining patients are classified according to the algorithm shown. Victims considered to need immediate care (*red*) are assessed and treated before those whose care can be delayed (*yellow*). The algorithm should be used with caution in classifying children younger than 8 years old, since it becomes increasingly less reliable with progressively younger patients [10] (Reproduced with permission)

be capable of performing on site surgical intervention, could save many lives until the patients can be transported to temporary or fixed medical facilities. Earthquakes cannot be predicted, but hurricanes and tsunamis do provide a window of opportunity to mobilize sheltered response teams. In the case of a terrorist attack with the release of toxic gases, mass casualties can occur rapidly from paralysis of the nervous system, but can lead to physical trauma associated with motor vehicle accidents, falls, etc., complicating the work of the medical response teams which must be equipped with protective devices and clothing in order not to become victims themselves. And is it even possible for responders to provide on site surgical intervention while wearing this necessary protective equipment? Intravenous access and airway management are both in the realm of expertise of anesthesiologists. But should they be in the field or await the arrival of patients transported to mobile hospitals outside of the exposure area?

Schultz, Koenig, and Noji proposed an initial disaster response scheme following an earthquake [10]. The response of course, begins with a triage process. But the triage responder may be different for different types of mass casualty disasters (see Fig. 26.1).

Shultz et al. then go on to describe a proposed treatment protocol for the field victims once transported to a secondary treatment center [10]. At this point additional triage and more definitive treatment can be provided (see Fig. 26.2).

But where does the anesthesiologist fit into these schemes? During daytime hours, most anesthesiologists would be in hospital operating rooms attending to patients. In the evenings, they would be scattered all over the city in their homes. On weekends, most would not be working and may be out enjoying various forms of recreation. So how do we design a response system that would take into account all contingencies for different types of disasters, different times of the day, and different access to the victims?

In effect, we cannot anticipate every contingency. But Schultz et al. do give us a basis upon which to design an emergency backpack that could be distributed to all anesthesiologists and maintained either in their cars or at depositories in neighborhoods, readily available for first response

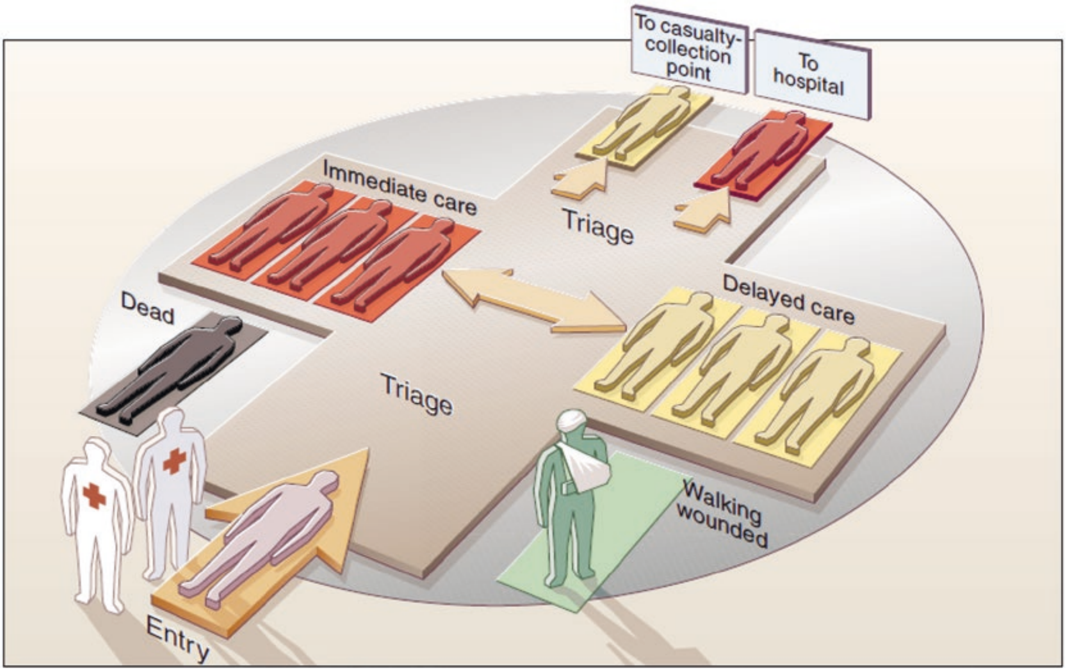

Fig. 26.2 Operations of a disaster-medical-aid center. As patients arrive, they undergo triage according to the Simple Triage and Rapid Treatment system. Dead or dying patients (*black*) and minimally injured victims (walking wounded, *green*) are identified. Those considered to require immediate care (*red*) or delayed care (*yellow*) are further evaluated. Patients with at least 50 % probability of survival if treated receive care. All victims are periodically reevaluated. Once their condition has been stabilized, patients are evacuated to nearby hospitals or casualty-collection points [10] (Reproduced with permission)

and field resuscitation and treatment (see Table 26.1) [10]. In case of a catastrophic event, those responders who survived themselves would mobilize to predetermined assigned locations with their equipment. Telecommunications may or may not be functioning and cannot be relied upon to coordinate efforts. Gasoline- or battery-powered generators could be stored at various points around cities along with tents to set up mobile medical facilities and accessible to those who have been designated as first responders. Security for these supplies would be a problem as well as restocking of expired medications. And of course the cost of such preparations would be high. Is the public willing to bear the costs in terms of taxes for the possibility of being rescued from a "possible" future catastrophic event?

What would be the role of the anesthesiologist who is engaged in an operative case at the time of a major catastrophe that damages or involves the hospital itself?

If a natural disaster were to occur such as a major earthquake, that caused immediate damage to a hospital structure, immediate evacuation of the operating rooms would have to be accomplished. If ceiling debris was falling onto the surgical field, fire had broken out, or the structure of the hospital had been damaged threatening collapse of the building, the anesthesiologist would need to take charge of the evacuation of the patient from the operating room and hospital who at that moment was under general anesthesia and incapable of spontaneous ventilation. Medications like ketamine are available which when administered would allow the anesthesiologist to discontinue the inhalation anesthetic gases and all that is necessary is an Ambu™ bag in order to ventilate patients with air. The surgeon can quickly close the wound with several large sutures. But a coordinated escape plan must be implemented to move the patient to safety. Elevators would not be functional, and the patients must be moved on

Table 26.1 Contents of medical-disaster-response backpack and equipment module

Maintenance of circulation	Airway management	Orthopedic treatment	Miscellaneous
Atropine (injectable)	Nasopharyngeal airway tubes (child)	Sodium bicarbonate (injectable)	Prochlorperazine (injectable)
Calcium chloride (injectable)	Nasopharyngeal airway tubes (adult)	Cephalexin (oral suspension)	Dextrose (50 %, injectable)
Epinephrine (1:1000, injectable)	Oropharyngeal airway tubes (child)	Cervical collar (adult)	Diazepam (injectable)
Furosemide (injectable)	Oropharyngeal airway tubes (adult)	Ceftriaxone (injectable)	Diazepam (tablets)
Intravenous catheters	Cricothyrotomy airway tube	Clindamycin (injectable)	Diphenhydramine (injectable)
Saline locks	Albuterol inhaler	Fasciotomy kit	Erythromycin (tablets)
Intraosseous needles	Bag–valve– mask device	Ketamine (injectable)	Foley catheter setups
Saline (0.9 %)	Chest tubes with insertion setups	Mannitol (injectable)	Gentamicin (ophthalmic solution)
Saline (7.5 %)	Endotracheal tubes (adult)	Bupivacaine (0.5 %)	Haloperidol (injectable)
Nitroglycerin (spray)	Endotracheal tubes (child)	Lidocaine (1 %)	Insulin (regular human)
Nitroglycerin (transdermal)	Heimlich valves	Femoral-block needle (20-gauge × 17.8 cm)	Methylprednisolone (injectable)
Propranolol (tablets)	Prednisone (tablets)	Amputation kit	Nasogastric tube
	Saline (0.9 %)	Saline (0.9 %)	Obstetrical kit
		Nalbuphine	D5 1/4 normal saline

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The packaging of the supplies could be color-coded according to their intended use, as follows: red, maintenance of circulation; blue, airway management; green, orthopedic treatment; and gray, miscellaneous

gurneys or stretchers down the stairwells. This takes adequate personnel [17, 18].

The Fukushima Medical University Hospital is a general hospital with 778 beds and 30 departments in a 10-story building that was completed in 1987 [17]. The hospital is also specified as an emergency medical care center and is the only one equipped with a helicopter for emergency medical care in the Tohoku region of Japan. It is located in the north central part of Fukushima prefecture, 57 km distant from the Fukushima Daiichi nuclear power plant. At the time of the earthquake, 9 patients were present in the surgical department, including those under local anesthesia. The surgeries were stopped because of the strong shaking. The surgical lights were removed from the surgical fields, and the surgical fields and instrument tables were covered with drapes because of the significant amount of dust and dirt falling from the ceiling. There were no problems in the electrical system or oxygen and air supply. Some electronic medical record displays fell, but none of the biologic information monitors, anesthesia apparatuses, or devices of electric scalpels tumbled or fell. Later, commands were integrated by the manager of the anesthesiology department, and stretchers, bag valve masks, circulatory agents, and sedatives were prepared in each room in preparation for moving. Forty minutes after the earthquake, the order came through to suspend any surgeries that could be suspended, and the patients were transported to the intensive care unit on the same floor. Removal of all patients from the surgical department was completed by 2 h after the earthquake [17].

Regarding access to utilities at the hospital, there were no problems in the supply of electricity or gas, but the water service stopped for 8 days. The water tank volume is 700 tons, which corresponds to only 1 day of consumption for normal practice. They attempted to save water as of the following day (i.e., they canceled the outpatient clinic and did not perform elective surgeries and discharged inpatients as much as possible to about 70 % of the normal number). More than 100 tons of water was supplied by the water wagons daily, but the supply was mostly exhausted after 1 week [17].

Oxygen was provided from a stationary cryogenic liquefied oxygen storage system with a volume of 8600 m^3, which was sufficient for more than 14 days for normal consumption (at about 600 m^3 per week day). Normally, the oxygen store was supplemented once a week, and reserve cylinders were available for 0.75 days (7000 L _ 72 cylinders 5453 m^3). On the day of the earthquake, there was sufficient liquefied oxygen for about 10 days, which was not damaged by the earthquake, and the oxygen was supplied normally. There was no problem in the provision of air supply because compressed air was used; however, the potential for radioactive contamination was of concern, as described later in this article. No problems occurred with the small oxygen cylinders. Three days of reserved food was on hand for patients, along with about 7 days of reserved drugs and reagents for tests. Because medical service was limited, there were no shortages of food, drugs, or oxygen, but reagents for tests were slightly short, because production plants were also affected. Modification of food service was necessary (i.e., cooking rice with bottled drinking water and putting cling wrap on the work surface to reduce the necessity for cleaning) because of the suspension of the water supply. Water service was resumed 8 days after the earthquake [17].

Outpatient services were reinitiated for outpatients with appointments and inpatient surgeries, beginning with scheduled surgeries that had been suspended. About 3 weeks were required to resume normal hospital function. The gasoline shortage became serious at that time, and it was difficult to ensure reliable methods for the staff to commute because of the location of the hospital in the suburbs [17].

The Boston Marathon bombing attacks on April 15, 2013 demonstrated another scenario for anesthesiologists. The bombings occurred close to the finish line of the race within 2 miles of five world renowned hospitals and trauma centers. The attacks took place just before 3 pm in the afternoon when the change of shift was occurring, and so many more personnel were available to assist the victims than at other times of the day. It was a holiday in Massachusetts, and so elective surgeries were at a minimum allowing more availability of the operating rooms. The temperature was cool and so first responders on the scene were not treating many victims of heat exhaustion.

According to the Anesthesiology News in June 2013, anesthesiologists did not have as difficult a response to these bomb blasts as they might have had to a different type of attack [19]. Face, head, thoracic, and abdominal injuries were few. Injuries to the heart were also few. While severe, the injuries to the extremities were handled expeditiously paying particular attention to pain management including peripheral nerve blocks in addition to general anesthesia. When necessary for amputation victims, continuous peripheral catheters were placed. Many of these patients arrived from the blast scene with notes written on their chests with marking pens describing their injuries which facilitated triage. Anesthesiologists were sent to the emergency departments to help with initial assessment because phone communication with the field was not available, and ultrasound machines were used to assess vascular injuries.

In a more urban or isolated environment, casualties from blast injuries would have less chance of arriving at a treating facility in time for optimum treatment. And that is the quandary of any mass casualty event whether from a terrorist attack, natural disaster, or industrial disaster; one does not know when it will happen, where it will happen, how many victims there will be, the nature of the injuries, and the ability for first responders to reach the victims. So how do we prepare for all contingencies? Training exercises, triage protocols, and access to resource materials such as protocols on tablet devices that do not rely on electrical supply or the Internet may be helpful in assisting all providers of emergency healthcare in the face of mass casualty events. Essential medical supplies kept in backpacks of anesthesiologists as suggested by Schultz et al.

would provide the possibility of immediate local responses, and storage facilities throughout a city could be ready and equipped to become first response treatment centers [10].

The cost of such programs would be high, but the potential to save lives is great. Society has to decide on its priorities.

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Part IV

Treatment of Orthopaedic Injuries: Specific Orthopaedic Injuries

27 Hand and Wrist Injuries

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27.1 Introduction

Upper limb injuries including the hand and wrist are common in natural disasters and mass casualties. Imagine that the victims are subjects involved in high-speed accidents or natural disasters; they would all try to meet the disaster with outstretched hands. Later, when they struggle for survival, they need to do the utmost using their upper limbs. One could not fail to assume that the classical injuries described systematically in different regions of the body in textbooks would be the presenting pictures. However, if solitary fractures were encountered, the conventional management procedures still need to be followed. Nevertheless, under most circumstances, and it is the intention of this book, much more complicated injuries are expected: multiple fractures, soft tissue crushes, open wounds, contaminations and other associated injuries all coexist.

27.2 In the Field of Mass Casualties

Within the chaos and confusion of the rescue activities, the aim of the orthopaedic team, like everyone involved in the rescue, is to maintain survival and prepare for ultimate treatment. Assuming that the victim suffering from hand and wrist injuries has been cleared of life-threatening challenges, the attending clinician must complete a quick emergency evaluation to ensure that proper subsequent measures would be feasible.

27.2.1 Emergency Evaluation

27.2.1.1 Vascular Status of the Involved Upper Limb

In the assessment of an injured limb, the vascular examination is mandatory. The clinician must check the peripheral pulses, extremity temperature and capillary refill. Although the absence of a palpable pulse is important information for a possible vascular impairment, the presence of pulse or capillary refill does not necessarily guarantee an intact vasculature. Therefore if Doppler equipment is available, examination of the

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_27

injured and unharmed extremities should be carried out. If there is a clear indication of vascular obstruction due to external cause, it must be removed if possible.

27.2.1.2 Neurological Status of the Involved Limb

Cross neurological assessment can be difficult in the multiply injured patient who might be unconscious. However, the reflex status and the responses to strong pain stimuli give at least an orientation in respect to possible major deficits. This check-up must be performed routinely because information on an existing neurological deficit can be detrimental in the decision of salvage attempts versus amputation in severely injured extremities.

27.2.1.3 Soft Tissue Examination

Although proper assessment of the soft tissues cannot be done in the open field, a quick look and gentle handling in order to define the vascular state, contaminations and complexity of the injury will be helpful. The result of the quick assessment might lead to the immediate arrangement of simple splinting and/or water lavage of open wounds.

27.2.2 After Admission into Proper Set-Ups

The next stage of management is started at a proper set-up: either a temporary treatment camp or an equipped hospital, when the victim is transferred to that venue.

The examinations done on the disaster spot should be rapidly repeated. If facilities are available, light anaesthesia should be given to allow a proper examination of any open wound which might require simple surgical cuts to gain better exposures.

At this stage, signs of compartmental syndrome must be checked. Compartment syndrome is defined as an increase in the interstitial fluid pressure of sufficient magnitude to compromise the microcirculation and neuromuscular function [1–3]. If the magnitude and duration of the increase in this interstitial pressure are great enough, it will lead to irreversible tissue necrosis. Patients who have suffered an untreated or overlooked compartment syndrome will develop a Volkmann's ischaemic contracture that manifests clinically as a contracted non-functional limb.

Envelopes surrounding a soft tissue space in which the pressure increases may be the epimysium, an osseofibrous sheath, a fascia, the skin or a constrictive dressing which creates a restrictive volume within. The increased pressure may result from an increase in volume within the involved compartment by haemorrhage, perivascular infusions or fluid collection due to abnormal capillary permeability such as in prolonged ischaemia. If there is hypotension due to various causes, compartmental syndrome might be more prone to develop.

Once compartmental syndrome is confirmed, when the patient feels numbness over the involved limb gradually progressing to total loss of sensation, together with the clinical confirmation of ischaemia in the hand and fingers, immediate action must be taken to restore the distal circulation. The treatment of choice is dermato-fasciotomy since the intact skin acts as a thick limiting membrane contributing greatly to the compartmental syndrome. The usual concomitant existence of oedema in the skin would not allow expansion. The dermo-fasciotomy starts at the observed site of obstruction, following the forearm to the wrist area. Usually a single ventral cut is sufficient. However, under special circumstances, if a ventral cut is found inefficient, repeating a partial dorsal cut might have to be done.

27.3 Proper Planning

At this stage, a proper planning of the surgical procedures to be taken needs to be carefully taken. The general conditions and the specific local injuries are equally important in the decision.

27.3.1 Timing of Surgical Treatment

The following observations support immediate or early surgery:

(i) Good general conditions of the patient
(ii) Close injuries or clean wounds
(iii) Little or no other involvements of the other limbs
(iv) Need for vascular intervention because of obvious ischaemia

The following observations demand a delay of surgery:

(i) Poor general conditions of the patient. Hand and wrist surgeries are done under haematocrit which limits haemorrhage. Unless other limbs or other surgeries are required, otherwise the general conditions of the patient would not be a crucial contraindication for early surgery.
(ii) Open injuries at the problem site with contamination. Surgery on the hand follows a well-established "delayed primary surgery" principle which refers to open injuries of the hand where contaminations are severe. The intentional delay of operative procedures for a few days while the open wounds are continuously cleaned and antibiotics given to prevent infections has been known to give better results compared with immediate or early surgery [4].

27.3.2 Achievement Goal of Surgical Treatment

If at all possible, modern hand surgery sets a goal of perfection for all injuries. However, for the severely injured, one must give a careful objective assessment before any decision is made.

Management of hand fractures has often been criticised as being either over-conservative or overaggressive. The former criticism is related to a failure to endorse the basic requirement for fracture treatment, while the latter could be due to an overestimation of surgical promises and underestimation of the surgical limitations. Surgeons should accept that the choice of management technique in hand injuries needs to be governed by the same principles in fracture treatment without exceptions. But more flexibility, more demanding technique and more careful observations are mandatory for a satisfactory restoration of hand function [5].

27.4 General Principles of Management

The general principles of management should be identical with those of fracture treatment for long bones; nevertheless, difficulties in their application are real. Rather than weighing conservative versus operative treatment, as is discussed in most books on hand surgery, it may be more revealing to young surgeons to analyse some of the dilemmas that exist [6].

With healthy soft tissues perfect reduction can be achieved for unstable fractures that are not comminuted but occur linearly across the bone. However, when there is comminution and soft tissue damage, notably of skin and extensor tendon expansions, reduction may become very difficult or impossible. This often happens in severe hand injuries.

After perfect reduction for the transverse and spiral types of fracture, sufficient friction across the fracture lines exists to keep the fragments together. This, however, does not apply for oblique or comminuted fractures. Apparently stable reduced fractures still displace within an external splint or cast as oedema of the injured part subsides and when the patient moves the other fingers, which causes a chain reaction movement of the flexor/extensor tendons, thus producing displacing strains on the fracture sites. When soft tissue damages are extensive, losing stability and re-displacement become more likely and internal splintage could be adopted as a rule.

External splintage cannot be applied with multiple finger involvement with soft tissue damages. Hence stiffness needs to be overcome subsequently.

This depends on the degree of comminution, extent of separation and soft tissue situation. Very often these factors are not promising. When the soft tissues are injured and oedematous, even apparently favourable comminuted fractures do not join. Moreover, reduction may appear reasonable, and yet collapse and displacement follow immediately after the removal of the distraction force because of empty spaces within the site of the fracture. As long as these gaps exist, reduction cannot stay perfect.

Feasibility of fixation depends on the success of reduction. External means of fixation are therefore extremely difficult. Internal means of fixation, given the best technique, are also difficult. Filling the bone gaps with different types of spacers, for example, bone grafts and bone substitutes, makes the procedures more practical. The presence of soft tissue damage is an adverse factor.

The general principles of fracture management advocate operative treatment for all juxta-articular fractures so that the joint architecture is preserved and motion can start immediately. If reduction and fixation are technically impossible, the choice is a stiff, painful joint. Early fusion of the joint can be a compromise resulting in a slightly shorter finger with the injured joint in a functionally flexed position.

Kirschner wires (K-wires) are still the most commonly used implants in hand fracture fixation. Longitudinal introduction of K-wires produces good alignment but no rigid fracture fixation. If K-wires can be crossed over a fracture, the rigidity is reasonable. However, the tough cortical diaphysis of small dimensions usually does not allow the effective introduction of K-wire. If the K-wire crosses a joint, it does provide a little more stability through the control of joint motion. However, one may have to face infection, adhesions and motion loss.

Mini- and micro-screws and plates offer more versatile alternative means of internal fixation. These are good for linear fractures and large fragments but still work badly with comminuted ones without bone grafting. Wire loops are useful as supportive or additional means of fixation to limit rotation and give tension band effects. Solitary loops hold small, indispensable fragments well, but their application is technically difficult. It is therefore apparent that no single entity of implant is capable of satisfying all the need and flexibility in the choice of management. All implants carry the common disadvantage of inducing more soft tissue trauma, more tendon adhesions, joint stiffness and secondary procedures of implant removal. When applied to open fractures with significant tissue damages, these become dangerous.

In the management of hand fractures related to severe injuries, therefore, the only suitable implants could be the K-wires.

27.5 Hand Injuries with Fractures

Although hand injuries involved in natural disasters are complicated, affecting different tissues of the hand, for the sake of systematic discussing, one may assume that the principle of management for individual components could be applied. Hence four separate sections, viz. distal phalanx, middle and proximal phalanx, metacarpal and soft tissue injuries, are to be described as follows.

27.5.1 Fracture of Distal Phalanx

An axial K-wire driven through the tip of the finger to splint the fracture is a commonly practised method. This does not always need to be driven through the distal interphalangeal joint, and early movement in that joint can be implemented. However, the fragments may not be adequately reduced by the K-wire, and non-union is still likely [7].

Another technique to fix a fracture of the shaft of the terminal phalanx is the use of a pull-out wire. This is first passed through the base of the phalanx, which comprises the proximal fragment, and then passed either through the medullary cavity of the shaft of the distal fragment or subcutaneously by the sides of the phalanx to emerge at the finger tip and be secured over a dental swab and a button. The wire loop provides compression of the fragments. This wire loop is retained for 3 weeks, after which the fracture is usually sufficiently stable (Fig. 27.1).

Avulsions of either the extensor or the flexor tendon from the base of the distal phalanx require reattachment for preservation of tendon functions [8, 9]. This is achieved with pull-out wiring through the distal phalanx which emerges through the distal part of the nail or the tip of the finger.

Fixation of the bone fragment in tendon avulsion is a difficult procedure, and the consideration is purely technical. For a small bone fragment of less than one-third of the joint surface, it may be better to disregard the reduction of the fragment or concentrate on the reattachment of the tendon.

27.5.2 Fracture of Middle and Proximal Phalanx

Fractures of the middle phalanx usually occur after direct trauma and are frequently associated with extensor tendon injuries. Such fractures are likely to be transverse and are unstable. We prefer open reduction and internal fixation. This also enables early mobilisation for the extensor tendon injury. An intraosseous wire loop (0.56 mm) plus either an intramedullary pin (1.6 or 2 mm) or an oblique K-wire (1.2 mm) is the simplest means to fix most middle and proximal phalangeal fractures. In competent hands, a mini-plate with four holes and 1.5-mm screws or interfragmentary screws alone can be placed on the lateral aspect of the bone. Bone exposure is limited to one side of the phalanx, and better stability is achieved [10–12] (Fig. 27.2).

Special consideration should be given to fractures at the base of the proximal phalanx [13]. These are usually transverse with a short oblique element and are usually the results of direct trauma. A mini-plate and screw system provides the best stability here. This can be placed on the dorsolateral aspect of the bone, and meticulous care is required to repair the extensor retinaculum. When the fracture is too close to the articular surface, one must resort to intraosseous wire loop supplemented with biodegradable implants or adhesives.

The management of avulsion fractures depends on the sizes and locations. When they are on the lateral aspects of the joints and are

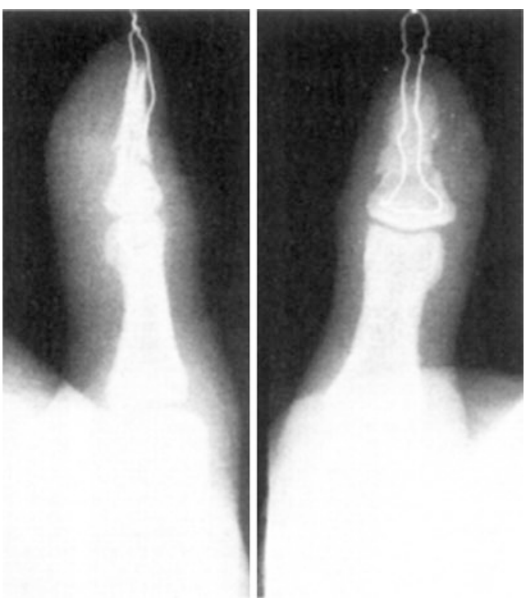

Fig. 27.1 Fixation of comminuted fracture of distal phalanx using pull-out wire loop

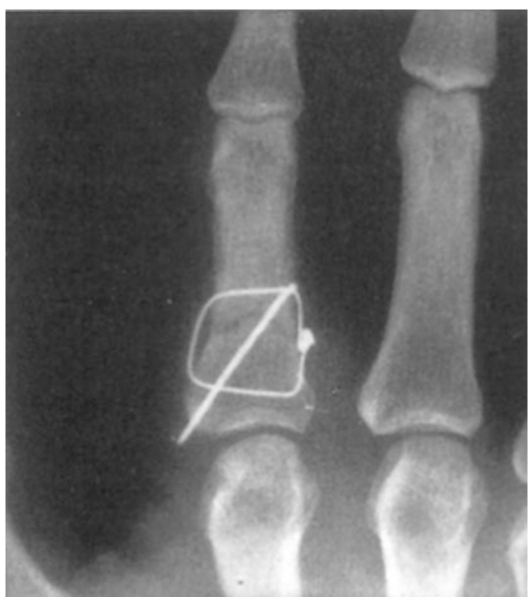

Fig. 27.2 Fracture of the proximal phalanx, fixed with an oblique Kirschner wire and an intraosseous wire loop

small, they are minor avulsions of the collateral ligaments and can be treated conservatively with cross-finger taping and early mobilisation. When they are associated with gross instability of the joint, they should be fixed with a small tension wire loop [14]. Avulsion of the anterior lip of the base of the middle phalanx occurs in dorsal dislocation of the proximal phalangeal joint and volar plate avulsion. Management depends on the size of the fragment [15, 16]. We follow the rule of the "thirds". When the fragment is less than one-third of the width of the base of proximal phalanx, early mobilisation can be started after a closed reduction.

A distinction must be made between condylar fractures and avulsion fractures, although the two may be associated. Condylar fractures are actually depression fractures of the part of the condyle. They are best fixed with mini-screws (1.5 mm) which may be incorporated in a mini-plate or a mini-condylar plate. The mini-condylar plates from the AO group [17] come in two sizes (2 and 1.5 mm) and have a small stylet at the distal part. The small stylet is meant to provide rotational stability to the fixation of the condyles. However, the stylet does not always match the drill hole well, may be too long and during insertion may distract the fragments in an inter-condylar fracture or may even shatter the fragments. They must be used with caution in small bones and in those with comminutions. When there is severe comminution, a mini-external fixator may be used, or one can consider the use of biodegradable implants or adhesives. It must be remembered that when comminution is severe, especially in situations of coexisting soft tissue injuries, internal fixation and joint reconstruction become technically impossible. This is particularly true when both proximal and distal sides of the joint are involved. Under such circumstances no hesitation should delay a compromising, "sacrifice" choice of fusing the joint in functional position. This allows early healing and gives a defective but functional finger. On the other hand, insistence on joint preservation may result in delayed healing, deformities, stiffness and multiple operations (Fig. 27.3a, b).

27.5.3 Fractures of Metacarpals

Although metacarpal fractures are usually stable in solitary situations, there are exceptions in complicated injuries. Fractures caused by direct trauma are unstable and are invariably associated with soft tissue injuries.

Fracture of the metacarpal head occurs distal to the collateral ligaments and is usually

Fig. 27.3 (**a**) Juxta-articular fractures of middle and proximal phalanges. (**b**) Fixation with K-wire, sacrificing interphalangeal joint

comminuted; the fragments have few soft tissue attachments and are therefore associated with a high risk of avascular necrosis [18, 19]. If the fragments are not grossly displaced and can be readily reduced, it is preferable to attempt reduction and to maintain it by either skeletal traction or external fixation. Traction or distraction is necessary to reduce loading on the fragments and at the same time to preserve the joint space. The collaterals are prevented from contracture, and future movement of the joint is preserved. A specially designed traction splint can be used to maintain traction and at the same time permit movement and therefore preserve joint function [20]. Alternatively, an external fixator may be used to maintain distraction of the joint and alignment of the fragments. The distraction is maintained for 2 weeks.

Open reduction for metacarpal head fractures is required if they are grossly displaced, and reduction cannot be achieved by closed means. An ulnar-dorsal incision is made and the extensor retinaculum opened through the ulnar side. This joint capsule is identified and opened longitudinally on the ulnar side. This may be extended into the shaft of the metacarpal and with the periosteum stripped off in continuity from the bone. The fragments are identified and reduced. They may be held in place by biodegradable pins or adhesives. Once again, adhesives are preferred. The joint should also be distracted by external fixators or skeletal traction for 2 weeks.

Fractures of the metacarpal neck occur proximal to the attachments of the collaterals [21]. These are usually impacted and flexed with a dorsal angulation. They rarely occur in the thumb, where treatment is usually not required because of the degree of mobility of the first metacarpal. When they occur in the index or the middle finger, they must be reduced. When they occur in the ring or the little finger, one can accept a certain degree of deformity. For the ring finger up to 15° flexion is accepted and for the little finger up to 30° [21].

Reduction of the fracture is not difficult. Correction of the flexion can be readily achieved by flexion of the metacarpophalangeal joint and then pushing up of the proximal phalanx. Since the collaterals are attached to the fragment, stacking the proximal phalanx to the adjacent fingers naturally aligns it to the other fingers. The problem with this fracture is in maintaining the reduction and allowing early mobilisation. The mini-plate and screw system is singularly unsuitable in this situation because when placed on the dorsum of the metacarpal it impedes the extensor tendon, which is closely applied to the joint. Placing the mini-plate on the lateral aspect of the bone is usually not feasible since this means either stripping of one collateral ligament or impeding its function. The approach is also limited by the adjacent metacarpals. However, it may be considered under special circumstances for the second and fifth metacarpals (Fig. 27.4).

Fractures of the base of the metacarpals require special attention [22]. These are joint injuries and are associated with subluxation of the metacarpals from the carpal bones. Bennett's fracture at the base of the thumb is a classical example. Although there are many ways of treating this fracture [23, 24], we favour open reduction and fixation of the avulsion fragment with either screws or screws and plate or with wire loop. An incision appearing curved as hockey stick is made on the radial aspect of the first metacarpal, just dorsal to the abductor pollicis brevis muscle, with the horizontal part of the incision curving towards the palm along the distal wrist crease. The plane between the abductor pollicis brevis and bone is developed and the muscle retracted. Part of the origin of the muscle may be detached from the flexor retinaculum. The fracture fragment is readily identified and fixed with the appropriate implant. If necessary, the extensor pollicis brevis tendon is freed from the dorsal aspect of the first metacarpal so that the dorsal aspect of the bone can be exposed. After the operation, the thumb is bandaged in a bulky compressive dressing which serves some immobilisation, and mobilisation can be started as soon as pain becomes tolerable.

For fractures occurring at the base of other metacarpals, the management is similar. Simple K-wire fixation is generally used, but occasionally the mini-plate is appropriate, and one can accept temporary violation of the

Fig. 27.4 Fixation of metacarpals using different implants

carpometacarpal joint, with the implants removed by 6 weeks. These unusual injuries are frequently associated with severe compression or crushing, with substantial soft tissue damage severely affecting treatment and results.

27.5.4 Soft Tissue Injuries

Hand injuries in natural disasters are too often involving severe soft tissue injuries of the regions. Attendants must be ready to offer soft tissue replacements at the very beginning of management, before bone fixation and other reconstruction considerations. The following consideration could be given:

Thorough debridement in order to achieve a healthy granulation bed Crush injuries and direct impacts result in extensive soft tissue damages which might not be obvious initially. This is the rationale behind the "delayed primary surgery" policy. With a clear history of crush and confirmation, in physical examination, after a careful examination, a super-radical debridement needs to be done because of the expected delayed ischaemia and necrosis. This has to be thoroughly done even at the expense of important structures like nerves, tendons, joint capsules and ligament. Undecisive manoeuvres may result in further necrosis and infection. It is a tough decision, but under such circumstances, tissue healing and skin coverage come before functional restoration may have to be left for later consideration. Once healthy granulation growth succeeds to cover the open wound, splint skin graft could be applied.

Temporary wound coverage Open injuries deserve early coverage to prevent infection, to protect viable soft tissues and to facilitate later reconstruction (Fig. 27.5). Coverage could be achieved using allograft or artificial skin.

Early skin flap coverage For a single digit this usually means a cross-finger island flap. This can also be a flag flap, but for a large defect one may take a digital artery island flap from a large area of the dorsal skin of an adjacent finger. When several digits are involved, or when the injury is on a proximal part of the hand, the groin flap or the reversed radial forearm flap may be considered. If the injury involves the dorsum of the hand, there is usually concomitant skin and extensor tendon damage, and a vascularised dorsalis pedis tendocutaneous flap provides ideal coverage. On the other hand, when the injury

Fig. 27.5 Crushed hand during the Sichuan earthquake of 2008. Extensive debridement of forearm defect was followed with split skin grafting. Finger fractures fixed with K-wire and wire loops

occurs on the palm, a vascularised skin flap plantar flap is the best (Fig. 27.6).

As a general rule, skin flap's face is more prone to complications when done as emergencies. The choice of skin coverage, therefore, remains simple split skin grafting, leaving the proper reconstruction to a later date [25].

27.5.5 Conclusion

Modern fracture treatment is structured to achieve the best functional results within the least possible time. The Swiss AO School has revolutionised the old practices of fracture treatment and introduced the concept of anatomical reduction, rigid fixation and atraumatic technique. The operative principles of this group are used, as far as possible when nonoperative means are not advisable. Such considerations are now standard policies in the planning of fracture treatment.

Since the hand has complicated structures and functions, immediate motion after treatment would be ideal to achieve the best possible functional restoration and to avoid stiffness. Aligning the fractures after reduction is easily achieved using external splintage or simple K-wire fixation. However, such procedures do not allow immediate finger mobilisation since little stability is provided.

In situations of crushed injuries of the hand, proper open reduction and internal fixation are usually infeasible. The essential management should start with a consideration of proper fracture stabilisation and soft tissue handling to reach a safe situation for fracture union while waiting for tissue healing and commencement of rehabilitation. There is little room for perfection.

Fig. 27.6 Vascularised forearm flap to resurface deficient tissues on radial side of the hand

Avoiding infection, non-union and disabling contractures would be of paramount importance towards the achievement of reasonable functional results.

27.6 Wrist Injuries

Although wrist injuries occurring in natural disasters are usually severe, complicated and involving multiple tissues, for the sake of logical discussion, we could discuss along the lines of common wrist fractures, and then venture into the special situations.

27.6.1 Distal Radius Fracture

Being the commonest fracture with long years of record, distal radius fracture has enjoyed many special classifications. The most frequently used classification of today is probably the Frykman's suggestion [26], which carries the following particulars:

I. Extra-articular, no fracture of the ulna
II. Extra-articular, fracture of the ulna
III. Intra-articular radio-carpal, no fracture of the ulna
IV. Intra-articular radio-carpal, fracture of the ulna
V. Intra-articular radio-ulnar, no fracture of the ulna
VI. Intra-articular radio-ulnar, fracture of the ulna
VII. Intra-articular radio-carpal and radio-ulnar, no fracture of the ulna
VIII. Intra-articular radio-carpal and radio-ulnar, fracture of the ulna

This classification is based on the extent of involvement of the radio-carpal joint and the distal radio-ulnar joint. It also takes into account the involvement of fractures in the ulnar styloid, which affect the stability of the triangular fibrocartilage complex.

Wrist fractures encountered in natural disasters most frequently belong to the more complicated types, viz. III, IV and VIII. Importantly, comminutions are common.

When both radius and ulnar are involved with comminutions, joint surface involvements are often combined with soft tissue injuries. Treatment with external fixators has become the preference.

The external fixator, if properly applied, can certainly provide the best stability for these fractures [27–31]. Maintenance of the reduction depends on the intact soft tissues, particularly the ligaments around the wrists, by the principle of ligamentotaxis. This technique, however, is criticised for failing to reduce the palmar tilt of the comminuted fragments [32] and failing to reduce the depressed intra-articular fragments, particularly the "die-punch" fragments [33], and the complications resulting from prolonged application [34]. In these comminuted fractures, most workers recommend 8–12 weeks of external fixation before considerable healing and stability is regained. Common complications of prolonged immobilizations include stiffness, Sudeck's dystrophy, pin tract infection and loosening. Since distal radius fractures in the natural disaster situations are associated with much soft tissue injuries, apart form external fixation, little alternatives can be offered (Fig. 27.7).

The problems of displaced intra-articular fractures remain unsolved with the use of the external fixator. Many advocate the combined used of the external fixator and limited open reduction and fixation of the intra-articular fragments with implants such as Kirschner wires, plates and screws. It is extremely difficult, however, if not impossible to fix the numerous tiny osteochondral fragments with implants. Furthermore, open reduction may lead to a loss of the effect of ligamentotaxis due the surgical trauma to the soft tissue around the wrist.

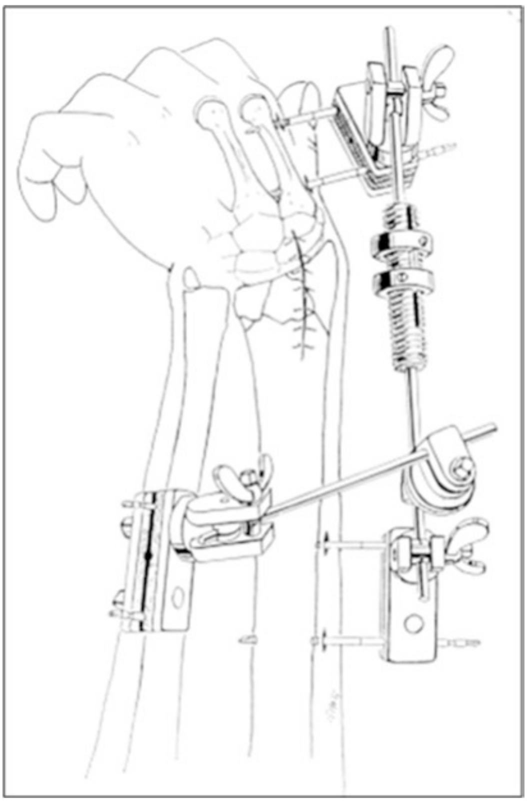

Fig. 27.7 A schematic drawing to show the application of an external fixator for the treatment of complicated wrist fractures

In the best hands multiple options and combinations of treatment protocols could be recommended. Nevertheless, the use of plates and screws in this region for communicated fracture is extremely demanding technically, and the amount of tissue trauma could leave tremendous problems of stiffness. The use of external fixator alone is much easier, but the empty gaps within the comminution tend to collapse even after long periods of distraction, not to speak to pin tract infections. Deformities and stiffness are still common with prolonged external fixator application. The addition of bone grafts maintains the reduction from within and significantly minimises the late complications of radial shortening and deformities. The relative simplicity of the operation allows this operation to be performed by even a junior surgeon who needs to master the basic techniques of the application of the external fixator and bone grafting.

27.6.2 Carpal Injuries

The fractures are intra-articular, and they may result in carpal instabilities or disruption of stability of the finger rays. There is no general rule of management, but the consensus is that most of these fractures are better treated with operative reduction and fixation by some form of devices. However, in the past fixation was usually achieved by K-wires. These are not entirely satisfactory (perhaps also because of the lack of good fluoroscopic machines for radiologically guided pinning), and additionally, usually prolonged casting is required and mobilisation delayed.

Scaphoid fracture is the commonest carpal injury, and it exemplifies this situation well. The scaphoid has long been recognised as the key bone linking the two carpal rows. It is put under tremendous stress during the extremes of wrist movements. Immobilisation of the bone inside a plaster cast is difficult, and some physicians even practise immobilisation of the whole forearm from the fingers up to and including the elbow in a long cast [35]. It would be logical to think that given a means of stabilising the fracture, wrist movement may be restored earlier and better.

The Herbert screw affords a relatively atraumatic and sufficiently stable fixation of the scaphoid, and early mobilisation can be implemented. Although criticisms have been raised regarding the disturbance to the trapezioscaphoid joint and articular cartilage during the placement of the jig, this has been largely overcome by inserting the screw without the placement of the jig [36]. Another criticism is the lack of rotational stability with the screw, although in most fractures with little comminution the fixation is usually sufficiently stable.

Carpal injuries in situations of severe soft tissues involvement should require the same degree of caution like hand and distal radial fractures. Flexibilities should be allowed to try achieving the best compromising results and not the best results. Thus complete or partial fusion of the wrist is better than a painful, unstable wrist with little function.

27.6.3 Combined Radial Carpal Fractures

Simultaneous fractures of the distal radius and the scaphoid commonly result from severe trauma [37, 38]. Distal radial fractures are unstable and comminuted. Opinions differ concerning the treatment of scaphoid fractures. As in the other unstable distal radial fractures, the external fixator and bone graft could be used for the radial component. The scaphoid fracture should then be treated at the same time with internal fixation. Fixation of the scaphoid not only allows distraction on the distal radius but also facilitates rehabilitation in the later stage.

More complicated combined radio-carpal fractures are the result of severe trauma associated invariably with soft tissue injuries. The principle of management should therefore be a combination of open fixation, soft tissue management and infection control with the aim of preserving as much wrist function as possible. A compromise approach of temporary wrist fusion aiming at early healing and subsequent painless fibrous ankylosis might be desirable for the most devastating damages if proper wrist function is not considered a realistic outlook. A half-hearted, indecisive staged approach to such problems may eventually be disappointing.

27.6.4 Fracture of the Distal Ulnar

The distal ulnar wrist complex is composed of the distal radio-ulnar articulation, triangular fibrocartilage, ulnar styloid and ulnar collateral ligament. The stability of the distal radio-ulnar joint depends on the volar and dorsal radio-ulnar ligaments. The volar ligament becomes taut when the forearm is supinated and is usually torn when the distal radio-ulnar joint is dislocated. The dorsal ligament is taut when the forearm is in pronated position. The triangular fibrocartilage is defined as the stabiliser of the distal radio-ulnar joint and the axial load bearing structure on the ulnar side of the wrist [39]. It sweeps across the distal surface of the ulnar head during rotational movement of the forearm. The close anatomical proximity and functional integration among these structures lead to the complexity of the injury pattern.

27.6.5 Injury of the Distal Ulnar Wrist Complex

Isolated fracture of the ulnar styloid can be at the tip or at the base. Since the triangular fibrocartilage is attached to the base of the ulnar styloid, the stability of the distal radio-ulnar joint depends on a good reduction of these basal ulnar styloid fractures. Instability of the distal radio-ulnar joint may result if these fractures are not properly treated. Treatment for undisplaced fractures uses a long-arm plaster slab to keep the forearm in supination and mild ulnar deviation. Displaced fractures should be treated with closed or open reduction and joint stabilisation. The technique of using temporary Kirschner wire transfixing the ulna to the radius is a simple and effective means of stabilising the distal radio-ulnar joint and hence the styloid process. A similar protocol

Fig. 27.8 Temporary fixation of the distal radio-ulnar joint after plating of the distal radius

should be used with the isolated fracture of the ulnar head. With demonstratable instability of the distal radio-ulnar joint, the fracture should be reduced and fixed early with a short one-third tubular plate to achieve early stability (Fig. 27.8).

In view of the complexity of the structure and the associated soft tissue injuries, it is most unlikely that reconstruction of the ligament-cartilaginous structures be performed at the emergency stage. Rather, temporary stabilisation using a K-wire to pass through the distal radial joint for a period of 4–6 weeks would be a reasonable choice. Reconstruction, if considered necessary, would be left to a later stage.

Conclusion

Straightforward distal radial fractures are simple and easy to treat. Problems of fractures in this region arise when the fractures are grossly unstable and when they have intra-articular involvements. In the situation of comminuted intra-articular distal radial fracture, the provision of immediate stability with external fixator distraction, rebuilding the bone stock with primary bone grafts and early functional rehabilitation, represents one of the most effective treatment protocols for these fractures. In situation of more complicated fractures with carpal and distal radial and ulnar involvements, a decisive, one-stage management in order to preserve major hand functions would often be indicated.

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28 Management of Mangled Extremities

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28.1 Introduction

Mangled extremities are high-energy injuries and are frequently associated with life-threatening systemic trauma. These injuries have severe bone and soft tissue involvement and are often complicated with other risk factors such as degloving of the skin, crushing of soft tissues, severe contamination and injury to neurovascular structures and hence carry a high risk for complications and amputation. Although advances in management of systemic injuries, availability of antibiotics, refinement in debridement techniques and bone and soft tissue reconstruction have helped salvage rates, the challenge to restore function and cosmesis as much as possible is still present. One should remember that patients with a painful or deformed extremity are highly dissatisfied and unhappily prefer an amputation as opposed to a prolonged and expensive treatment.

Tscherne has grouped the development of the management of mangled extremities into four areas of life preservation, limb presentation, infection prevention and functional restoration [1].

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The recent understanding that mangled extremities do not fall in the domain of any single specialty but need to be managed by a combined multi-specialty approach has helped to improve salvage and functional results. It is now a routinely practiced standard of care when the 'orthoplastic approach' is used, where the orthopaedic and plastic surgeons combine their input right from the stage of assessment and debridement [2, 3]. There is also a need for trauma intensivists and anaesthetists skilled in the management of severely injured patients.

28.2 Initial Evaluation

Mangled extremities are emergencies and require a thorough initial evaluation and management measures that start at the emergency room and even at the place of occurrence. They are dramatic injuries and can distract the untrained person from more serious occult injuries that may be life-threatening (Fig. 28.1). The surgeon must not restrict his attention to the obvious but must follow a disciplined protocol of evaluation and emergency measures as per ATLS protocols. In needy cases, a whole-body fast CT scan which helps to identify injuries to the head, neck, chest, spine and pelvis is appropriate [4].

Resuscitation measures must be effective and immediate as persistent shock is an important cause for avoidable deaths and complications

N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_28

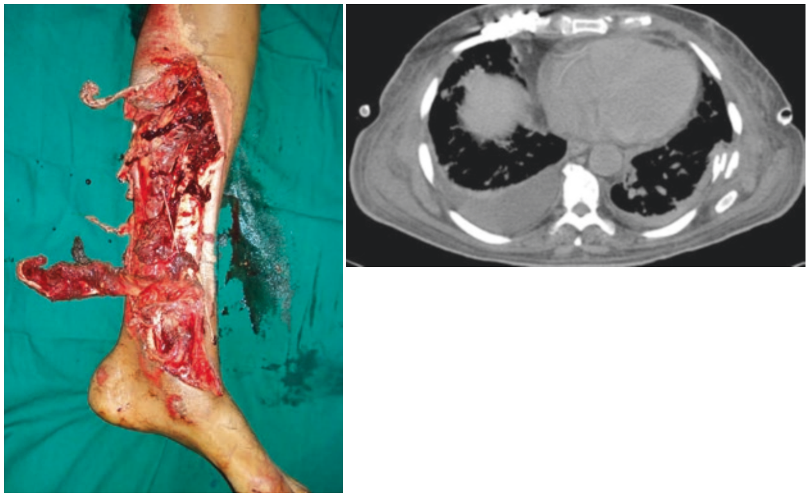

Fig. 28.1 Mangled Extremities and Open Injuries are dramatic injuries that can distract the untrained person from more serious occult injuries that may be life threatening. In this patient with a limb injury, there was an associated severe chest injury with multiple rib fractures and hemothorax that required immediate attention

like infection, pulmonary complications and delayed wound healing. The 'triad of death' of hypothermia, acidosis and coagulopathy is frequently present in these patients and must be corrected swiftly [5–7]. Measurement of vital signs is often inadequate in determining the adequacy of resuscitation [8–10], and biochemical markers such as serum lactate and interleukin-6 are increasingly being used to evaluate adequacy of resuscitation and guide management. Many of these patients will require damage control orthopaedics as a part of resuscitation [11–13].

Once the general condition is stabilized, meticulous documentation is a must. This should include details of the accident, the probable energy of injury, any loss of consciousness and evidence of head injury, temporary or partial paralysis, the use of seat belts or helmets and emergency medical treatment at the site of accident. All co-morbidities must be documented and highlighted. Systemic illnesses, metabolic illnesses like diabetes, bleeding disorders, pertinent drug allergies, routine medications and history of smoking should be specifically documented [14, 15].

28.3 Examination

Physical examination of the entire individual is mandatory as small lacerations, bruising or contusions in other parts of the body may indicate deeper injury. The limbs must be released of any constrictive clothing, and vascularity and gross movements in all four limbs must be checked. A grossly deformed or shortened limb must be gently brought to anatomical orientation and splinted so that vascularity is not compromised. Persistent dislocation of the joints around the ankle and knee requires urgent reduction as they can compromise distal vascularity and skin integrity.

The nature of the wound is then documented. The relationship of the wound to the fracture is important. Although the wound may be small and may lie away from the fracture, communication with the fracture site is often present with disruption of the fascia and degloving of the skin. The size of the external wound may not frequently be in proportion to the damage to the deeper structures.

In the emergency setting, examination must be restricted to gross description of the wound, and photographic documentation [16] in a few important angles is vital. Good visual documentation surpasses any written description. The wound must then quickly be covered by a sterile dressing as unnecessary handling carry the disadvantage of provoking unnecessary bleeding and increasing the chances of secondary contamination. Continuous bleeding from the wound, if present, is usually well controlled by application of compression dressing and elevation of the limb. Blind clamping of the vein or artery in the emergency room may result in clamping of the adjacent major neurovascular structures and lead to irreversible neurological loss. In assessing vascularity, if pulses are absent, one must re-examine after realigning the limb to anatomical position. An arterial Doppler or CT angiogram is rarely necessary. CT angiograms have the disadvantage of being time-consuming and also having the potential risk of acute renal failure when contrast is used in patients with compromised renal status.

The practice of routine cultures from the wound in the emergency room is no longer advocated as studies have clearly shown poor correlation between the presence of positive cultures and the rate or flora of subsequent wound infection. Antibiotic therapy must be instituted at the earliest possible moment [13, 17, 18], and first- or second-generation cepholosporins are given intravenously as soon as possible. An aminoglycoside is also added in type III injuries. Penicillin with or without metronidazole is used in patients with gross organic contamination.

28.4 Radiographic Examination

Good anteroposterior and lateral radiographs of the injured bone including the adjacent joints are compulsory. In high-energy violence of the lower limb, radiographs of the pelvis showing the status of sacroiliac joints, pubic symphysis and both hips are important. In appropriate cases, clearance of the cervical and whole spine will be needed. In the absence of life-threatening injuries, CT scans may be performed in intra-articular fractures as this will reveal the 3D orientation of the fracture planes and provide helpful data for achieving good skeletal stabilization during the index surgery. The role of MRI of the limb or the body in an acute setting is minimal and rarely performed.

28.5 Decision of Salvage

The decision to amputate or salvage a mangled extremity is often a difficult decision that demands experience. An inappropriate decision may subject the patient to prolonged process of reconstruction with multiple surgeries but finally ending in secondary amputation [19–23]. The surgeon must avoid 'triumph of technique over reason'. It is prudent that the decision to amputate must be made during the index procedure or surely at least before definitive soft tissue reconstruction procedure is attempted. Patient and his near family members must be actively involved in the decision at all stages.

In certain situations, the need for primary amputation is obvious. However, in less obvious situations, many different scores such as Mangled Extremity Severity Score [24], the limb salvage index [25], the predictive salvage index [26], nerve injury, ischemia, soft tissue injury, skeletal injury, shock and age patient (NISSA) score [27] and the Hannover fracture scale [28] have been proposed to bring some objectivity into the decision-making process (Table 28.1). These scores are primarily designed to address limbs which have combined orthopaedic and vascular injuries and have the disadvantage of grossly

Table 28.1 Components of lower-extremity injury-severity scoring systems

	Scoring systems					
	Mess	LSI	PSI	NISSSA	HFS-97	GHOIS
Age	X			X		X
Shock	X			X	X	X
Warm ischemia time	X	X	X	X	X	X
Bone injury		X	X		X	X
Muscle injury		X	X			X
Skin injury		X			X	X
Never injury		X		X	X	
Deep-vein injury		X				
Skeletal/soft-tissue injury	X			X		
Contamination	X			X	X	X
Time to treatment			X			
Comorbid conditions						X

MESS Mangled Severity Score, *LSI* Salvage Index, *PSI* Predictive Salvage Index, *NISSSA* Nerve Injury, Ischemia, Soft-Tissue Injury, Skeletal Injury, Shock, and Age of Patient Score, *HFS-97* Hannover Fracture Scale (1997 version), *GHOIS* Ganga Hospital open Injury score

Table 28.2 Mangled Extremity Severity Score (MESS)

Type	Definition	Points
A	Skeletal/soft tissue injury	
	Low energy (stab; simple fracture; "civilian" GSW)	1
	Medium energy (open or multiple fractures; dislocation)	2
	High energy (close-range shotgun or "military" GSW; crush injury)	3
	Very high energy (above and gross contamination; soft-tissue avulsion)	4
B	*Limp ischemia* (*Score doubled for ischemia >6 h)	
	Pulse reduced or absent but perfusion normal	1*
	Pulse reduced or absent but perfusion normal	2*
	Pulseless; paraesthesias; diminished capillary refill	3*
	Cool; paralyzed; insensate; numb.	
C	Shock	
	Systolic BP always >90 mmHg	0
	Hypotensive transiently	1
	Persistent hypotension	2
D	Age (years)	
	<30	0
	30–50	1
	>50	2

under-weighing the severity when vascularity is intact. They also have the disadvantage of being difficult to apply and therefore not regularly using practice.

The Mangled Extremity Severity Score [24] (MESS) for III-C injuries and the Ganga Hospital Open Injury Score (GHOIS) for III-B injuries are currently the most used scores to assess injuries. MESS is based on four criteria of the energy of trauma, the presence and duration of limb ischemia, the presence of shock and the age of the patient (Table 28.2). A score of >7 has been reported to predict amputation accurately but has poor sensitivity and specificity when only III-B injuries are considered. The Ganga Hospital Open Injury Score was described by Rajasekaran et al. [15] to specifically address the question of salvage in III-B injuries. Here, the severity of injury to the three components of the limb – covering tissues (skin), structural tissues (bone) and functional tissues (muscles, tendons and nerves) – is graded separately by points ranging from 1 to 5 (Table 28.3). In

Table 28.3 Ganga Hospital Open Injury Score (GHOIS)

Covering Structures: Skin and Fascia	
Wound with no skin loss and not over the fracture site	1
Wound with no	2
Wound with no skin loss and over the fracture site	3
Wound with skin loss and over the fracture site	4
Wound with circumferential skin loss	5
Functional Tissues: Musculotendinous and Nerve Units	
Partial injury to musculotendinous unit	1
Complete but repairable injury to musculotendinous units	2
Irreparable injury to musculotendinous units, partial loss of a compartment, or complete injury to posterior tibial nerve	3
Loss of one compartment of musculotendinous units	4
Loss of two or more compartments or subtotal amputation	5
Skeletal Structures: Bone and Joints	
Transverse or oblique fracture or butterfly fragment <50 % circumference	1
Large butterfly fragment >50 % circumference:	2
Comminution or segment fractures without bone loss	3
Bone loss <4 cm	4
Bone loss >4 cm	5
Comorbid Conditions: Add 2 points for Each Condition Present	
Injury leading to debridement interval >12 h	
Sewage or organic contamination or farmyard injuries	
Age >65 years	
Drug-dependent diabetes mellitus or cardiorespirator diseases leading to increased anesthetic risk	
Polytrauma involving chest or abdomen with injury severity score >25 or embolism	
Hypotension with systolic pressure <90 mmHg at presentation	
Another major injury to the same limb or compartment syndrome.	
Injuries with a score equal to 14 or below are advised salvage.	
Injuries with score 17 and above usually end up in amputation.	
Injuries with score 15 and 16 fall into Grey zone where decision is made on patient to patient basis.	

addition, seven co-morbidities that are known to influence the outcome are given two points each. The score has a high sensitivity and specificity when used for tibial fractures. The authors while recommending salvage in all injuries below 14 and amputation in injuries above 17 also provided a grey zone of score 15 and 16 where the decision to salvage or amputate must be based on a case to case basis. It should be emphasized that upper limb injuries are more amenable to salvage and attempts to salvage must be made even in injuries exceeding the threshold score.

28.6 Debridement

The quality of debridement of a mangled extremity is one of the key factors which prevents infection and determines the ultimate outcome of management. Infection negatively impacts the outcome in two ways. Firstly, it causes further loss of critical tissues like tendons, nerves and bone, and secondly, it delays the secondary stages of reconstruction which are almost always required in mangled extremities. An infected wound also offers a poor bed for gliding tissues. Primary healing of the wound is thus a basic requirement for a good outcome, and proper debridement holds the key to success.

28.7 Timing of Debridement

The classical teaching is to debride the wound as early as possible. A 6 h period from the time of injury was kept as a 'golden rule'. Some studies have questioned this rule [29]. Staggs et al. in a retrospective study of 554 open fractures in children found that the incidence of infection was no higher when the wounds were debrided within 6 h after injury when compared with wounds debrided within 24 h of injury when early antibiotic therapy is administered [30], implying that infection could still be prevented when good debridement is done even after 6 h, and Sears et al. [31] analyzed the relationship between the timing of emergency procedures and limb amputation in patients with open tibia fractures in the USA, 2003–2009, wherein 7560 patients were included in the study. In adjusted analyses, timing of the first operative procedure beyond the day of admission was associated with more than three times greater odds of amputation. They suggested that all surgeons involved in the management of these patients should seek a solution for any barrier, other than medical stability of the patient, to achieve early operative intervention.

Debridement not only involves removal of dead and devitalized tissue but in addition also achieves haemostasis and further leads to skeletal stabilization and pain relief. All these factors add to the comfort and recovery of the patient, and so debridement has to be done as early as possible. Good debridement is mandatory, and hence for patients in the war front or in mass casualties, it may be prudent to shift the patients to referral centres whenever safely possible rather than performing inadequate debridement at the primary centre.

28.8 Technique of Debridement

28.8.1 Essentials

A good operating room infrastructure with provision for good anaesthesia is essential, and the surgeon must preferably use loupe magnification. Regional anaesthesia is being increasingly used for debridement. There are differing views on the use of tourniquet, but the authors believe that the use of tourniquet has great advantages. The authors start the debridement with tourniquet inflated. Although some are of the opinion that it will be difficult to distinguish the viable and the non-viable tissues with tourniquet inflated, our experience is otherwise. If one starts the debridement without tourniquet, the moment the skin edges are incised, the bleeding that occurs covers the wound and gives a false appearance of security. In the presence of bleeding, the contaminants in the intermuscular plane are easily missed. They are easier to identify in a bloodless field. Viable muscle under tourniquet looks moist, contracts to touch and is pale. On the other hand, the muscles to be debrided look dull, have a variegated appearance, mould to pressure, have small haematomas in them and do not contract to touch. One can start the debridement under tourniquet and at the end deflate it and inspect the wound, and in case of any areas which are not bleeding, further debridement of such areas can be done. An additional advantage of using the tourniquet is its effect on the reduction of blood loss. Mangled extremities have large raw areas to debride and usage of tourniquet results in less transfusion needs. Most patients are already in a compromised state and it is preferable to prevent further blood loss.

It is an advantage to have a well-experienced surgeon debride a mangled extremity. This will reduce judgmental errors in the assessment of tissue viability and reduce operating time and transfusion needs. This will also aid the efficient planning of the subsequent stages of reconstruction.

28.8.2 The Technique

Debridement of a mangled extremity must follow a regular sequence [32]. Under tourniquet the wound is washed to remove all the loose contaminants. However, one cannot rely on irrigation alone, and no advantage has been proved for the use of pressure and pulsatile irrigation or antibiotic containing solutions [33]. The goal of surgical debridement is to convert a crushed and contaminated wound into a surgical wound [34]. The procedure is called wound excision. It is done in a definitive sequence. The skin margins of the mangled extremity wound is excised to leave a healthy margin. Then a thin margin of exposed tissue is excised to leave behind viable tissue. Viable and non-viable muscles are distinguished. Longitudinal structures are preserved. The tendons if contaminated are painstakingly cleaned or a thin layer is shaved off to leave behind a clean tendon. If muscles are attached to the avulsed tendons on the distal side, the muscle tissue must be excised. They can never be vascularized. The vessels and nerves if contaminated pose a challenge. Usually there is a thin flimsy layer of tissue covering the vessels and nerves, and even if they are badly contaminated, by slow dissection the layer with contaminants can be removed to leave behind healthy vessels and nerves. Loose cortical bone pieces and fracture fragments without any soft tissue attachment are removed. They do not act as bone grafts. One of the commonest causes of inadequate debridement is not removing dead bone. Even a good vascularized flap cover will not make a dead bone alive.

28.8.3 Second Look after Debridement

A second-look debridement is justified in patients following blast injuries or in the presence of severe contamination and crushing of the tissues [35]. Second-look or serial debridements are not a substitute for poor primary debridement but indicated in doubtful situations where the intrinsic nature of injury precludes from exercising correct judgment during the index surgery. The opportunity to have a ‘second look’ must not lead to any compromise in technique during the performance of the primary debridement.

28.9 Skeletal Management

Extensive damage to the bone is very common, and debridement and reconstruction of bone will require judicious management. Avascular bone is a rich source of infection and hence the decision to retain comminuted pieces must be based on the presence of vascularity and whether the pieces are from the diaphysis or metaphysis and carry articular surfaces. In general, diaphyseal bone devoid of soft tissues must be removed, and cancellous metaphyseal bones which have a higher capacity for revascularization and union can be preserved. The fractured ends of the bones often carry deep impregnation of paint, mud and other organic material at the fractured ends, and it is ideal that the contaminated edges are nibbled away to avoid infection. Comminution in the metaphyseal region producing articular instability must be dealt with stable fixation to establish joint congruity and stability.

28.9.1 Skeletal Stabilization

In patients with severe contamination, it is a good practice to discard the instruments and table utilized for debridement and to re-drape the limb for reconstruction. The aim will be to achieve skeletal stabilization with restoration of anatomical alignment and length of the limb as it improves circulation and helps in venous and lymphatic return. Stability allows comfort for the patient during wound infections and early movement of joints. The choice of plate or nailing depends upon the location of injury with plate fixations being preferred in most upper limb injuries and periarticular injuries with or without articular surface involvement. Nailing is preferred for diaphyseal injuries especially on the lower limb.

External fixators are the work horse for skeletal stabilization in open fractures. It provides a quick and versatile method for stability without the need for additional exposure or soft tissue damage. Although mostly used as a temporary measure, they can be extended as a definitive treatment in cases where a stable fracture configuration has been achieved with good circumferential contact. It is however important to avoid chances of infection, and the guidelines given in Table 28.4 must be meticulously followed.

When staged reconstruction is performed, it is advantageous to perform the definitive internal fixation by either an interlocking nail or a plate before performing a definitive soft tissue cover. Once a flap is performed, flap settling time may take 4–6 weeks, and there is a possibility of colonization of pin tracks during this time. There is proof [36] that delay of conversion of external fixator beyond 28 days increased infection to 22 % from 3.7 %. If delay is unavoidable, an interval time of about 2 weeks between removal and internal fixation is advised to reduce infection.

Table 28.4 Principles of pin placement for external fixators

Predrilling must be done to minimize thermal necrosis, pin loosening, and infection.
Pins must be judiciously places to allow access for bone and soft tissue reconstruction.
Pin should be placed through intact soft tissue rather than through the exposed wound.
Fixator must be applied with the fracture well reduced. If the fracture is away from the wound, this can be helped by making a small wound incision
Pin placement must be made avoiding the line of further surgical incisions
In articular fractures, joint congruity must be achieved during the index procedure with screws and suitable fixation as late reconstruction may not be possible.
Pins must be placed with a good knowledge of the regional anatomy so that injury to the nerves and vessels are avoided.
Pins must avoid intra-articular passage as any infection will lead to septic arthritis.
Drill sleeves must be used to avoid critical muscle and tendon implacement.

28.10 Primary Internal Fixation

The phobia of increased infection with foreign bodies is now over, and primary plate fixation for upper limbs and both plate and reamed locking nails for the lower limbs have become routine whenever good debridement has been possible [37, 38]. Plate fixation is also the method of choice in all periarticular and juxta-articular fractures. In the lower limb, intramedullary nails are now frequently the first choice from diaphyseal fractures due to the superior biomechanical advantage and its capacity to maintain length and rotation of the limb. In a large series, 15.5 % of patients required bone grafting and 32 % an additional procedure to achieve bone union [21]. The infection rate was only 3–6 % [39–41].

28.11 Vascular Reconstruction

In a mangled extremity, three presentations are possible. In the first situation, the distal part is surely viable, with the finger tips blanching within 2 s on pressure and pulse oximeter picking up signals. The second situation is when the distal part is pale, with no capillary refill and obvious evidence of injury to the major vessels. Here there is no doubt about the need for vascular reconstruction. The third presentation, where the decision-making becomes crucial, is when the finger tips are pink but capillary refill is delayed, with no palpable distal pulses and pulse oximeter does not pick up signals. In closed fractures in such cases, though quite often one will get away without vascular reconstruction, in mangled extremities such chances are remote. It is important to get pulsatile blood flow into the distal part in every mangled extremity. Collaterals are insufficient, due to the

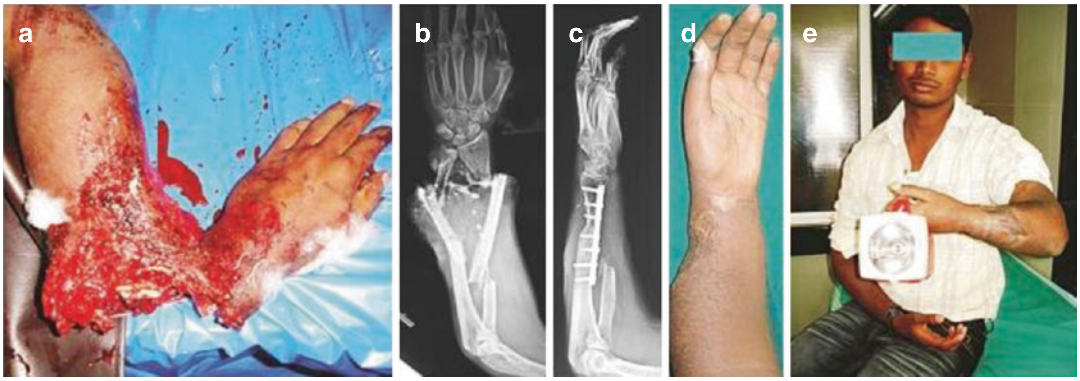

Fig. 28.2 Mangled Extremity of the left upper limb in a young male (**a**). There was poor distal vascularity with minimal capillary refill and poor pulse oximeter signals in such cases (**b**), primary vascular reconstruction (**c**) is necessary to enhance viability but also to make secondary reconstruction more successful. Here (**d, e**) vein grafts were used for vascular augmentation and the limb was reconstructed by single bone forearm technique and free flap

segmental major injury, and if vascular reconstruction is not done, there will be extensive distal soft tissue necrosis. In such instances primary vascular reconstruction not only enhances viability but also makes secondary reconstruction easier by providing a good and stable bed for flap cover (Fig. 28.2). Vein grafts may have to be used and final debridement has to be done after vascular repair. The vein grafts must lie on a good bed and must have good soft tissue cover.

In mangled extremities common injury is avulsion of the vessels. Sometimes at the site of impact, there may be thrombosis in continuity. This is particularly common in major vessels of the lower limb like the femoral and the popliteal arteries. Embolectomy will not be useful in these trauma situations, where recurrence of thrombosis will be the norm. This is because intimal damage at the site of impact is the basic problem, and so excision of the involved area and reconstruction is recommended.

28.12 Bone Loss

Bone gaps in the upper limb are usually managed by shortening of the bone and the adequate bone graft. In the humerus, even 4 cm of shortening is well tolerated, whereas in the forearm, acute shortening should be done carefully due to the presence of two bones. In extreme cases of severe bone loss, reconstruction with a single bone forearm is a viable option. In very complex injuries, we have utilized this option to not only avoid amputation but also good function.

Bone loss in the lower limb, loss of less than 2 cms, can be well accepted with good functional results. A loss up to 4 cms can be managed by copious amount of iliac crest bone grafting provided the bed of soft tissue is vascular. If the loss exceeds 4 cms, the choice lies between primary shortening and gradual lengthening (Fig. 28.3) or bridging the gap by bone transport. While the ring fixators offer excellent stability and provision for bone transport, they are time-consuming and cumbersome in the acute setting. The unilateral limb reconstruction system in comparison is easy and quick in application and has the advantage of being more accommodative to future plastic surgery reconstructive procedures.

28.13 Source of Infection in Open Injuries

The traditional concept that infection is a result of contamination of the wounds has now been discarded in favour of the understanding that most infection after open injuries are from pathogens acquired in the hospital rather than from the site of injury. Gustilo Anderson in a prospective study of 326 patients identified that five of the eight patients who had infection in that series had hospital-acquired infection [42]. In a later pro-

Fig. 28.3 Primary shortening and lengthening. This technique can be utilised in the lower limb. Here 7 cms shortening was primarily achieved for communited supracondylar fracture with bone loss. Through the same index surgery, a corticotomy was performed and the bone was gradually lengthened to achieve limb length equalisation. Patient regained good function

spective study by Patzakis et al. [43], only 18 % of the infections of seven following open injuries were found to be caused by organisms which were initially isolated from the wound. The knowledge that most infections are acquired in the hospital should prompt the treating surgeon to follow the process of asepsis strictly at all times for wound inspection and dressing and also perform soft tissue cover at the earliest possible.

28.14 Zone of Injury

Blunt injuries and open injuries with crush element have a larger area of impact and tissue destruction than penetrating injuries [44–46]. The extent of damage especially to the deeper tissues may be much wider than what appears initially, giving rise to the concept of zone of injury. Three typical zones of injury are described. The direct trauma contact area is the central zone or 'zone of necrosis' and is directly beneath the wound. Surrounding this is the 'zone of injury' extending into the peripheral 'uninjured viable zone'. The extent of these zones depends on the amount of energy imparted to the tissues at the time of impact and also the anatomy of the area of impact and the relationship of the soft and surrounding hard tissues at this level. This zone of injury is characterized by inflammatory edematous soft tissue with disturbed microcirculation. In severe impact, this area may not appear non-viable at initial debridement but may show a partial or complete non-viability and loss of tissues over the next few days. It is often difficult to clearly distinguish the zone from adjacent healthy tissues immediately after trauma and during debridement. This has considerable clinical importance because vascular pedicles of flaps which are based in this zone of injury or microvascular anastomosis performed in this area are associated with an increased rate of failure. Failure to recognize this phenomenon will result in soft tissue reconstruction failures and may burn important bridges, making further reconstruction impossible.

Wherever there is suspicion of a severe crush element, it is better to stage any soft tissue reconstruction so that the zone of injury will reveal itself over the next few days and all soft tissue reconstruction procedures can be planned from the healthy zone. In our experience whenever GHOIS is >9, it is preferable to stage the soft tissue reconstruction.

28.15 Timing of Soft Tissue Reconstruction

Soft tissue reconstruction is advocated as early as possible. The reasons are twofold. Firstly, the exposed critical structures are prone for infection.

In a mangled injury, almost all infections occur after the patient arrives at the hospital. This is related to the number of days the wound remains open, frequency of dressing changes and the quality of debridement. In addition the longer the critical tissues are exposed, the living tissues suffer desiccation and necrosis. If they are 'allowed to dry, they die'. The timing also depends upon the general condition of the patient. We rely on the level of serum lactate touching the normal base before starting. Serum lactate levels correspond to the adequacy of the resuscitation. Serum lactate levels are monitored every 6 h until they reach normal values. The trend is more important than the absolute values.

Godina [47] was the champion of radical debridement and early flap cover, and he was the first to popularize the idea. He found that open fractures of the tibia when they had free flap coverage within 72 h of injury had a free flap failure rate of 0.75 % and an infection rate of 1.5 %. This was compared to a group of patients who had free flap cover between 72 h and 3 months, and this group had a flap failure rate of 12 % and infection rate of 17.5 %. Though we have moved on many aspects in trauma care since the period of Godina, this concept led to further studies and organization of reconstructive surgery services. Lister [48] and Schekar [49] introduced the emergency free flap when the wound was covered within 24 h and found good results. The message that is got from the literature available is that the earlier the soft tissue cover is provided, the better it is for the patient. With that principle in mind, decision has to be individualized for each patient depending upon other variables like associated injuries, adequacy of resuscitation and co-morbid factors. Most trauma units find logistical deficiencies as the common cause for delay in soft tissue cover than patient-related issues.

28.15.1 Problem of Delay

The longer the wound is exposed and left uncovered, the greater the inflammation. This leads to induration of the surrounding healthy tissues. They are not good for functional tissues like tendons and nerves. The oedema of the inflammation travels along the neurovascular plane, and in 2–3 weeks time, the tissues around the vessels and nerves become indurated. Later fibrosis sets in. When a recipient vessel for the free flap is chosen dissection of vessels in area of injury becomes difficult. With the veins being friable, one then has to go far from the zone of injury into areas where the dissection of the vessels is easy. This necessarily leads to larger and longer flaps.

28.16 Type of Soft Tissue Reconstruction

Skin grafts are sufficient if critical structures and fracture site is not exposed. There is no difference in infection rates or fracture union rates between muscle and skin flaps, and the surgeon usually goes by his personal preference and comfort levels in doing the particular flap. If secondary surgeries like bone grafting or tenolysis are to be done, skin flaps are preferred than muscle flaps.

28.17 Vacuum-Assisted Closure Devices in Open Fractures

Vacuum-assisted closure (VAC) devices or negative-pressure wound therapy (NPWT) is presently used extensively in open fractures. In its use in the management of a mangled extremity, three issues need to be highlighted. The first is the intrinsic advantage of the VAC system over the traditional repeated wet to wet dressing changes, the second is the possible change into a simpler plan for soft tissue cover, and the third is its influence on the timing of soft tissue cover and its relation to the incidence of infection.

A traditionally regular wet to wet dressing was practised to keep the wound moist and prevent the secondary loss of critical tissues due to desiccation. Every dressing episode opens up a window for hospital infection. When VAC dressings are used, the number of dressing changes gets minimized. It then becomes a closed system with no soakage of dressings, which again insulates the wound from the outside environment. Most studies on infection rates in open fractures compare the use of VAC dressings with traditional dressing changes and not with radical debridement and early soft tissue cover. Undoubtedly VAC dressings are found to be superior to conventional regular dressing changes, when applied after good debridement. It has been found to reduce the size of the flap needed and might cause change in the type of flap required, but prolonged periods of VAC usage, greater than 7 days, should be avoided to reduce higher infection rates and amputation risks. It may help to reduce the importance of emergency reconstructions, especially in poly-traumatized patients, sick and the elderly [50]. A review of the literature sums it up, stating that the VAC system applied as a temporizing dressing simplifies soft tissue coverage on the 'reconstructive ladder' [51]. The only level 1 data on that topic showed a significant decrease in infections. However, the negative-pressure wound therapy does not allow delay in soft tissue coverage without a concomitant elevation in infection rates [52, 53]. These studies with the use of VAC have still suggested soft tissue coverage within 7 days.

Table 28.5 Definitive limb reconstructive pathway in major open injuries

"Fix and close" protocol.
"Fix, bone graft and close" protocol
"Fix and flap" protocol
Fix, delayed flap technique
"Stabilize, watch, assess, and reconstruct" protocol

28.18 Ganga Hospital Protocol Based on GHOIS

Our unit treats more than 300 type III-B injuries every year, and our choice of reconstruction pathway is guided by the GHOIS. On an analysis of the last 965 injuries in a 3-year period, we found that the limb reconstruction pathway followed fits into one of the following options (Table 28.5). A common requirement for success is a thorough debridement by an experienced 'orthoplastic' team. Bone stabilization is tailored to the fracture needs and the cover is provided at the earliest. The individual skin score is used to choose the method of wound cover, and the total score guides the time of treatment (Fig. 28.4).

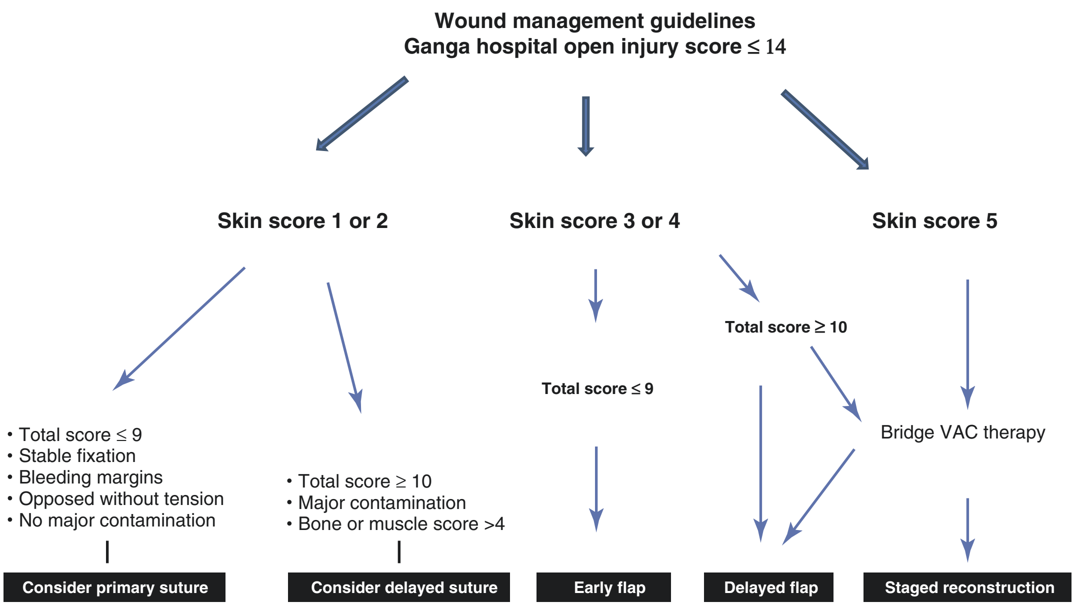

Fig. 28.4 Ganga Hospital Open Injury Score can be utilised to determine wound cover. The above algorithm is utilised where the skin score is used to choose the method of wound cover and the total score guides the time of treatment

28.19 Fix and Primary Closure

Injuries with a skin score of 1 and 2 have no skin loss at injury or during debridement. When contamination is low with satisfactory debridement, these patients are suitable for direct suturing. The total score must be <9 as this indicates low-energy violence, and the chances for postoperative swelling or compartment syndrome are low. Stable skeletal fixation and bleeding skin margins which are opposed without tension are the prerequisites. It should be noted that the length of the wound is not a criteria for suitability of suture (Fig. 28.5).

28.19.1 Fix and Delayed Closure

Injuries with skin score of 1 or 2, but with either a total score of >9 or with moderate or severe contamination, are not to be primarily closed. A higher score of >9 indicates a high-energy violence and a reassessment at 48 or 72 h is necessary. A delayed closure is performed if the wound characteristics at second-look debridement allow closure. If additional debridement is required at the second-look surgery, leading to skin and soft tissue loss, the patient is managed by staged flap protocol.

28.19.2 Fix and Skin Grafting

A skin score of 3 indicates skin loss either at injury or during debridement. In a score of 3, the wound does not expose the fracture site or there is an adequate cover of soft tissue. A classic example is open fractures of the femur where a good soft tissue cover is usually available after skeletal stabilization.

28.19.3 Fix and Early Flap

A skin score of 3 or 4 indicates skin loss either at injury or during debridement. If the wound exposes bone, articular cartilage, tendons or a vascular anastomosis site, a flap is necessary. The nature of the flap will be determined by the location and size of the defect and the structures exposed. Again the timing is guided by the total score of GHOIS. An early flap can be done if the total score is less than 9. This indicates a less energy violence and a more definable zone of injury.

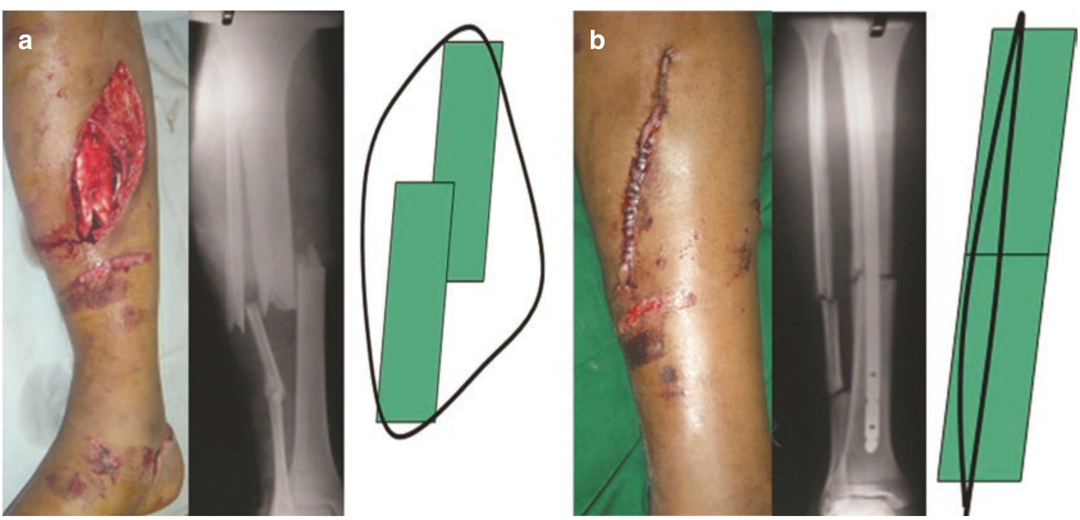

Fig. 28.5 Occassionally bone injuries can be treated by primary closure. When there is no skin loss and the bleeding margins can be opposed without any tension, when the fracture is not reduced and the limb is shortened, wound always appear gaping and gives the appearance of skin loss (**a**). When the fracture is reduced, many times the skin margins oppose without much tension (**b**)

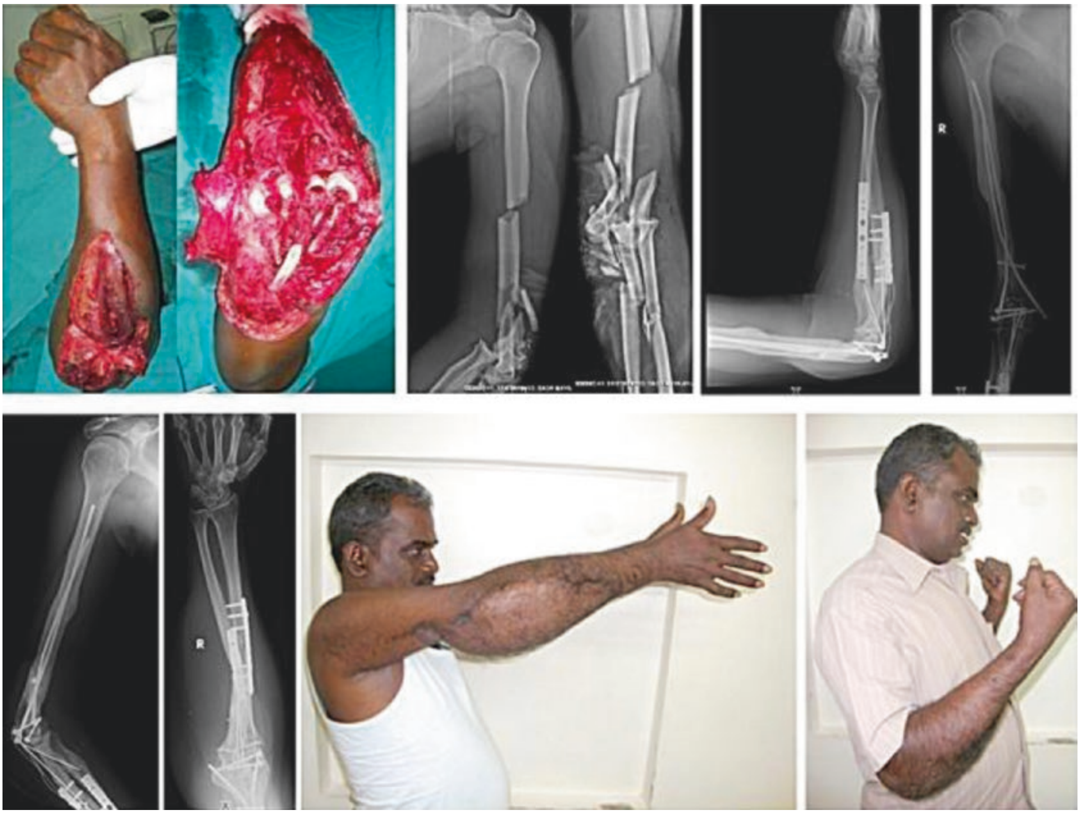

Fig. 28.6 Mangled Extremity with soft tissue loss and severe bone communition. Here considerable swelling of the wound is expected for the first few days. After bony stabilisation, the flap was delayed for four days before soft tissue reconstruction can be successfully achieved

We do not favour the traditional reconstructive ladder philosophy but rather would choose the most appropriate procedure that would best suit the injury and the needs as per the bone and soft tissue defect. Often a well-performed free tissue transfer would bring better functional results and can even make the difference between salvage and amputation.

28.19.4 Fix and Delayed Flap

A fix and delayed flap protocol is performed whenever there is severe contamination or the total score is >10 (Fig. 28.6). The duration of delay will depend on the condition of the wound, the swelling of surrounding soft tissues and any evidence of infection. If during the relook procedure, the wound is not suitable for flap, usage of NPWT following another debridement is an attractive option.

28.19.5 Staged Reconstructions

A score of 5 in any of the tissue scores and a total score of >9 indicate a limb that is not suitable for immediate or even early reconstruction. These limbs have considerable associated bony and soft tissue injury or loss (Fig. 28.7). Often the wound may not be ready for reconstruction even for a few weeks. Here the option of immediate or early application of NPWT at the index procedure must be seriously considered. The expertise of a skilled plastic surgical team with microsurgical reconstruction capability and an orthopaedic team capable of bone reconstruction and regeneration techniques is essential. If not available,

Fig. 28.7 Bilateral open injuries of both bone leg with severe soft tissue and bone loss. These injuries require staged reconstruction which has been achieved here by bone transport and soft tissue staged reconstruction and free LD flap. Patient ultimately regained near normal functional result

patients must be shifted to a centre where such facilities are available at the earliest. The choice of reconstruction and timing must be made on an individual patient basis.

Conclusion

Open injuries of limbs are severe injuries that often result in a poor outcome or amputations. Advances like early and adequate resuscitation, availability of good antibiotics, improvement in debridement techniques, and good soft tissue and bone reconstruction techniques have improved salvage and functional outcome. Many different scores have been proposed to assess the severity of injury of which the Ganga Hospital Open Injury Score is specific to type III-B injuries. It offers the possibility of both accurate assessment of the severity of injury to various tissues of the limb and also appropriate reconstruction protocols. The most important advance in the last two decades is the adoption of 'orthoplastic approach' from the stage of debridement and the recognition for the need for through debridement and early soft tissue reconstruction.

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Limb Salvage: Lower Extremity

29

Gerald E. Wozasek and Lukas Zak

29.1 Introduction

Extremity damage in disaster as well as combat situation, particularly of the lower limb, is typically a high-energy trauma with open injury [1, 2]. These dramatic conditions confront surgeons among others with significant human and ethical problems [3]. Hereby treatment of severely injured limbs challenges orthopedic surgeons [4]. It is important that in these extreme situations, only surgical specialists and senior trainees should be deployed and not be used as a training field for junior residents [5].

Limb reconstruction is defined as the intention to save a patient's leg or arm. However the basic principles of trauma "life before limb" have to be observed. Limb salvage was previously considered successful if the anatomic structure was retained and viable. In the meantime we have learned that function and patient satisfaction are equally important parameters [6, 7]. Decision-making in complex extremity trauma remains controversial. This involves multiple surgeries, requires special procedures, and demands long treatment time. Unfortunately the result may be poor and not every salvaged limb becomes functional to the patient's satisfaction [6, 7].

Even today the majority of clinical decision-making is subjective depending on the surgeon on call and the trauma setup. This means calculating the risk as there is only a short initial period for decision finding [4, 7]. In most cases a multidisciplinary approach will be necessary with innovative and controversial solutions [4, 6, 7]. Especially in trauma surgery, you cannot choose your patient. The first order of care is to determine what treatment is best suited for the individual and the individual injury itself.

Russel et al. [4] published the limb salvage index (LSI) which relates to the quantitative degree of the vascular (arteries and veins), nervous, bone, and soft tissue (muscles and skin) injury, as well as the warm ischemic time. Hereby absolute criteria for amputation are a LSI greater than six and open fractures Gustilo III-C (see Table 29.3) with nerve injuries. Additionally other scores such as the mangled extremity severity score (MESS) have been widely referenced including the parameters of skeletal and soft tissue injuries, limb ischemia, shock, and age [10, 11]. Also here, the key point appears to be the soft tissue injury [12].

The ultimate goal in limb reconstruction is to reconstruct bone; to preserve body shape, length, and appearance; to restore full function; and to return the patient to an independent and productive life. In many complex cases, these factors

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_29

play a crucial role in reintegration into society. However, limb salvage may result to major complications and delayed amputation [7].

The treatment protocol in initial damage control consists of:

- Debridement and (pulsated) irrigation
- Vascular repair (within the first 6 h, fasciotomy)
- Fracture repair (realignment, simple frame, antibiotic beads, spacers)
- Temporary synthetic skin coverage or VAC system

29.2 Soft Tissue Injuries

Soft tissue injuries occur with open fractures or with intact bone. These include cuts, bruises, contusions, and lacerations up to large skin and soft tissue defects, penetration traumata, nerve and vessel injuries, as well as crush injuries (see below, Sect. 5.3). Wounds are classified as clean, clean contaminated (normal but colonized tissue), contaminated (foreign or infected material), or infected (with pus present). Therefore, clean wounds have to be closed immediately for healing by primary intention; however, contaminated or infected wounds have to be left open for secondary wound healing [13] (Fig. 29.1).

Fig. 29.1 Extensive soft tissue defect on the lower limb in a patient with a totally destroyed knee joint after a motorcycle accident

29.2.1 Debridement and Irrigation

To promote healing by secondary intention, early surgical debridement has to be performed [14–16]. All visible dirt and (non-penetrating) foreign bodies have to be removed. A bacteriological smear should be taken before disinfection. The wound environment should be cleaned with brushes and disinfection fluid. After inspection, layer by layer has to be systematically debrided. Hereby, necrotic tissue is removed, first of all in the subcutaneous and muscle region. Wounds and wound bags have to be explored meticulously, hematomas have to be removed, muscle compartments under high pressure have to be opened, and the fracture area has to be cleaned.

Irrigation is performed with high volume of saline solution [15]. A further treatment option is the pulsating water jet lavage, with cautious handling near vessels and nerves. This system is much more effective in reducing the bacterial contamination and in removing necrotic tissue and foreign particles from the wounds than simple irrigation with a bulb syringe [17]. Hereby low-pressure pulsatile lavage has been shown to be as effective as high-pressure pulsatile lavage, with less damage on bone and soft tissue [18]. The use of antibiotics and antiseptics as additives should be limited because of inconclusive evidence and potential risks [19]. Antibiotic solutions offer no advantage over soap solution for irrigation of open fracture wounds and may be even detrimental to wound healing [19]. Inadequate debridement still remains the major cause of chronic infection after severe extremity trauma.

Further "second look" surgeries are required every 48–72 h to excise nonviable tissue, to retrieve new bacteriological smears, and to drain existing or new developed "wound bags" (Fig. 29.2).

29.2.2 Vessel Injuries

Vessel injuries commonly occur in multiple-injured patients especially in the lower extremities [20]. Direct injuries are caused by sharp and

Fig. 29.2 Pulsating irrigation reduces bacterial contamination

stump violence, indirect mechanisms by tension, distraction, or torsion [21].

The diagnosis or suspicion of a vascular injury begins with the clinical investigation. Hard signs include active hemorrhage, large expanding or pulsatile hematoma, absent palpable pulses distally, and distal ischemic manifestations [22]. Anamnestic and obvious clues for vessel injuries are penetrating traumata, high velocity traumata, ligated extremity after major bleeding, hypovolemic shock, dislocation of the knee joint, disturbance of peripheral sensation, major swelling, and difference in perfusion compared to the contralateral side. They are often associated with open fractures (see Chap. 3). The clinical checkup includes the peripheral blood flow (palpable pulse compared to contralateral side), the skin color and temperature, as well as the capillary refill.

The liberal use of imaging in the presence of any hard sign to confirm or exclude vascular injury is recommended. Equipment-based diagnostic starts with ultrasound sonography (audible), pulse oximetry, color-coded vascular duplex sonography up to angio-CT with contrast agent.

As soon as diagnosis of vascular injury is made, the majority of patients with hard signs of vascular damage will require surgical exploration and repair [22]. This has to be attempted within the first 6 h to achieve reperfusion of the limb. In these extreme situations, combined work of vascular and orthopedic surgeons becomes necessary. It is generally agreed that autologous vein grafts are the best for bypassing vascular defects [22]. In all cases of vascular repair, extensive fasciotomy is mandatory at the time of initial intervention [22].

Fig. 29.3 15 cm shortened limb for vascular repair – stabilization by an external fixator

In cases of open fractures with large bone and vessel defects, an alternative treatment strategy is to shorten the limb and to bring the bone and vessel ends together, using an external fixator (for further bone lengthening) [23, 24] (Fig. 29.3).

29.2.3 Nerve Injuries

Nerve injuries are classified in neuropraxia, axonotmesis, and neurotmesis with different predictive outcome. Obvious for potential nerve injuries are open and penetrating trauma. It becomes very difficult to assess primary nerve damage on initial examination with an intubated patient. This is a major limiting factor in limb salvage during the reconstruction phase.

29.3 Fractures

Fractures are classified by cause, by mechanisms of injury, by anatomical location, or by involvement of the surrounding soft tissue. Several classification systems are available to help surgeons to assess limb-threatening injuries. Hereby the one of Oestern and Tscherne, for closed and open fractures, has been very useful in clinical work (Tables 29.1 and 29.2). A further very practical one is that of Gustilo [8, 9] (Table 29.3). Even in patients who suffer from closed fractures, soft tissue injury plays a major role in prognosis.

Table 29.1 Classification of soft tissue injury in *closed fractures*

Grade 0
Minimal soft tissue damage
Indirect injury to limb (torsion)
Simple fracture pattern
Grade 1
Superficial abrasion or contusion
Mild fracture pattern
Grade 2
Deep abrasion
Skin or muscle contusion
Severe fracture pattern
Direct trauma to limb
Grade 3
Extensive skin contusion or crush injury
Severe damage to underlying muscle
Compartment syndrome
Subcutaneous avulsion

Table 29.2 Classification for *open fractures*

Grade I
Open fractures with a small puncture wound without skin contusion
Negligible bacterial contamination
Low-energy fracture pattern
Grade II
Open injuries with small skin and soft tissue contusions
Moderate contamination
Variable fracture patterns
Grade III
Open fractures with heavy contamination
Extensive soft tissue damage
Often, associated arterial or neural injuries
Grade IV
Open fractures with incomplete or complete amputations

Table 29.3 Open fractures Gustilo classification [8, 9]

Type I: wound size <1 cm
Type II: wound size between 1–10 cm
Type III: wound size >10 cm or high energy
A – adequate tissue for coverage
B – extensive periosteal stripping and requires flap
C – vascular injury requiring vascular repair

Oestern and Tscherne classification of soft tissue injury in closed fractures (Table 29.1).

Oestern and Tscherne classification for open fractures uses wound size, level of contamination, and fracture pattern to grade open fractures (Table 29.2).

Damage Control Orthopedics

Damage Control Orthopedics involves only immediate lifesaving procedures. This surgical strategy focuses on prompt hemorrhage control, early fracture stabilization, and timely management of significant soft tissue defects, avoiding additional surgical insults to the patient. Different protocols in pre- and in-hospital treatment have reduced post-traumatic complications [25–27]. They have shown a general decrease of systemic inflammatory response syndrome (SIRS) [28], adult respiratory distress syndrome (ARDS), pneumonia, and fat embolus syndrome when applying initially only minimally invasive surgical techniques [29]. At the same time, early patient's mobilization is accomplished [30].

29.3.1 External Fixation

Damage Control Orthopedics emphasizes primary on external fixation. Especially in open fractures with severe soft tissue injuries, frame fixation has been shown today to be the gold standard [31]. External fixation can be applied for both acute trauma [1, 32] and can be secondarily modified for post-traumatic reconstruction [24, 33].

For correct and safe pin positioning, good anatomical knowledge is mandatory to avoid injuries and transfixation of vessels, nerves, tendons, or muscles. The pins should be placed in the "safe zones" of the particular limb [34].

However in an austere environment, provisional and definitive external fixation devices can pose different technical challenges due to resource limitations. Lack of fluoroscopy or the unavailability of power is not seldom in these situations [1]. Simple axis realignment should be initially attempted. The aim hereby is to enable a transport to the next hospital for further, adequate diagnostics and interventions.

29.3.1.1 External (Pin) Fixators

The indirect bone fixation with Schanz screws is minimally invasive and allows a good approach to the soft tissue. During mobilization the transfer of load can be gradually shifted from the frame to the bone. Secondary axis correction is easily performed and as a modular system, the frame can be used in most bone locations.

The advantage of these systems is the simple and fast application. Sterile, prepackaged sets of external fixators including hand drill, 5 mm pins, and sufficient connecting hardware are available to construct a basic frame for fractures of the lower limb [1].

29.3.1.2 Ring Fixator (Wires)

In 1951, Ilizarov developed an external fixator with three basic elements: rings attached to the bone with tensioned transfixation wires and threaded rods connecting the rings to each other. Hinges, posts, support plates, translation assemblies, or rotation mechanisms allow modification of the frame [33]. It can be used primarily [35], early secondarily after consecutive conversion out of a simple external fixation [36], or late secondarily for treatment of complications, e.g., pseudarthrosis, bone lengthening, axis correction, or segment transport [33, 37, 38].

Further developments of the original Ilizarov external fixator are different types of hexapod ring fixators [39]. These circular frames are used with wires and pins and allow a simple secondary correction. With a computer-based software, corrections in all planes are easily achievable. After defining frame position and deformity [40], shortening, translation, and malalignment in AP and lateral view are corrected.

29.3.1.3 Hybrid Fixator

The hybrid fixator combines a circular frame with planar frames. The advantage, compared to the monolateral external fixator, is that the wires of a circular fixator can be placed close to the joint line. Therefore these systems are used in treatment of simple articular fractures, to avoid joint-bridging frames [41], combined with a unilateral fixator for fractures in the diaphyseal area.

In certain indications, e.g., in large bone defects, the combination of a hexapod frame with a joint-bridging external fixator is useful (Fig. 29.4).

29.3.1.4 Joint-Bridging External Fixation

Anatomic joint reconstruction in cases of articular fractures is usually not possible in damage control surgery [32]. In these cases a joint-bridging frame

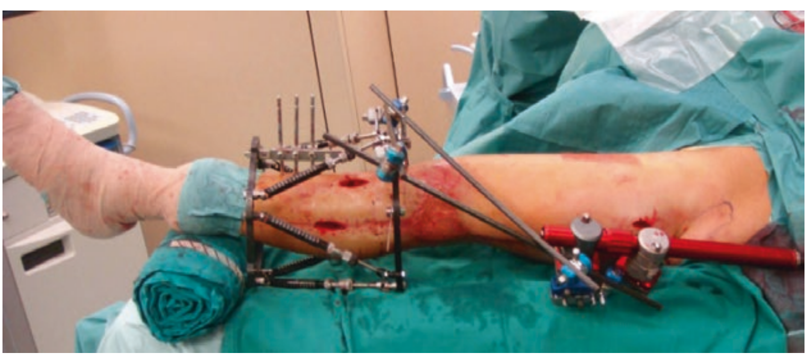

Fig. 29.4 Hexapod external frame on the tibia combined with a planar joint-bridging fixator and a monolateral external fixator for distraction osteogenesis on the femur in case of multilevel large bone defects on the lower limb

is useful to protect the soft tissue and to stabilize the joint when severe ligament injury is present or when a vascular repair was performed. Ligamentotaxis has been shown to be successful to reduce fragments in the joint area.

29.3.2 Internal Stabilization

The treatment of open tibial and femoral fractures remains controversial [30, 42–45]. Contrary to the damage control philosophy, early total care favors primary nailing [44] or plating [46].

However external fixation (EF) in open fractures has become very popular with shorter surgical time and less blood loss. The potential risk of pin site infections and risk of malunion [43] is acceptable and is compensated by the risk of systemic complications during damage control surgery.

In contrast the major advantage of internal fixation using unreamed nails has been shown to reduce the incidence of reoperations, with lower risk of superficial infections and malunions, compared to external fixation [42]. In tibial or femoral open fractures, the decrease of infection depends on the concomitant injuries and the degree of soft tissue injury [42, 44]. Disadvantageous for reamed intramedullary nailing are the theoretical risk of additional central nervous system injury in patients with head injuries caused by fat embolization during fracture fixation [30, 47]. This is due to the intramedullary pressure rise as a consequence of manipulation in the medullary canal. Therefore the irrigation-suction technique has been developed for reamed nailing to reduce the viscosity of the medullary content [48].

Other studies compared plates versus external fixation in severe open tibial fractures [49]. Joint stiffness, angular malunion, and high infection rate occurred during treatment. The end result however showed good clinical outcome and excellent recovery of the limb function [46]. Furthermore minimally invasive plating techniques have been recommended with a supposed lower infection rate [50]. The soft tissue coverage has to be reconstructed, and plate fixation has to be performed on the soft tissue covered side of the tibia [50].

Fig. 29.5 Plating after lengthening

From a biomechanical standpoint, nail fixation is always superior to plating in shaft reconstruction [51]. However there are clear indications for plating especially in the tibia close to the joint area (Fig. 29.5).

29.4 Wound Closure/Soft Tissue Closure

29.4.1 Vacuum-Assisted Closing (VAC)

The soft tissue injury has the greatest impact on successful limb salvage. Hereby vacuum-assisted closing (VAC®) has shown to be most

Fig. 29.6 Vacuum-assisted closure of a wound after large bone defect and fasciotomy on the lower limb, combined with a joint-bridging external fixator

effective in wound closure of large skin and soft tissue defects [52]. It bases upon negative pressure wound therapy removing edema, putting mechanical tension on tissues, and encouraging vascular ingrowth, as well as granulation tissue. After creating a clean and living wound, a sponge is cut to the size of the missing skin coverage. Care has to be taken that vessels and nerves are protected, and the foam does not overlap into healthy skin. Furthermore, bone should not be in direct contact with the sponge. The fixing plastic drape should not be brought up circularly to avoid compromise of the circulation. If VAC therapy has stopped for more than 2 h, the sponge has to be changed. Otherwise change of the sponge is recommended every 3–5 days (Fig. 29.6).

29.4.2 Synthetic Skin Coverage

As a first- or second-line treatment, temporary synthetic skin coverage is useful in the treatment after fasciotomy or in cases of large skin defects. Epigard® is a two-layer, non-medicated wound dressing, which fulfills the task of natural skin providing some wound protection. This biological dressing acts as a one-way diffusion area, which allows conductive growth on granulation tissue. It has shown to improve the wound healing time and to decrease the patient's hospital stay [53]. The synthetic skin is fixed to the surrounding skin by sutures or skin staples and has to be changed every 3–5 days. After reduction of the swelling and edema, the skin can be adapted, approximated by elastic bands, or directly sutured (Fig. 29.7).

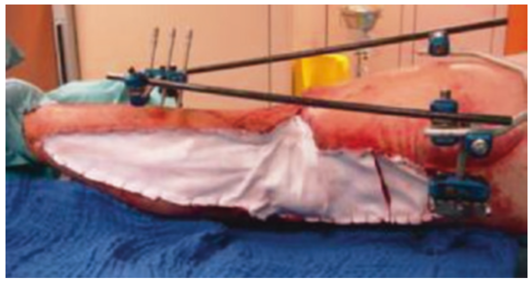

Fig. 29.7 Synthetic skin coverage of a wound after large bone defect and fasciotomy on the lower limb, combined with a joint-bridging external fixator

29.4.3 Skin Grafting

Secondary skin grafting is performed to definitely cover skin defects as soon as the wound is clean and granulation tissue is seen. Skin grafts heal well over muscle. The split-thickness skin graft is harvested with a power-driven dermatome, placed on the rough side of the carrier, passed through a mesher, and spread onto the recipient site. A layer of nonstick material has to be placed over the graft and has to be kept in place for 5–7 days.

The option to use complex grafts and flaps to cover large soft tissue and skin defects depends on the size and location.

29.5 Complications

29.5.1 Infections

Multiple factors increase the risk for infection in trauma patients. These occur primarily or secondarily. Depending on the location and kind of infection, different treatment approaches are available. Bacteriological smears are recommended to choose specific antibiotic treatment according to the bacteriogram.

Pin track infections with pin loosening during external fixation require pin removal and replacement at a safe location. More dangerous and invasive are infections in large bone defects, after primary wound closure or after fracture stabilization. The basic principles in the treatment of infected bone are to debride infected and dead tissue, to reduce dead space, to provide mechanical stability to the bone ends, and to fill the dead space. Antibiotic beads have been used to fill up the dead space. The beads are excellent treatment device during the early debridement of the fracture, but they become rapidly entrenched in the soft tissues and surrounded by fibrous scarring. Therefore removal of the beads can become difficult (Fig. 29.8).

29.5.2 Compartment Syndrome

Severe soft tissue trauma with or without bone fracture of any limb is often associated with an acute compartment syndrome, with subsequent disability if treatment is delayed [54]. The elevated pressure in the non-expandable compartment can lead to hypoxic necrosis of nerves and muscle tissue leading to ischemic contractures or even amputation [55].

Especially in unconscious and uncooperative patients after high-energy trauma of the lower limb, monitoring of the intercompartmental pressure is mandatory [15]. A difference of 30 mmHg (4 kPa) or less between the measured pressure and the diastolic (or medial arterial) blood pressure indicates a surgical intervention. Under normal conditions, values over 40 mmHg (5.3 kPa) will compromise capillary perfusion; under shock conditions these values are significantly less [56, 57].

Fasciotomy

Different approaches are described for decompression of the calf. We recommend a medial incision for the deep and superficial posterior compartments, as well as a lateral incision for the anterior and peroneal compartment. A single lateral incision is described as well. In the thigh, we differentiate an anterior compartment for the quadriceps muscles, a posterior one for the hamstring muscles, and a medial one for the adductor muscles. Usually, a lateral incision of the thigh is performed first and will sufficiently relieve the compartment pressure. Occasionally a medial incision will be needed as well. In all cases of vascular repair, wide fasciotomy should be applied [22] (Fig. 29.9).

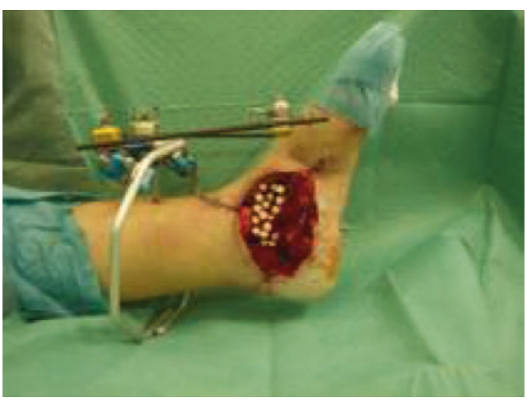

Fig. 29.8 Antibiotic beads used in an open fracture with bone and soft tissue defect

29.5.3 Crush Injury

Crush injuries are caused by compression on the body. Most frequently the lower limb is affected during collapse of buildings after earthquakes, explosions, or other natural disasters, trapping victims beneath the fallen debris [58].

Depending on the grade of impact, the injury leads to simple soft tissue lesions, up to major injuries of tissue, muscle or bone - often with the need of primary amputation.

Major crush injuries of the muscle can cause a compartment syndrome or subsequently

Fig. 29.9 Angiography of the lower extremities after road traffic injury

Fig. 29.10 Custom-made spacer with wires and bone cement on the lower limb in AP (**a**) and lateral view (**b**)

rhabdomyolysis leading to acute renal failure. Early infusion of intravenous fluids will lessen the severity of a crush syndrome [59].

29.6 Large Bone Defects

29.6.1 Wire and Bone Cement Constructs

As an alternative application of local antibiotics, the wire and bone cement technique has been propagated to prevent the problem of beads left long term in the defect area. Multiple 2 mm stainless wires are placed into the bone defect and seized into the proximal and distal intramedullary canal of the bone ends providing basic stability. Then antibiotic bone cement is molded around these wires in the size of the missing bone. This spacer block avoids soft tissue collapse into the defect, prevents adherence of free flaps with the surrounding musculature, creates a soft tissue tunnel for later reconstruction, and maintains the soft tissue anatomy [60, 61]. Especially in children no additional frame is necessary as this construct provides sufficient temporary mechanical stability for early partial weight bearing and limb function [60]. The spacer induces a pseudosynovial membrane creating a local biological chamber with an active membrane, which promotes the bone repair process. The newly formed membrane avoids the resorption of the bone graft, promotes revascularization of the graft, and delivers growth factors [61]. Absent pins and wires keep the soft tissue envelop intact for second stage surgery. Usually these spacers are easily removable (Fig. 29.10).

29.6.2 Distraction Osteogenesis

Limb salvage in patients with third-degree open, complex lower limb fractures resulting in large bone defects continues to pose a significant surgical task. Several techniques, including vascularized bone transfer [61], distraction osteogenesis accompanied by use of the Papineau technique [62], the classic Ilizarov callus distraction [33], the induced membrane concept as proposed by Masquelet [63] and allograft bone transplantation [6, 64, 65] have been developed to bridge the segmental bone defects.

In bone transport a corticotomized bone fragment is moved axially within the soft tissue to fill a defect and thus develop regenerate bone especially in large bone defects. In contrast acute closure with subsequent slow distraction at the same or a different site is used in smaller bone loss and bases on the compression-distraction principle [6].

Bone transport allows new bone formation to occur at a location outside of the zone of injury. New bone is created in the least damaged section, bringing its own blood supply and recruiting soft tissues to close open wounds. This is performed by two techniques:

In acute shortening the defect is closed by compressing the proximal fracture segment into the opposite one. It has been reported that acute femoral shortening in traumatic leg injuries can be performed for 3–5 cm and in the tibia for 2–3 cm. Shortening can even be greater if a delayed rate is used. However there are literature reports and personal experience which clearly showed greater shortening [23, 24].

The advantages are that local viable bone is transported acutely into the large bone defect, acute alignment of the fracture is established with compressed bone surfaces, and soft tissues are recruited into the zone of injury. There is less need for local and free flaps thus reducing donor-site morbidity, a decrease of the operating time because the bone and soft tissue loss are handled at the same time and less complications. Furthermore docking site revision surgeries are diminished [24]. No absolutely safe limits for acute shortening have been suggested, and therefore every case has to be carefully observed during surgery. Postoperative monitoring is mandatory because soft tissue edema can result in late neurovascular compromise.

The disadvantages of acute shortening are the risk to kinking of the vessels and the bulbous expansion of the soft tissues. Hereby the muscle tendon unit loses its mechanical efficiency.

The second method of bone transport is the intercalary one [66, 67]. The fracture is aligned and stabilized with the external frame maintaining length. A corticotomy is done proximally, distally, or at both sites, and the transport segment is distracted according to Ilizarov principles. Hereby living bone is moved into the defect zone. Management of the docking site becomes essential. During prolonged transport, the end of bone pushing through the tissues will develop a fibrous cap that inhibits healing at the docking site. Furthermore a deep invaginated skin cleft will develop that impedes docking. Therefore denuding of the bone fragments until bleeding bone is exposed, bone grafting will become necessary in most cases (Fig. 29.11). Recent developments for limb length discrepancy and callus distraction work with fully implantable devices as lengthening nails. They occur with better patient's compliance, but lack in usage of acute treatment, soft tissue injuries or infection.

29.6.3 Nailing After Lengthening

The treatment in an external fixation over months is associated with several complications and is stressful for the patient and the treating orthopedic surgeon. Although osteodistraction performed according to Ilizarov's principles remains a reliable method, fractures and complications at the docking site are reported in up to 25 % of patients [68]. Furthermore bending of the new bone regenerate in long bone defects is often noticed [69, 70].

Therefore a novel concept of primary external fixation and limb lengthening followed by internal stabilization with either nailing [71] or

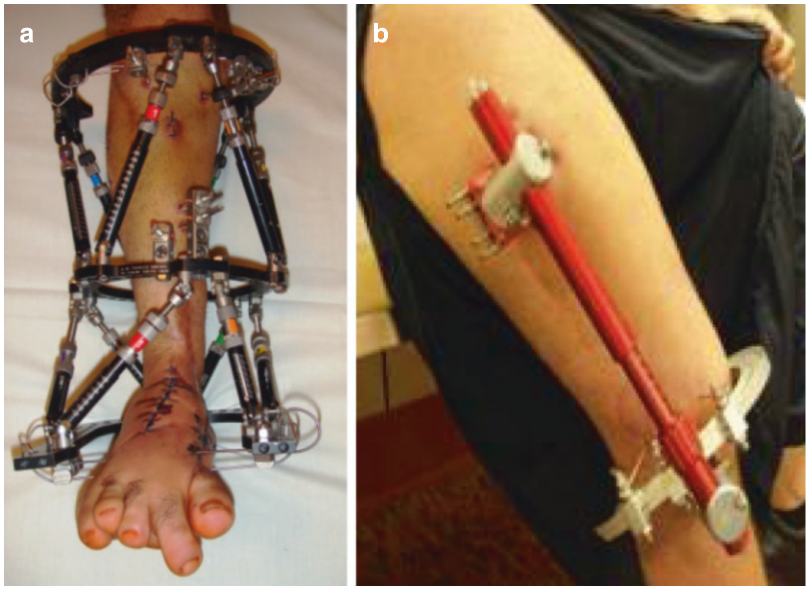

Fig. 29.11 (**a**) Hexapod external frame; (**b**) monolateral external fixator for distraction osteogenesis

plating [72] has been established to provide initial damage control in staged definitive limb reconstruction. Indications for nailing after lengthening include poor bone quality and osteoporosis, bending or fracture of the new bone, malalignment, compromised soft tissue, missing or delayed bone healing, increase patient's activity level, and in cases of destroyed knee or ankle joints (Figs. 29.12 and 29.13).

In this technique, as soon as limb length has been achieved, the external frame is removed and internal fixation supports the new bone against bending or refracture during the consolidation phase. In a recent study, we showed that additional internal fixation after osteodistraction ensures good clinical and radiological outcome [73]. In particular, a reduced incidence of axis deviation at the lengthening site and refracture in patients who underwent additional internal fixation after osteodistraction, without an increase of infectious complications was seen.

Despite the obvious advantages of internal fixation when used to treat third-degree open fractures, this treatment remains a topic of controversial debate [42, 44]. First of all the incidence of infection is of major concern. Therefore we delayed internal fixation after frame removal for about 10 days and no deep infection was seen. Similar results of no difference in the incidence of deep infection were reported by Rozbruch et al. when comparing a classic Ilizarov osteodistraction (OD) technique with or without secondary nailing [71].

A further intriguing advantage appears to be the reaming of the medullary canal prior to nail insertion with an early periosteal vascular proliferation and hyperemia, which is often associated with periosteal new bone formation. The products of reaming, which contain osteoblasts and multipotent stem cells, serve as local bone graft that stimulates medullary healing. Nevertheless care has to be taken when passing the reamer through the new bone generate to avoid thermal necrosis.

29.6.4 Bone Grafting

Treatment strategies for large bony defects include the use of autogenous materials, allogenic bone, synthetic bone substitutes, and stimulating growth factors. Despite these developments, autogenous bone graft is still

Fig. 29.12 Preoperative planning procedure for nailing after lengthening including realignment of the bone segments

Fig. 29.13 NAL in large bone defects

considered the gold standard in defect reconstruction [74] because of its intrinsic osteogenic activity. However, the donor-site morbidity after iliac crest harvesting is significant. Other possible harvesting sites such as rib grafts, distal femur, proximal tibia, distal tibia, calcaneus, or hemifibula are described, but they are not used very often in long bone treatment because of the small amount of graft obtained [65].

A new approach in bone grafting is the reamer-irrigator-aspirator system (RIA-DePuy Synthes®), which was developed initially to prevent pressure rise during reaming [75]. It is described as a sufficient and safe procedure in the treatment of long bone nonunions [65], with reaming debris rich in growth factors [76, 77].

Using the RIA system, different facts have to be noticed: preoperatively cortical diameter at harvest site has to be assessed, intraoperative reaming has to be monitored with fluoroscopy, bone harvesting in osteoporotic patients has to be avoided, and the technique requires clinical experience with intramedullary osteosynthesis.

The advantage of this technique is the reliability that sufficient quantity of bone graft is available. Intramedullary bone graft is biologically active with osteogenic, osteoconductive, and osteoinductive properties; donor-site morbidity appears to be less compared to iliac bone graft harvest. Combining new proteins like BMP with intramedullary graft is supposed to improve bone healing (Fig. 29.14).

Fig. 29.14 Intraoperative X-ray of the reaming-irrigation-aspiration system

Conclusion

Limb salvage in the lower extremity has to be aimed at the patient's maximum benefit. Many ways lead to successful extremity reconstruction. There always has to be the harmony between biology and surgical procedures. However with modern surgical techniques, almost everything is possible, but not everything which is possible is necessarily worthwhile.

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30 Foot and Ankle Trauma: From the Crush to the Missed and Neglected Injuries

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30.1 Introduction

In the face of major long-bone fracture, head injury, or life-threatening blunt trauma to the chest or abdomen, injuries to the foot and ankle, particularly if they are closed and not associated with gross deformity, are often missed or simply neglected. In major disasters or mass casualties where providers are overwhelmed and diagnostic and therapeutic facilities are stretched to the limit, neglected noncritical trauma is the norm.

Definitive management of these injuries is complicated in an austere environment, as there are limited medical resources, damaged public infrastructure, and unstable social situations. Surgeons caring for patients with foot crush injuries in these scenarios need to address open fractures, acute and delayed compartment syndromes, and crush syndrome. Fixation of forefoot and midfoot fractures is often achieved with K-wires and external fixation; however, internal fixation can be used in midfoot injuries if the soft tissues allow. Appropriate management of the soft tissues is paramount to a successful outcome. Staged approach will allow achieving appropriate reduction of fractures that present late and will minimize both soft tissue complications and risk of infection, both superficial and deep.

The objective of any intervention for posttraumatic foot and ankle conditions is to establish a stable, painless, plantigrade foot. This may involve the realignment of malunited fractures, healing chronic nonunions, eliminating chronic osteomyelitis, stabilizing recurrently unstable joints, or fusing joints with posttraumatic arthritis. Not all cases require surgery. Bracing, either over the counter or custom, often is helpful and in some cases curative. Although not the primary focus of this chapter, amputation is in some circumstances the best course of action in lieu of multiple ill-fated procedures that have little chance of restoring normal form or function. Probably one of the most difficult decisions facing the clinician dealing with severe posttraumatic foot and ankle pain is to recommend an amputation. In some cultures amputation is associated with a stigma that reinforces a patient's reluctance. The lack of

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_30

availability of prosthetic limbs can make this an even more difficult course to recommend. Notwithstanding these issues many patients, especially if already subjected to multiple surgeries to manage their initial injuries, will welcome amputation, rather than be subjected to procedures with marginal possibility of a successful outcome.

The purpose of this chapter is to discuss the spectrum of foot and ankle injuries that are related to the crush or are consequences of the more common neglected foot and ankle injuries and to outline management both when resources are limited and under optimal conditions.

30.2 Epidemiology

There are several reports of injury profiles following natural disasters in the orthopedic literature. By far, earthquakes are the most common natural disaster associated with crush injuries. These injuries are due to entrapment from falling debris with subsequent tissue compression [1, 2]. It is believed that injuries to the axial skeleton and proximal extremities occur during nighttime earthquakes when patients are asleep and laying down, whereas distal extremity injuries are felt to occur more commonly with daytime earthquakes when victims are injured while attempting to escape falling debris [2, 3]. Injuries to the lower extremities are more common than those to the upper extremities following earthquakes [2–7]. However injuries localized to the foot are much less common than those of the femur or tibia. The exact incidence of crush injuries to the foot following seismic events is unknown, as this metric has not been reported in previous studies; however, foot fractures following natural disasters account for between 5.7 and 17.1 % of all fractures [2, 4–6, 8].

30.3 Evaluation

Standard ATLS protocols for primary and secondary survey should be performed on all injured patients. Often, foot injuries present in a delayed fashion. Evaluation of the soft tissue envelope about the foot is paramount, as this will frequently dictate treatment options. Puncture wounds, abrasions, lacerations, and skin avulsion injuries should be noted, since incisions usually need to be planned around these. If the trauma is secondary to a tsunami, open wounds associated with fractures, albeit small, are often severely contaminated and may go on to develop gram-negative wound infection [9]. Likewise, wounds from tornado events are associated with high levels of soiling and contamination and may be subsequently infected with gram-negative organisms [10]. A neurovascular exam should be documented. Plain radiographs or a fluoroscopic image may be all that is immediately available to the orthopedic surgeon.

When dealing with crush injuries following a seismic event, time under rubble and time from rescue to first medical aid are important predictors of subsequent complications. It has been demonstrated [6] that the likelihood of developing compartment syndrome increased by 13.3 % in the lower extremities with each hour passing under rubble. Furthermore there was a 5 % increase in the likelihood of developing acute renal failure with each passing hour from rescue to receiving first medical aid.

In addition to identifying open fractures and compartment syndromes, the orthopedic surgeon must be cognizant of patients with a crush injury who go on to develop crush syndrome. Whereas crash injury is a descriptive term indicating the mechanism of injury, crush syndrome is a condition where rhabdomyolysis occurs secondary to prolonged muscle compression from a crush injury, and following extraction, the by-products of rhabdomyolysis cause systemic complications which include hypotension, acute renal failure, electrolyte abnormalities, and arrhythmias [11–13]. There should be a high index of suspicion for this diagnosis in patients with a prolonged crush injury, and the protocols for the disaster response team (laboratory studies, fluid resuscitation, nephrology consultation, etc.) should be in place to evaluate and subsequently treat these patients. In patients with a closed injury with concomitant crush syndrome, efforts should be made to treat that injury in a closed or percutaneous manner, as managing these injuries with formal open reduction and internal fixation is associated with a high rate of infection [8, 11, 13]. Patients with crush injuries to the midfoot who do not develop a crush syndrome can be definitively treated with internal fixation if the soft tissue envelope allows.

30.4 Soft Tissue Management

30.4.1 General Principles

Soft tissue condition plays a paramount role in the treatment of foot and ankle injuries. In severe foot and ankle injury, late presentation is common during natural disasters and other mass casualty events. Closed or open fractures can be treated in a definitive way only if and when soft tissues are ready for surgical intervention. It is often not a case upon initial presentation. The foot and ankle might be very swollen and even blistering (Fig. 30.1). The skin can be violated and opened in case of fractures and even isolated dislocations (Fig. 30.2).

Fig. 30.1 Fracture blisters

Fig. 30.2 Open ankle fracture dislocation

Damage control approach should then be implemented. When under these circumstances bone pathology is significant, whether it is a fracture with major displacement or angulation of the main fragments, or if there is major joint dislocation, use of temporizing external fixation is recommended to either correct some of the displacement or to stabilize the affected limb for the time needed for the soft tissue envelope to settle and be ready for next-stage surgery (Fig. 30.3a, b). A number of surgical procedures might be needed to achieve desired results.

Wounds that are not suitable for primary closure need, at a minimum, an occlusive dressing [14] following debridement. If available, negative-pressure wound therapy creates a favorable environment for granulation tissue and may convert some open wounds from a type IIIB to a IIIA and allow for split-thickness skin grafting as opposed to local rotational or free flap coverage. Management of wounds that are not capable of primary closure will depend on the resources available as well as the skill set of the surgeon. In situations where a plastic/reconstructive surgeon is not available, the orthopedic surgeon is often responsible for advanced soft tissue management.

For wounds with a degloving component, split-thickness skin excision (STSE) [15, 16] can be used to determine what tissue remains viable. The degloved flap of skin and subcutaneous tissue are sutured back to its native bed, and the skin from this flap as well as the surrounding healthy, intact skin is harvested as a split-thickness skin graft. Dermal capillary bleeding is used to identify deeper tissue that remains viable and guide excision of the portion of the flap that is nonviable. Fracture fixation can then be undertaken and the skin graft is then applied to the wound with local rotation of muscle if necessary to allow for an appropriate wound bed. Myerson's report of eight patients [17] with crush injuries to the foot description of the technique showed 100 % take of the grafts. It should be noted this was used in dorsal foot wounds only. He cautions that it should be used in injuries with a shear component where the skin and subcutaneous tissue are separated from the deeper fascia and skeleton. In

Fig. 30.3 (**a**) External fixation of open ankle fracture dislocation. (**b**) External fixation of midfoot open fracture

cases where bone is exposed or deeper tissue is injured, a free flap may be a better option.

For wounds with a significant soft tissue defect with exposed bone, the decision to undergo reconstruction with flap coverage is based on several factors including the availability of a plastic/reconstructive surgeon, availability of a microscope and micro instruments, appropriate facilities for postoperative care of flap patients, and medical resources available to the patient in the postoperative period. All of these are affected in some way following a natural disaster. If the wound requires flap coverage and the bony injury is not amenable to fixation, then amputation should ensue with attempts to utilize viable tissue (toe flaps, skin flaps, etc.) for coverage of the residual limb.

30.4.2 Compartment Syndrome

Crush injuries are the most common cause of foot compartment syndrome [18, 19]. It has been found [20] that a crush mechanism almost doubles the relative risk of developing a foot compartment syndrome. Additionally, crush injuries in combination with a forefoot injury were found to have the highest rate of foot fasciotomy [18, 19].

The classic signs and symptoms of compartment syndrome in the upper extremity and lower leg may not be as reliable in attempting to diagnose compartment syndrome of the foot [26, 28, 29]. Pain with passive dorsiflexion of the toes was found to be the most common symptom in a series of 14 foot compartment syndromes. If there is suspicion for foot compartment syndrome, compartment pressures should be checked. Compartment pressures greater than 30 mmhg or within 10–30 mmhg of the diastolic pressure in patients with systemic hypotension are indicative of compartment syndrome [21]. If clinical suspicion is high compartment decompression should be performed regardless of pressure. The presence of an open fracture does not rule out the possibility of a compartment syndrome [22].

The management of foot compartment syndrome remains controversial [21]. In the setting of a crush injury, particularly when the presentation may be delayed secondary to a natural disaster, issues arise as to whether there is an indication for release and whether the release of the patient's foot compartments could further compromise the already tenuous soft tissue envelope.

Ideally fasciotomies for foot compartment syndrome should be performed within 8–10 h of the onset of symptoms [23]. Given the delay in treatment associated with natural disasters, adherence to this rule is not feasible. Mohammad Naghi et al. [6] discussed the management of patients with compartment syndrome in their series from the 2003 Bam earthquake in Iran. Patients with compartment syndrome that were admitted within 48–72 h after the incident were managed with fasciotomy. In that series, those admitted after the first 48–72 h were managed with therapy and staged reconstructive procedures due to the historic high rate of wound complications associated with delayed fasciotomy. The authors do not report outcomes on those patients who underwent fasciotomy. In contrast, Bar-on et al. [8] indicated that all patients that presented with compartment syndrome to their field hospital in Haiti following the 2010 earthquake were deemed chronic, and subsequently they were treated supportively without fasciotomy.

Should the orthopedic surgeon choose to perform fasciotomies, various techniques exist for the decompression of the fascial compartments about the foot. The variability in technique is based on the perceived differences in the number of formal compartments felt to be present in the foot. The three-incision technique described by Manoli and Weber [19] allows for adequate decompression of all 9 ft compartments; however, issues arise typically with the dorsal wounds as these may allow for primary closure and require skin grafting.

Multiple relaxing incisions or “pie crusting” of the dorsal skin as described by Dunbar [24] may be an alternative to formal dorsal fasciotomy wounds. Decompression of deeper compartments can be performed through these wounds, and this technique may decrease the need for dorsal foot skin grafting following traditional dorsal fasciotomy wounds.

An alternative approach is described by Ling [25], who felt that only the intermediate and lateral hindfoot compartments were rigidly bound by fascia and would require formal decompression. A plantar incision starting 5 cm from the posterior aspect of the heel on the non-weight-bearing aspect of the instep is extended 5 cm distally. As this plantar skin is stouter and less vulnerable following a crush injury, this may be an acceptable alternative, although there are no clinical series reported using this particular technique.

As stated previously, the alternative approach to the acute management of foot compartment syndrome is to manage the resultant deformities in lieu of fasciotomies with the rationale that the morbidity from these deformities is far less than that which would be incurred secondary to a wound complication or infection. The resultant deformities include hammertoes, claw toes, and cavus foot deformity. Patients may also be at risk for development of foot stiffness as well as chronic pain; however in the setting of trauma associated with other musculoskeletal injuries about the foot, the development of these sequelae is likely multifactorial. Furthermore, the surgeon must take into account what orthopedic resources the patient will have available if the decision is made to forego fasciotomy in favor of delayed reconstruction.

Fasciotomies should not be performed in a patient with a concomitant crush syndrome unless distal pulses and capillary refill are compromised. Should this situation arise, fasciotomy followed by radical debridement of necrotic muscle should be performed [13].

30.5 Fractures and Dislocations

30.5.1 Open Fractures

Open fractures are common following crush injuries to the ankle and more so to the foot due to the limited soft tissue coverage above medial and lateral malleoli and on the dorsum of the foot. The management of open fractures is made more complicated following natural disasters. Early antibiotic administration and urgent surgical debridement are the pillars of management in the usual treatment of open fractures in attempts to decrease infection [26–28]. The timing of both antibiotic administration and surgical debridement is delayed in natural disasters. Open injuries are graded according to the system first proposed by Gustilo and Anderson in 1976 [26] with type III injuries further classified by Gustilo in 1984 [29]. The urgent administration of antibiotics is universally supported. Administration within the first three hours of identification of an open injury was found to lower the infection rate according to a study by Patzakis [30]. A recent survey of trauma surgeons [28] showed that 88 % of traumatologists felt antibiotic administration in the first 60 min was crucial.

For grade I injuries, a first-generation cephalosporin is utilized. Aminoglycosides [26, 29] have been recommended for grade II and III injuries with the addition of penicillin G for severely contaminated wounds to prevent clostridial myonecrosis; however, there is insufficient evidence to support use of either of these agents [27]. Despite the lack of data, 76 % of traumatologists still use aminoglycosides in the treatment of open fractures [28]. In this particular cohort of patients who are at risk for renal complications secondary to their crush injury, aminoglycosides should be used judiciously.

There is no consensus on duration of antibiotic use. A 24–72 h course may be adequate [28, 31] so long as appropriate debridement is undertaken. There is no evidence to support subsequent courses of antibiotics following each debridement until the wound is definitively closed [27].

Primary wound closure is felt to be a reasonable option in type I–IIIA injuries, so long as antibiotics are administered in a timely manner, the wound is adequately debrided, and the closure is tensionless [20].

Use of negative-pressure wound therapy (NPWT) is useful in the management of many open wounds (Fig. 30.4a, b). By creating a favorable environment for granulation tissue, vacuum therapy may decrease the need for free soft tissue transfer [32], although it has not been shown to decrease infection rates if flap coverage is required and delayed longer than 7 days [33]. If negative-pressure wound therapy is not available, an occlusive dressing is a reasonable alternative [14, 28] and has been shown to decrease the infection rate compared to nonocclusive dressings or wounds left open to air.

30.5.2 Ankle Fractures

The main goal of any ankle fracture treatment is to achieve anatomic reduction of the ankle joint and to maintain the reduced position, with the dome of the talus congruently located under the tibial plafond. In case of mass casualties realignment of the deformed extremity and closed reduction should be attempted first under appropriate pain control. The extremity is then splinted and imaging is done when available.

Decision to treat the fractured ankle in a cast or splint or surgically is based on fracture pattern, soft tissue condition, patient's general condition, associated injuries, and resources available.

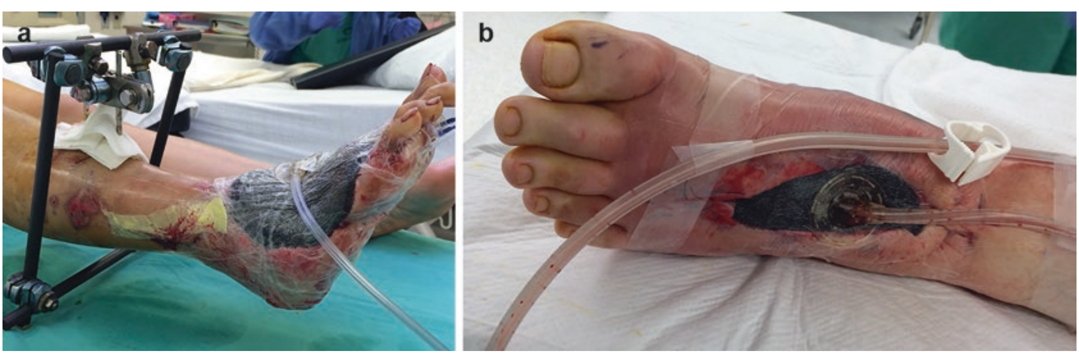

Fig. 30.4 (**a**, **b**) Foot and ankle NPWT

If the fractured ankle is unstable despite attempted closed reduction, temporarily bridging fixation is used (Fig. 30.5a, b).

Surgical approach is based on either Weber or Lauge-Hansen classification. The main goals of the surgical treatment are: (1) anatomic reduction of intra-articular fracture fragments and (2) absolute stability of the reduced fracture. If the dome of the talus despite reduced position cannot stay under the tibial plafond and feels unstable, two 2–3 mm K-wires are used and introduced from the plantar aspect of the foot, through the calcaneus, talus, into distal tibia. They stay in between 4 and 6 weeks. Following this temporary stabilization appropriate radiological imaging is recommended and if and when available is used utilizing either x-ray or preferably CT scan, to accurately assess the relationship between fractured fragments and different components of the ankle joint structures and the attempt to identify the source of ankle joint instability.

30.5.3 Talus and Calcaneus Fractures

Most talus and calcaneus fractures are a result of high-energy trauma such as motorcycle, car collision, or fall from a height. They can occur as a result of either gunshot wound or blast injury. Patient's general condition, neurovascular status of the lower extremity, and degree of damage of the soft tissues will determine treatment strategy during MCE.

As in other extremity fractures, soft tissue condition will determine both timing of the surgical intervention and surgical approach. If possible

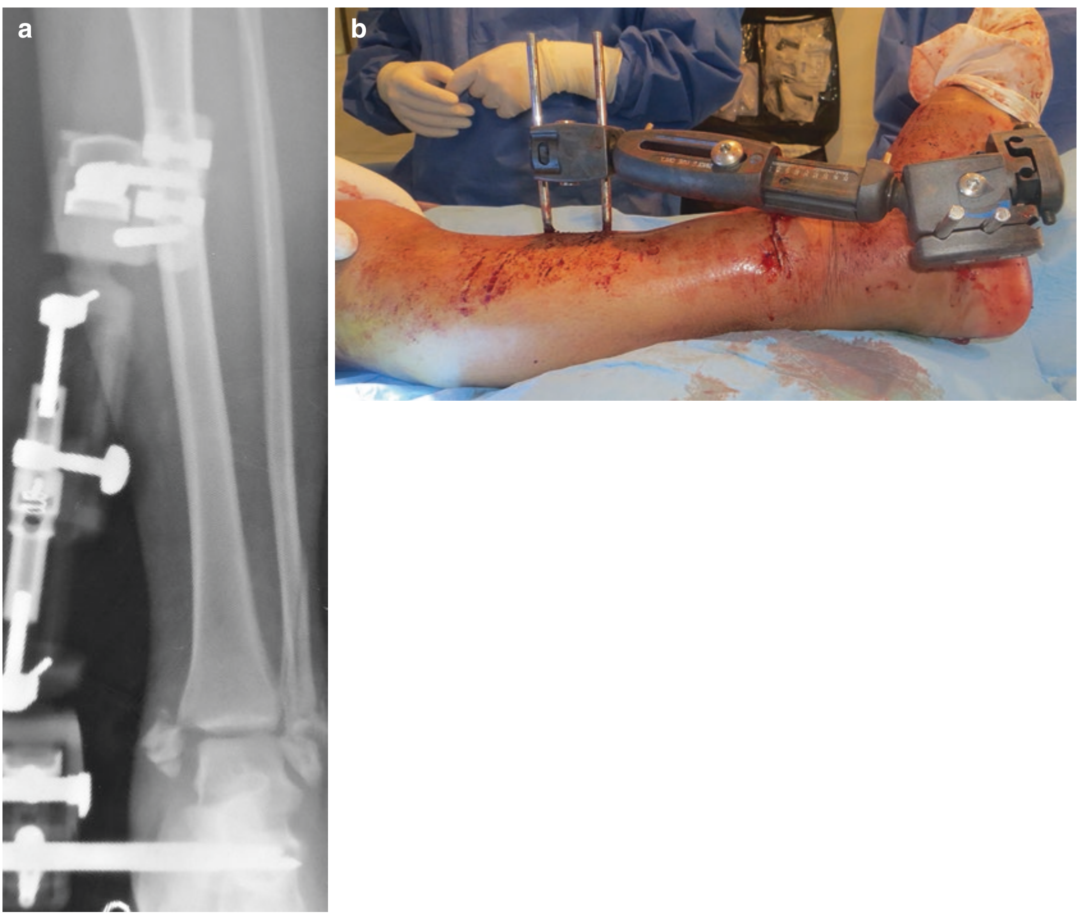

Fig. 30.5 (**a**, **b**) Bridging external fixation in unstable ankle fracture

closed reduction is performed and affected extremity is immobilized. If splinting is not possible, external spanning fixation is used until soft tissues heal to allow open reduction and internal fixation. This may take up to 2 weeks.

The goal of treatment is to achieve a functional and pain-free foot and ankle. In situations when multiple casualties are overwhelming, a more conservative approach is preferred.

30.5.4 Midfoot Injuries

Fractures and dislocations of the midfoot are common following crush injuries to the foot. Direct trauma to the dorsum of the foot can produce variable patterns of dislocation predicated on the point of impact and foot position [17, 34–36]. While open injuries are easily diagnosed, closed injuries may be more subtle. These patients often are unable to bear weight and have significant edema of the forefoot and midfoot as well as plantar ecchymosis [37].

Imaging studies should include weight-bearing AP and lateral and oblique radiographs of the foot, as up to 50 % of non-weight-bearing radiographs may be interpreted as normal [38]. Whereas fractures and dislocations of the tarsometatarsal joint are fairly obvious, identification of purely ligamentous injuries or those injuries with spontaneous relocation may be more subtle. The medial border of the second metatarsal should line up with the medial border of the middle cuneiform on the AP view, while the medial border of the fourth metatarsal should line up with the medial border of the cuboid on the oblique. Diastasis between the medial cuneiform-first metatarsal complex and the second metatarsal is indicative of instability. The “fleck sign” [39] an avulsion of the second metatarsal base or medial cuneiform is indicative of an unstable injury. On lateral radiographs, loss of the midfoot arch with plantar displacement of the medial cuneiform relative to the fifth metatarsal is indicative of an unstable injury [39].

Advanced imaging modalities such as CT and MRI may not be available following natural disasters; therefore if any question remains after weight-bearing radiographs, stress exam is indicated. The foot is simultaneously pronated and abducted on the AP view to determine if there is instability through the tarsometatarsal joint [40]. On the lateral view, attempted plantar flexion of the foot through the tarsometatarsal joint with dorsal gapping is indicative of instability [34].

In the setting of a crush injury with multiple fractures or a fracture-dislocation of the tarsometatarsal joint, if the injury is closed, fixation should be delayed until the soft tissue envelope is appropriate. Splinting is reasonable if the foot is stable and the midfoot joints are located; however if grossly unstable, external fixation with a 6 mm calcaneal pin and 4 mm pins in the first and fifth metatarsal is appropriate. If compartment syndrome is diagnosed and the surgeon elects to proceed with fasciotomy, dorsal incisions should be planned appropriately so they can be used for eventual definitive fixation.

Fixation for Lisfranc injuries is typically achieved with 3.5 mm screws following open reduction of the first, second, and third tarsometatarsal joints via a dorsal approach. Bridge plating with 2.7 mm plates across the TMT joint is also reasonable and has been shown to be biomechanically equivalent [41]. Subluxation of the fourth and fifth metatarsal-cuboid joints is typically managed with K-wire fixation. Stress evaluation of the intercuneiform joints as well as the navicular-cuneiform joints should be performed intraoperatively. If instability of these joints is detected, additional fixation with a screw or K-wire is warranted.

In cases of open midfoot injuries, definitive management with external fixation, supplemental K-wires, and concomitant soft tissue coverage has been described [16, 17, 42]. Skin from nonviable flaps can be harvested utilizing the STSE technique [15] described earlier in this chapter. This skin can then be replaced on the wound bed with local rotation of muscle if necessary.

30.5.5 Multiple Metatarsal Fractures

The presence of the metatarsal fractures should alert the surgeon to consider a concomitant Lisfranc injury. Management of metatarsal neck and shaft fractures typically involves use of intramedullary 0.062 in. K-wires. Although plates can be used on the metatarsal shaft, as the soft tissue envelope is typically compromised in crush injures, concern exists for complications associated with exposure and placement of plate fixation. K-wire fixation can be placed in a anretrograde fashion through the metatarsal head, while the proximal phalanx is dorsiflexed. Alternatively, the toe can be held in neutral position with the K-wire capturing the flare of the proximal phalanx base prior to engaging the metatarsal head. The wire should always enter the center of the head. Reduction of the fracture is achieved with a combination of longitudinal traction and percutaneous placement of a dental pick or bone hook to line up the fracture fragments. Once reduction is obtained, the wire then can be passed across the fracture site [43]. Antegrade K-wire placement with a pre-bent wire has also been described [44].

30.6 Sequelae of Foot and Ankle Injuries

30.6.1 Distal Tibial Nonunion and Nonunion After Open Fracture

Inadequate or inappropriate management of high-energy open distal tibia fractures will result in a relatively high rate of tibial nonunion, tibial malunion, and/or osteomyelitis (Fig. 30.6a–d).

Fig. 30.6 (**a**, **b**) AP and lateral of ankle after neglected distal tibia and fibula fracture. (**c**, **d**) CT demonstrating angulated tibial nonunion (**c**) and fibular malunion (**d**)

In cases of nonunion that is not long-standing and without radiographic evidence of arthrosis, fracture reduction and fixation, with or without cancellous grafting of the fracture site, can have excellent outcomes. Similarly, fracture malunions if long-standing are usually associated with arthrosis. Whether arthrosis is related to nonunion or malunion, ankle fusion or arthroplasty is advisable.

Two fracture malunions that may benefit from osteotomy and realignment are shortened and malrotated distal fibular fractures and coronal plane fractures of the distal tibia that have a vertical offset in the weight-bearing area of the tibial plafond. In both cases, if available, CT scan can help with preoperative deformity evaluation and operative planning. In the case of fibular malunion, the fibula can be osteotomized obliquely, brought out to length and rotated to correct rotational malalignment, and then fixed with a plate and screws. With malunited coronal plane distal tibia fractures, reduction necessitates osteotomy of the distal tibia along the line of the prior fracture and translation of the vertically displaced posterior fragment inferiorly until the joint surface is reduced. Once reduced, the broad cancellous contact area allows for excellent fixation with multiple interfragment lag screws.

With fracture nonunion one should always consider the possibility of infection, especially in the case of open fractures. A history of preceding infection or drainage or episodic erythema and exquisite tenderness suggests the possibility of infection. Blood work such as an erythrocyte sedimentation rate and C-reactive protein may be helpful. MRI can help but findings of chronic nonunion may be hard to distinguish from infection. An indium-labeled WBC scan may also help. Regardless of these results culture at the time of surgery is generally indicated especially if signs of infection are present at the fracture site. If available, noninvasive methods of attempting to gain union with electromagnetic and ultrasound-based healing systems can be tried, in conjunction with immobilization and non-weight bearing.

A variety of techniques are available to manage noninfected tibial nonunion, and in most cases, bone grafting with rigid internal fixation will result in a satisfactory outcome. Infected nonunion or distal tibial osteomyelitis will usually require staged treatment. The first stage usually involves the debridement of infected bone, placement of antibiotic beads or a spacer if available, open packing if they are not, and subsequent cancellous grafting with either the open Papineau technique or closed treatment with the Masquelet technique. If the problem involves significant soft tissue loss, flap coverage will need to be considered (Fig. 30.7a, b). Large-bone defects can be managed with tensioned fine wire external fixation and bone transport in younger individuals. Extensive soft tissue loss, bone infection, or bone necrosis may make below-knee amputation the optimal treatment with the most rapid recovery and return to function.

In smokers the treatment should not be initiated unless they are truly willing to stop smoking. Unfortunately these reassurances preoperatively are rarely followed by compliance postoperatively, and it is a wise surgeon that will only operate if patient is able to stop preoperatively as proven by preoperative blood nicotine levels.

30.6.2 Chronic Osteomyelitis

Chronic osteomyelitis is a common problem in foot and ankle injuries as many of the initial injuries involve open injuries, particularly around the ankle. Not infrequently, fracture-dislocation of the ankle results in perforation of the distal medial tibia through the skin and thin subcutaneous layer of the lower leg. Particularly if contamination is gross or the time to debridement and reduction is long, common factors in a mass casualty situation, the risk of deep infection is increased. Post-injury and perioperative prophylactic antibiotics taken for granted in hospitals in the developed world are often not available.

Chronic osteomyelitis is usually recognized by the presence of a persistently draining sinus. In most cases the infection is loculated, surrounding tissues appear quite normal, and erythema and swelling may be minimal. In patients with normal sensation, weight-bearing pain is common, but not invariable, often being related to associated bone or joint damage, rather than to the infection itself. Radiographs are usually abnormal with

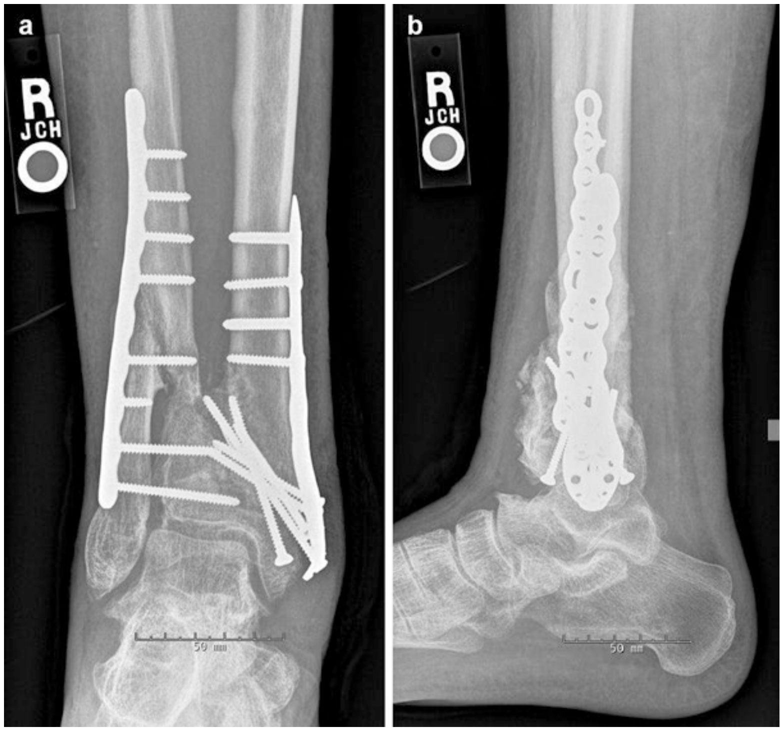

Fig. 30.7 (**a**, **b**) Final internal stable fixation with healed nonunion and realignment

evidence of fracture nonunion, moth-eaten or regionally sclerotic cancellous bone, and cortical loss. Involved articulations have joint space loss, areas of periarticular bone erosion, and subluxation or dislocation. In very long-standing cases there may be longitudinal pericortical calcification and a frank involucrum. To cure the patient, all infected bone needs to be resected, particularly in environments where prolonged courses of postoperative IV antibiotics are not possible. Use of antibiotic spacers in large defects and antibiotic beads in smaller areas is very helpful in eradicating the infection. Antibiotics most often used in these beads are tobramycin, vancomycin, and/or gentamicin. In addition spacers are used in the Masquelet delayed grafting technique of reconstruction. In the Masquelet technique the soft tissues are closed over an antibiotic spacer that is molded to model the bone to be replaced with cancellous graft about 6 weeks after spacer implantation. Where wounds cannot be closed over an antibiotic spacer, the Papineau technique of delayed grafting is often an effective means of dealing with bone defects left by the resection of infected bone. The Papineau technique involves packing the defect created by infected bone resection with saline-soaked gauze that is changed twice a day. Once the walls of the defect are covered with granulation tissue, the space is filled with cancellous graft, leaving the surface open. Once the graft is completely vascularized and incorporated, the surface can be left to epithelize or covered with split-thickness skin. This is a very cost-effective solution for sites with limited resources lacking access to bone cement and/or the appropriate antibiotics. These techniques are normally combined with the use of external fixation to stabilize the bone from debridement through graft incorporation.

30.6.3 Nerve and Vascular Injury and Residuals of Compartment Syndrome

Especially with open injuries around the ankle and in severe calcaneal trauma, injury to major nerves and vessels about the ankle and hindfoot can be a cause of significant late morbidity. Injuries to the posterior tibial artery can result in ischemia of the plantar musculature and secondary ischemic contractures as can an untreated foot compartment syndrome. Resulting toe deformities can be managed with IP joint fusions or other procedures for claw toes as considered appropriate. Minor nerve injuries and the resulting neuromas are usually best managed with neuroma excision and implantation of the proximal end of the transected nerve in adjacent soft tissue away from the incision or into a drill hole in bone.

Major nerve injuries present a bigger problem. First any possible bone impingement on the nerve should be identified by x-ray. An axial view of the heel will give good visualization of the tarsal tunnel where malunited calcaneal fracture fragments are most likely to cause trouble. Fragments of the posteromedial tibia can cause similar irritation. If a positive percussion test over the nerve correlates with bony protuberances, excising these fragments and decompressing the nerves may be helpful. If there are no impinging bones, the decision about surgical intervention is much more difficult. Exploring and decompressing the major nerves can help, but the patient should not be given any assurances preoperatively as the chance of a positive outcome is not particularly high.

30.6.4 Foot Deformity

Besides posttraumatic arthritis and nonunion, a frequent cause of long-term pain after foot and ankle injury is deformity. Most major deformities after trauma are the result of malunited fractures or dislocations or severe subluxations that have not been reduced. The most common deformities are pes planus, hindfoot varus or valgus, and forefoot abductus. Pes planus is a common finding in untreated Lisfranc injuries as competence of the medial column is lost with lateral and dorsal subluxation of the first metatarsal base on the medial cuneiform and associated dorsolateral subluxation of the lateral metatarsal bases. In some cases associated crush injury of the cuboid, the nutcracker injury, accentuates the deformity. Competence of the medial column may also be compromised by a comminuted fracture of the tarsal navicular. In these cases the inferior half to one-third of the navicular is crushed, and the larger dorsal fragments are extruded dorsally. The effect is that of removing the keystone from the arch with subsequent arch collapse. Pes planus may also be a consequence of a malunited fracture of the calcaneus. Loss of Bohler's angle with impaction of the posterior facet and lateral and superior displacement of the tuberosity eliminate the normal 30° calcaneal pitch angle and flatten the arch.

The most common cause of a cavovarus foot is malunion of a talar neck fracture. Medial comminution of these fractures is most common, and untreated these fractures will often heal with medial deviation of the talar head and secondary varus posturing of the foot. Equinus deformity, although uncommon, can be a consequence of a malunited pilon fracture with posterior subluxation of the talus. Deformities can also be the result of muscular imbalance resulting from peripheral nerve injury, CNS trauma, and compartment syndrome.

In most cases correction is possible through osteotomies and arthrodeses, often with interposition bone grafting, and in the case of neuromuscular problems, muscle-balancing procedures with osteotomies or fusions. The specific procedures will be discussed by anatomic area.

30.6.5 Skin Coverage

Skin-healing issues have a major influence on outcome when the foot is the site of injury. Although plantar skin loss is of greatest concern, even dorsal skin injuries can be problematic when shoes are worn after recovery. Although split-thickness skin grafting is very successful in other body regions for dealing with skin defects, it often does not stand up well to the abuse the skin of the foot is subjected to. Normal plantar skin is well suited to deal with the shear forces it encounters. Although callus formation in areas of high shear may be a source of pain in the sensate foot, this thickening of the skin is protective especially in unshod populations. Split-thickness skin that is adherent to underlying structures is very prone to breakdown when subjected to shear and lacks the capacity to adapt by hypertrophy. When plantar skin can heal without grafting, let it do so. Dorsal skin grafting is less of a problem.

Flap coverage is usually performed relatively soon after injury to cover tissue defects over bone, tendons, or neurovascular structures. Flaps may play a role in late reconstruction as well. The application of these techniques in the foot and ankle is beyond the scope of this chapter.

30.6.6 Forefoot and Midfoot Injuries

30.6.6.1 Toe Injuries

Malunion of lesser toe fractures can result in deformities that cause irritation on shoe wear and, if intra-articular, can result in painful arthrosis. Although osteotomy to correct deformity can be considered, the mainstay of treatment of malunited lesser toe fractures is either resection arthroplasty or realignment and fusion at either the PIP or DIP joints. Either procedure fixation can be achieved with an intramedullary smooth pin. For resection arthroplasty the pin can be left in for 4 weeks. Pin fixation for 6 weeks is usually adequate for lesser toe IP joint fusion; alternatively, a variety of fixation alternatives exist including small screws with and without a head and a number of intramedullary devices inserted through the open joint. The advantages of these devices include the absence of a pin protruding from the toe for 6 weeks. This allows mobilization without a bandage at 2 weeks and longer term stabilization if the fusion does not appear solid at 6 weeks, without the need to leave the pin in place. The downside is the difficulty in removing these intramedullary devices if the need arises.

The residual problems following great toe injuries are a little different from those involving the lesser toes. Crush injuries resulting in open fractures are not uncommon. If chronic osteomyelitis occurs, amputation is usually necessary. Posttraumatic arthrosis of the IP or MTP joint may be a source of chronic pain, and arthrodesis is the best solution if just one joint is involved. If both joints have painful arthrosis, the IP joint can be fused, and a resection arthroplasty can be performed at the MTP joint. In performing the resection arthroplasty, it is advisable to remove less than 9 mm of the phalangeal base and to interpose capsular tissue. When fusing the IP joint of the hallux with a single longitudinal screw, it should be supplemented with a small smooth oblique wire to control rotation and enhance the union rate.

30.6.6.2 Lesser Metatarsal Fractures

Overload of metatarsals adjacent to malunited displaced metatarsal fractures is the most common problem following neglected metatarsal fractures. Dorsal angulation at the fracture results in dorsal displacement of the involved metatarsal head compared to the adjacent intact metatarsals or those that are fractured but not displaced. The overload can result in pain under the head of the correctly aligned metatarsal. This may be aggravated by shortening of the involved metatarsal. In most cases the appropriate management consists of osteotomy, realignment, and dorsal plating of the malaligned metatarsal (Fig. 30.8a, b). In some cases local bone graft obtained from the distal tibia can be used at the osteotomy site to aid healing (Fig. 30.8c, d).

30.6.6.3 First Metatarsal Fractures

As with the lesser metatarsal malunited fractures, dorsal angulation malunion of the first metatarsal is common. An additional potential problem with the first metatarsal is shortening which can contribute significantly to second metatarsal overload. The temptation is to restore the lost length with an interposition bone graft while correcting the angular deformity. The problem with this, particularly if the problem has been long-standing, is that stiffness in the first MTP joint will result. This is especially a problem if any degree of posttraumatic arthrosis exists at the MTP joint. If lengthening is needed due to severe shortening, consideration should be given to a simultaneous first MTP arthrodesis.

Fig. 30.8 (**a**, **b**) Malunited 3rd metatarsal. (**c**, **d**) Healed 3rd metatarsal after correcting osteotomy

30.6.6.4 Partial Forefoot Amputation

When initial surgery is performed under less than optimal conditions, the resultant foot may be less than optimal functionally. This is particularly common in partial forefoot amputation. If the forefoot has three or less rays, the remaining metatarsals are often overloaded and can be painful and prone to thick callus formation or skin breakdown. In these cases, conversion to a transmetatarsal amputation with plantar skin and the forefoot fat pad covering the distal stump is usually more comfortable and functional for the patient.

30.6.6.5 Neglected Lisfranc Injuries

Neglected or missed Lisfranc dislocations or fracture-dislocations of the tarsal metatarsal joint are a frequent cause of late morbidity after foot injury. Two late problems are observed. In some cases deformity will be minimal, but subtle instability or arthrosis at the first or second MTP joint makes push-off painful. In cases where ligament damage is more extensive or fractures are malunited, complete collapse of the longitudinal arch with pes planus (Fig. 30.9a) and abduction of the forefoot result in intractable weight-bearing pain (Fig. 30.9b). In these advanced cases radiographs often show dorsolateral subluxation at the first TMT joint and/or lateral deviation and subluxation of metatarsals 2 through 5. Arthrosis of these joints is common. In some cases the situation is aggravated by a malunited crush injury of the cuboid that is referred to as the "nutcracker" fracture.

In some cases pain may be due to more subtle instability which may require stress abduction radiographs to recognize the pathology (Fig. 30.10a).

Because of the high incidence of arthrosis in cases managed late, the most common surgical correction of this injury consists of joint takedown, removal of articular cartilage and subchondral bone, realignment, and fusion. This is optimally achieved through a medial or dorsomedial incision over the first TMT joint and additional longitudinal incisions between the 2nd, 3rd, 4th, and 5th metatarsal bases. Joint debridement should extend into the intervals between the metatarsal bases and the adjacent cuneiform and the cuboid. Bone graft obtained from the iliac crest should be used to fill all debrided areas prior to fixation. Fixation is achieved with a combination of screws and plates (Fig. 30.11).

Care should be taken to establish correct alignment at the first TMT joint as this is the key to establishing a good arch and eliminating forefoot abductus. Despite my best efforts, I have been less than completely satisfied with my results in these cases. Although the fusion will often relieve pain, forefoot abductus and flat foot deformity have often persisted. To try to improve my results, I have resorted to placing a medial plate that spans the medial cuneiform and first metatarsal base to supplement screw fixation. The other rays can be fixed with screws placed in an oblique manner supplemented by dorsal

Fig. 30.9 (**a**) Midfoot collapse and pes planus in patient with untreated Lisfranc injury. (**b**) Forefoot abductus in patient with untreated Lisfranc injury

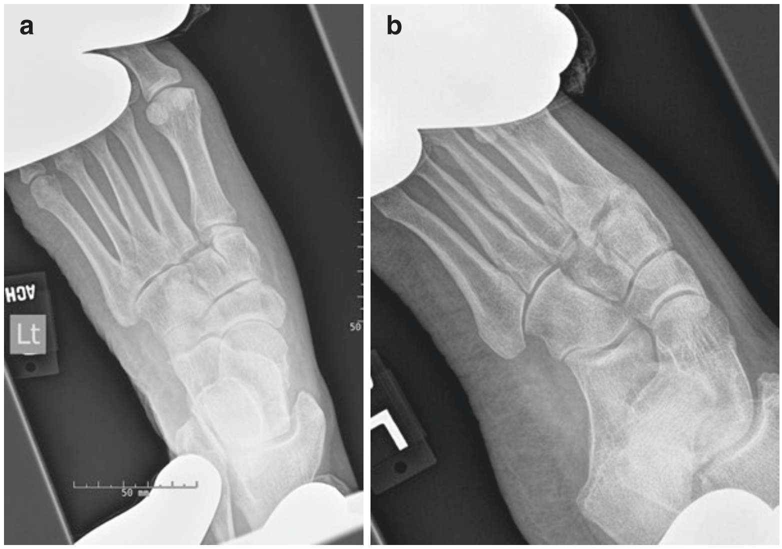

Fig. 30.10 (**a**) Stress abduction AP view showing medial column instability. (**b**) Stress abduction oblique showing intact lateral column

Fig. 30.11 Medial column arthrodesis for realignment and stabilization of Lisfranc injury

plates. Over the years author (IA) has had issues with pain caused by persistent motion between solidly fused 3rd and 4th rays. To avoid this I have paid more attention to debridement of the interval and cancellous grafting. It is important to ensure that screws cross this interval from the fourth metatarsal base into the lateral cuneiform, the third metatarsal base into the cuboid, or both.

30.6.7 Navicular Fractures

The most common late problem after navicular fracture is arch collapse with talonavicular and/or naviculocuneiform arthrosis. Two fracture patterns lead to loss of the keystone of the longitudinal arch, either severe comminution of the navicular or, more commonly, plantar comminution of the navicular with dorsal extrusion of the upper half of the bone. In either case the outcome is the same, a painful flat foot, and fusion with restoration of the arch is obligatory for pain relief. In cases of severe navicular comminution, my choice has been navicular replacement with side-by-side tricortical iliac crest interposition grafts. Optimally this graft is obtained from the patient's ipsilateral iliac crest; however, the use of allograft iliac crest is an option. The distal talar head and proximal cuneiform surfaces are planed flat with a microsagittal saw to receive the grafts. Fixation with a plate that spans from the talar neck to the medial and middle cuneiforms prevents dorsal graft migration (Fig. 30.12a, b). Surprisingly, these grafts are often incorporated

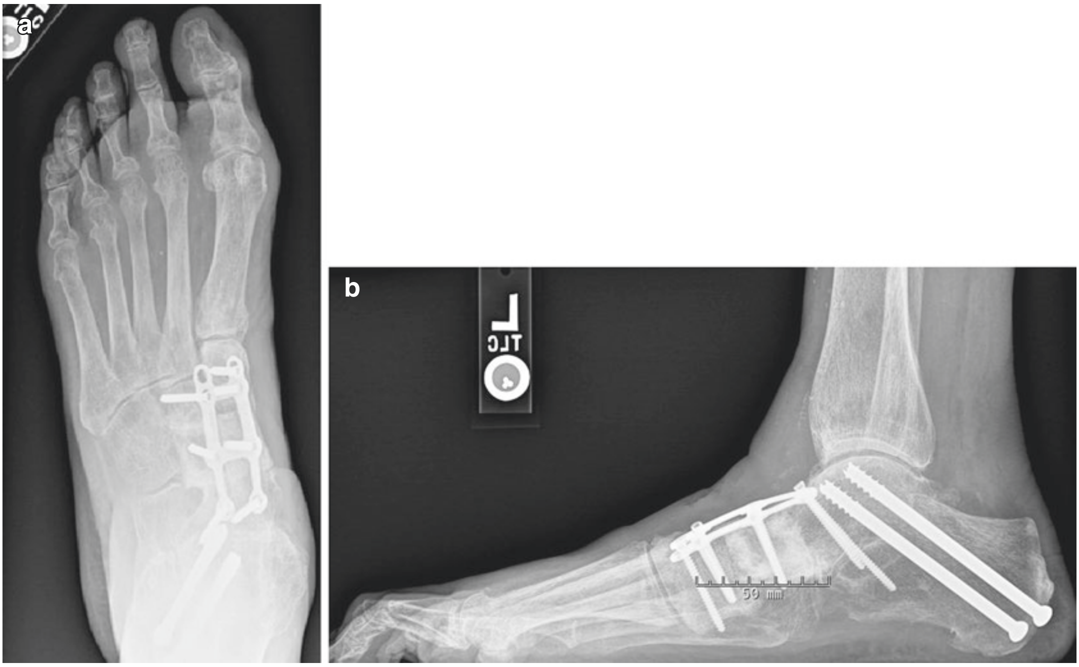

Fig. 30.12 (**a**, **b**) AP and lateral of foot after double interposition tricortical iliac crest bone graft for navicular deficiency

by 6 weeks, but cautious resumption of weight bearing is advisable, with delay to 3 months often a good idea.

30.6.8 Hindfoot Injuries

30.6.8.1 Late Problems After Calcaneal Fractures

Malunion or nonunion of calcaneal fractures is a common cause of residual pain after foot injury. Pain may result from arthrosis due to posterior facet articular incongruity or mechanical symptoms that are a result of healing in positions of major displacement. Loss of normal talar inclination will cause painful impingement of the anterior margin of the tibial plafond against the talar neck, and loss of calcaneal height may cause irritating shoe counter-abutment against the distal fibula. Extrusion of the lateral wall of the calcaneus into the subfibular space can cause painful calcaneofibular impingement (Fig. 30.13c) and peroneal tendon entrapment. In widely displaced fractures, nonunion between the sustentacular and body fragments can occur and cause persistent pain (Fig. 30.13b). This is most easily appreciated with CT, but, lacking a CT scanner, it should be able to be seen on the axial calcaneal view. Careful evaluation of the calcaneocuboid joint is also critical. In many cases the fracture splits the anterior process of the calcaneus vertically and, if not reduced, can lead to calcaneocuboid joint arthrosis (Fig. 30.13a). Failure to address this at the time of the subtalar fusion may cause persistent pain.

Correcting the often coexistent problems of subtalar arthrosis and loss of calcaneal height is often best accomplished with interposition of tricortical iliac crest bone graft in the subtalar joint. If the sagittal split between the sustentaculum and the body has failed to heal debridement of the fracture site, grafting the fracture site with cancellous bone, fracture reduction with a pelvic reduction clamp, and fixation with a transverse screw placed from medial to lateral just below the sinus tarsi should precede subtalar grafting and calcaneal talar fixation (Fig. 30.14). If subtalar distraction arthrodesis is planned, transverse

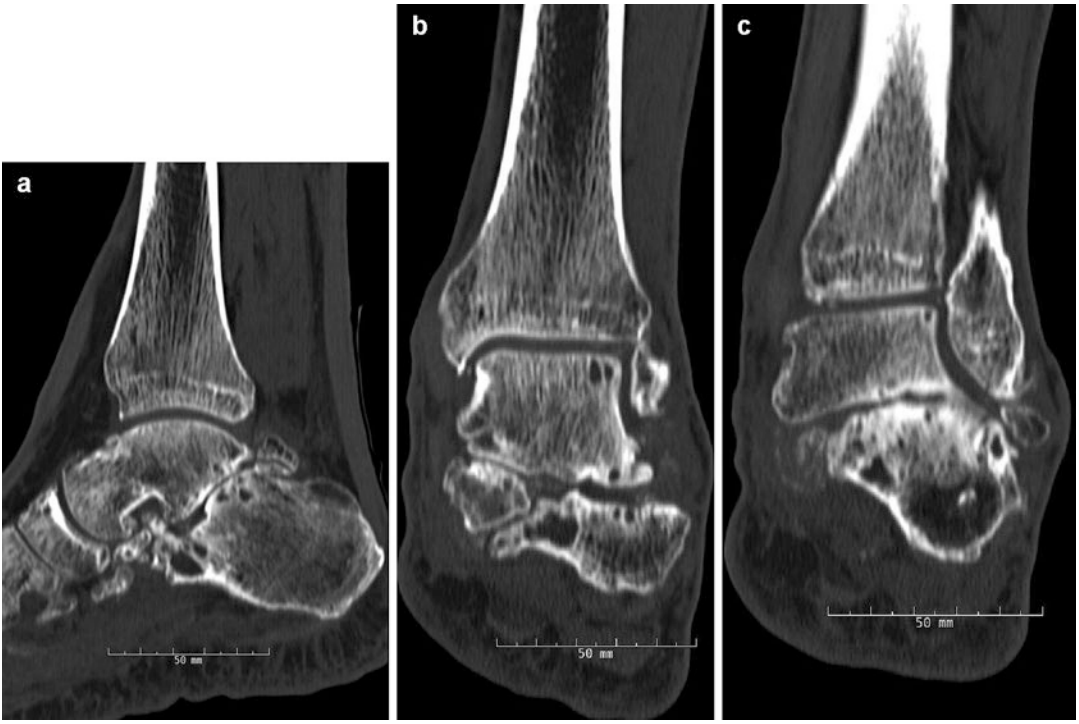

Fig. 30.13 (**a**) Subtalar arthrosis, (**b**) nonunion, and (**c**) impingement after calcaneus fracture

Fig. 30.14 Subtalar arthrodesis with interposition iliac crest bone graft

incisions perpendicular to the plane of the distraction must be avoided to allow wound closure. In general, a vertical incision along the posterior margin of the fibula that hockey sticks a little distally at the tip of the fibula will allow access to the posterolateral subtalar joint. Care must be taken to avoid the sural nerve at the distal end of the incision. After removing the articular cartilage and subchondral bone, the superior calcaneal and inferior talar surfaces are planed flat with a microsagittal saw. With a laminar spreader in place to distract the joint, the gap is measured, and a block of tricortical bone twice the measured length is harvested from the crest and then cut exactly in half. The first graft is inserted with the cancellous surfaces opposed to the talus and calcaneus, and dorsal aspect of the crest cortex lodged distally and medially into the sinus tarsi. The second tricortical graft is inserted with the dorsal cortex of the graft at the posterior margin of the subtalar joint overlapping the first graft anteriorly.

30.6.8.2 Posttraumatic Talar Deformity and Talar Body AVN

The two most common talar fractures are those of the talar neck and the talar body. Residual problems from talar neck fractures can include malunion with varus, supinated foot malalignment, or dorsal displacement of the talar head with anterior ankle impingement at the fracture site blocking ankle dorsiflexion. If the fracture has disrupted talar blood supply, talar body avascular necrosis results. Malunited talar neck fractures can be treated with talar neck osteotomy and realignment, but there is some risk of inducing talar body AVN. If osteoarthrosis is already present, arthrodesis of the involved joint with realignment is preferable. As the only solution for talar body AVN is a tibiotalocalcaneal arthrodesis, the procedure is deferred until the patient has intractable pain.

Talar body fractures usually involve both the ankle and subtalar joint. It has been my experience that, acutely, the ankle side of the fracture is usually minimally comminuted with the majority of the comminution being on the subtalar joint side. With or without acute fixation, arthrosis of the ankle and subtalar joint can occur as well as talar AVN. In all cases, arthrodesis of the involved joints is indicated. With arthrosis the procedure is fairly routine but total talar body AVN does present challenges. Although the extra-articular posterior bridging graft is a viable technique, I generally replace the body with an interposition and cancellous graft, either autograft or allograft. The cancellous bone is usually placed medially and the interposition centrally and laterally. Interposition to maintain length can include tricortical iliac crest, a partially decorticated distal fibular strut, or allograft such as an allograft femoral head. Fixation is with a spanning periarticular locking plate. I have personally used distal femoral locking plates with variable angle locking screws for this task.

30.7 Summary

The long-term outcome of severe foot and ankle trauma, especially if neglected early on, is posttraumatic joint arthrosis. Fortunately, arthrodesis is an effective means of eliminating pain and restoring function even if motion is sacrificed. In many instances the injured joint has limited motion which is not recoverable; thus, arthrodesis eliminates pain without loss of function. Also fortunate is that in sites with limited resources, arthrodesis is possible in most cases with iliac crest bone graft and threaded Steinman pins.

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31 Spine Injuries in Mass Casualties

Evalina L. Burger and V.V. Patel

31.1 Introduction

When preparing for a disaster or entering a disaster zone, one must stay organized and ready [1]. Remember that different types of disasters will lead to different types of injuries.

Many times these may be similar to general trauma seen on a day to day basis or it may be dramatically different. Thus disaster spine care may require triage, based on mechanism before any imaging or definitive diagnosis can be made. Preparation may also mean having equipment ready for typical injuries, for example, lumbar braces and/or implants for earthquake victims as they are more likely to have lumbar injuries. Spine injuries are a part of the spectrum of injuries seen in mass casualties following both war and natural disasters. Over the recent years several massive natural disasters have occurred all around the world including earthquakes, hurricanes, and tsunamis. In dealing with spine injuries as part of a mass casualty, it is clear that spine trauma is part of a spectrum of injuries. A systems approach is needed in these circumstances [2] and spine care should be both systematic and methodical. The success of the recovery is directly related to the availability of resources and coordination of various emergency authorities. The command system in a mass disaster of any kind is crucial and control needs to integrate emergency services with medical care.

31.2 Earthquakes

The epidemiology of earthquake-related injuries is unique for these kinds of disasters. Earthquakes frequently affect populated urban areas, and more often than not, these earthquakes do occur in areas where there are poor structural standards resulting in high death rates and mass casualties. The injuries are often multisystem with crush injuries and their complications lead to a high level of morbidity and mortality [3]. The pathophysiological changes that occur with a crush injury such as renal shutdown are more likely the cause of death than the spinal injury itself. It is therefore important to recognize this in triaging patients during an earthquake and to follow the resuscitation codes according to the ATLS principles carefully despite trying to minimize the neurological fallout from such an injury [1].

It is also important to remember that during an earthquake the surrounding structures and the local responses are also partly disrupted. There is then a significant time delay before help can arrive complicating these injuries and leading to

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_31

further rise in morbidity and mortality [3]. Patients with spinal cord injuries, more often than not, have to be evacuated as local structures and ICUs that are disrupted cannot render the level of care that they need in order to survive these injuries. In the triage process, it is important to realize which patients can be dealt with locally such as minor injuries and which patients will need to be evacuated in order to survive their injuries [4].

During an earthquake, 82.96 % of patients experience a crush injury with significant differences in anatomic distribution compared to regular population control groups. In the regular population control groups, cervical spine injuries were the most common whereas lumbar spine injuries are most common in earthquake-related injury groups. The AO type A or type B flexion distraction lesions were the most frequently seen in earthquake-related victims whereas the severe high-energy type C lesions were more related to non-earthquake victims. It is concluded that the type A lesions are most common and that type A lesions with neurological injury in the lumbar spine are the most likely spinal injury to be sustained during an earthquake [5]. As many as 194 patients were admitted to a surgical neurosurgical hospital after the northern Pakistan earthquakes so the number of patients involved in these disasters can be huge [6]. In an analysis of the 2005 earthquake in Pakistan, it is clear that the late implications of spinal cord injury after an earthquake are also devastating and spinal cord injury centers need to be established after the disaster. Many victims did not have appropriate rehabilitation which should be part of the planning for any large disaster including earthquakes. Eventually this will cut the cost as well-rehabilitated patients will be a lesser burden on the medical system in the long run. For example, without rehabilitation and education, it is inevitable that patients will present with large sacral pressures. Stephenson reports on two interesting cases in how simple wound management can help heal broken skin in paraplegic patients and even this can be prevented with proper training and education [7].

31.3 Urban Terrorism

While natural disasters such as earthquakes and ensuing tsunamis are devastating with a high loss of life and high incidence of spinal cord injury and lumbar spine fractures, urban terrorism with bomb blasts is on the increase. In all disaster plans with the increase of urban terrorism, medical emergency services need to understand potential biological, chemical, and nuclear agent warfare and the clinical symptoms that can be presented from these substances [8]. The data from a bomb blast in Jerusalem showed that they admitted an average of 28 patients after every rocket attack with 4.7 % of these patients going to the ICU. 70 % of these patients had lung blast injuries and 73 % had ruptured tympanic membranes. 73 % of patients required mechanical ventilation and ICUs are critical in the comanagement of patients involved in bomb blasts [9].

During a blast it is important to realize that there are primary and secondary injuries and those primary injuries are caused directly by the sudden increase of pressure on the tissue from the direct blast. Secondary injuries are caused by flying objects and tertiary injuries are caused by the body that is actually displaced in space. The primary injuries typically result in traumatic amputations and crush injuries with compartment syndromes. Secondary injuries are the most common seen after blast injuries. They also include amputations but might be more contaminated. The tertiary injuries caused by the body displacement cause severe soft tissue damage and fractures. A fourth group, quaternary injuries are often associated with severe burns [10]. It is important when triaging patients from a blast injury to first take care of the life-threatening injuries especially maintenance of the airway and stabilization of immediate life-threatening conditions. Antibiotics should be used extensively and tetanus prophylaxis and debridement of wounds should be performed early [11].

During the bomb explosions in Madrid, Spain, 177 people were killed and there were more than 2000 patients injured. 63 % of patients had blast injuries to the lungs and 52 % suffered head trauma [12]. It is important to remember that bomb blast survivors can occasionally suffer from profound shock and hypoxemia without signs of injury. The hypothesis is that this is a vagally mediated defense reflex resulting from the shock blast with injury to the lungs. It is important to distinguish this from the hypotensive shock that is commonly seen in spinal cord injuries in the spinal shock phase [13]. It is also important to realize that the modern chemicals used in the manufacturing of explosive devices can be partly responsible for the quaternary blast injury pattern which leads to hyper-inflammatory behavior. Hare also points out that as part of the multidisciplinary team, it is important for radiology to have a specific protocol understanding the different stages of blast injuries and the concept of distant trauma with different anatomic sites. Utilization of standardized imaging protocol to find undetected traumatic effects after a bomb blast should be in place as a discussion for the management of multiple human and non-human flying fragments. The role of radiology should be planned prior to the disaster and is important to remember that one injury of the spine can be accompanied by a second injury in the spinal column and therefore complete imaging of the spinal column is important [14].

In modern-day warfare, the threat of nuclear exposure and contamination also poses an additional threat not only to the patient but also to the healthcare workers. As surreal as this may sound, it is important to recognize this as an additional complicating factor to patients with spinal injuries [15].

31.4 Special Injuries

Victims from airplane crashes that are fortunate enough to survive also present with a very high incidence of spine and extremity injuries. As pointed out during the Schiphol incident, there were 135 passengers, of which 120 were injured. Most of the injuries were to the spine and the extremities [16]. Spinal injuries were present in 18 % of the patients and the injury severity score was more than six on average. Spine injuries are always high on the list for other accidents such as micro lights and parachuting but fortunately these never present as mass casualties [17].

Since all of the passengers on a commercial flight sit in the same position and experience the same extreme forces, injuries are typically very similar for everyone. During a minor runway accident at the Denver airport in December 2006, we had two spine injury victims who were sitting next to each other in the same airplane, both suffering flexion distraction injuries at the T12–L1 level. They were both near the emergency exit and were both type B injuries. The classic seatbelt configuration of airliners could contribute to this flexion distraction injury or “lap belt injuries” as is known to us in the literature. Both of these patients were neurologically intact and had a full recovery after stabilization (Fig. 31.1).

31.5 Hurricanes

During Hurricane Katrina, we had no reported mass injuries of the spine. Most of the injuries were to the extremities and most of the injuries following the hurricane were due to construction [18, 19]. In the tornado that went through Birmingham, they report a significant amount of children that were injured with high injury severity scores with head injuries as the major diagnosis for admission. It is to be remembered that the relative bigger size of the child’s head can lead to significant cervical spine injuries, as well as occult injuries [20].

Conclusion

Spine injuries during mass casualties are related to the type of energy associated with the disaster. The highest number of spine injuries occurs during earthquakes where the collapse of structures and the nature of the injury lead particularly to fractures in the thoracolumbar area, commonly with neurological injury in the survivors. Not only is the recognition and awareness of these fractures very important but the acute management as well as the ongoing rehab of these fractures is vital. Most often spine injuries are part of a multisystem injury and therefore patients need to be triaged according to injury severity scores and life-threatening injuries should take preference above the treatment of spinal cord injuries. It is clear that these patients are also to be prioritized during evacuation planning as ICU and specialized care usually do

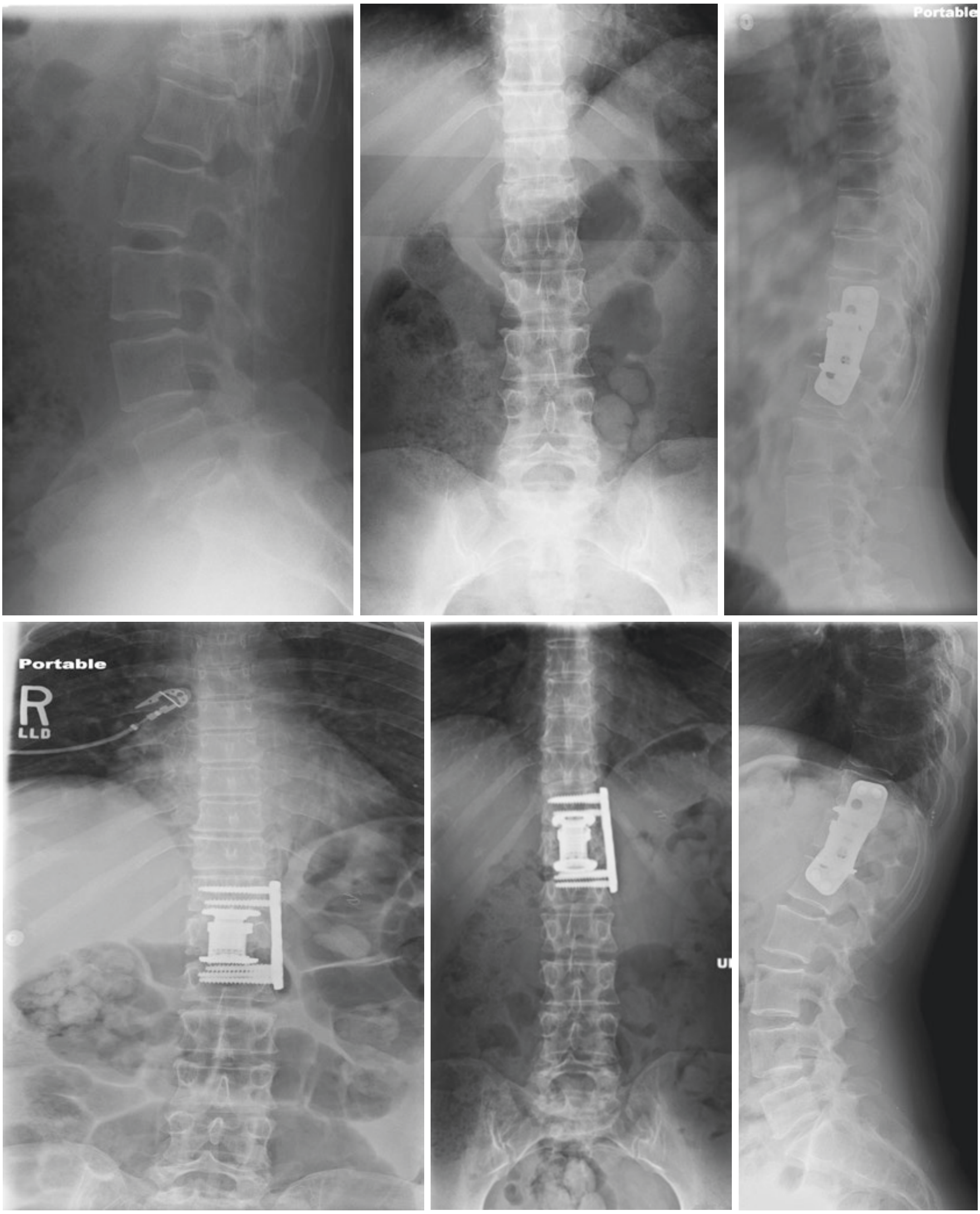

Fig. 31.1 Pre-operative and Post-operative images of thoracolumbar burst fractures sustained in commercial airplane crash showing treatment with anterior corpectomy, cage placement, and fixation with lateral plate spanning the fractured level

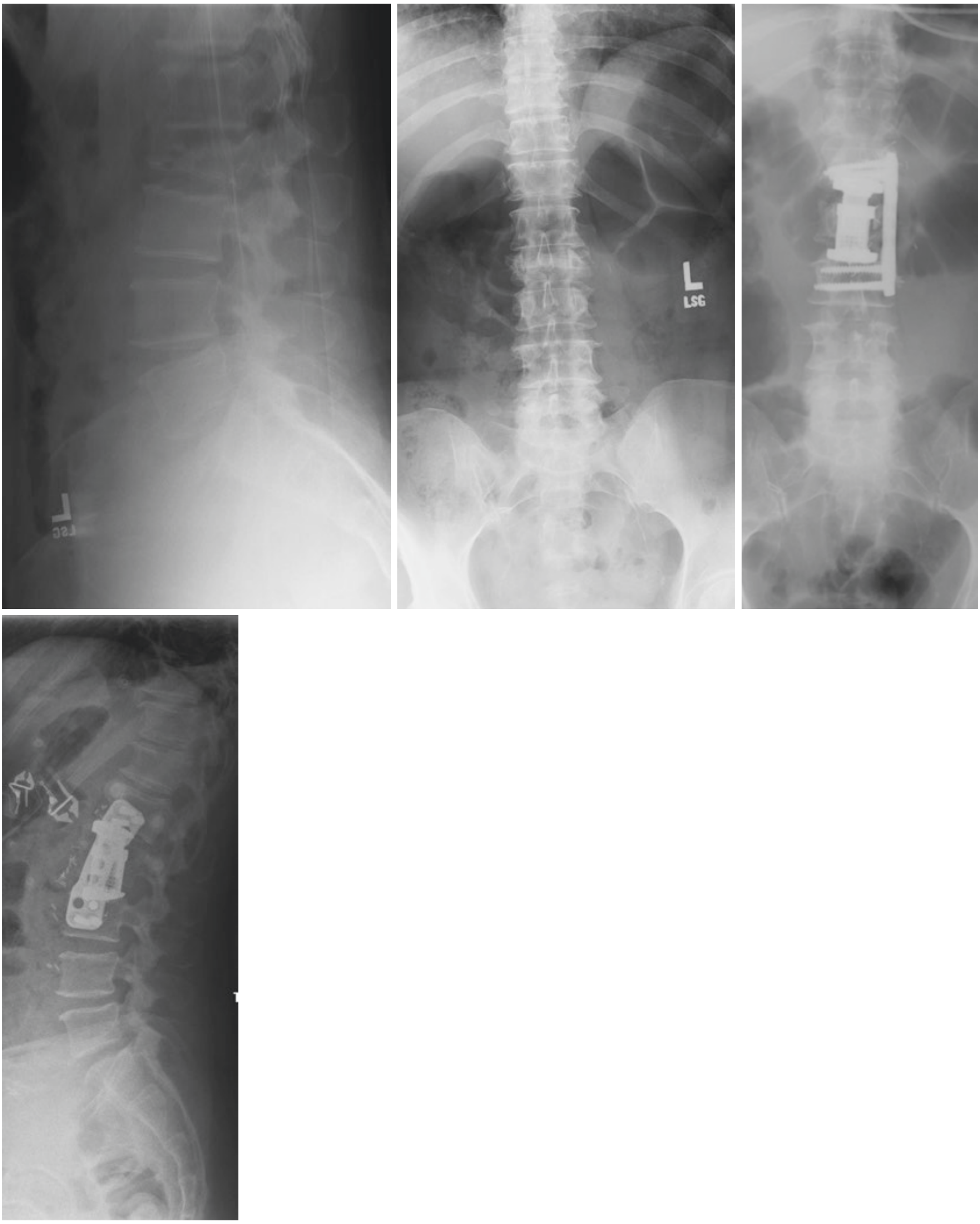

Fig. 31.1 (continued)

not exist following a mass natural disaster. Hospitals as well as emergency management crews should be urged to have specific protocols for the management of spinal cord injuries in place.

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Pelvic and Acetabular Trauma

32

Marcel Winkelmann, Sebastian Decker, and Christian Krettek

32.1 Introduction

With an incidence of 3–8 % of all fractures, pelvic fractures are relatively rare [1–4]. They range from low-energy stable fractures to high-energy unstable fractures with accompanying soft tissue injuries (complex pelvic trauma). Within polytrauma patients the percentage ascends to 25 %, which is similar to the incidence of pelvic fracture in fatal motor vehicle accidents with 23–25 % [5–7] .

There are two peak ages. First are younger adults (20–35 years) who present primarily unstable fractures due to high-energy trauma. Second are elderlies (>70 years) who present primarily stable fractures due to minimal trauma benefited by osteoporosis and higher risk of falling [8].

The mortality rate varies from 4 to 30 %. But one should not underestimate the danger of a pelvic fracture, because 80 % of decedents who sustained pelvic fractures due to immediately fatal motor vehicle accidents died of blunt force trauma to the abdomen or torso [7, 9]. 50 % of all decedents die within the first 24 h due to fatal hemorrhage. The other 50 % die because of multiorgan failure over the course. In case of emergency, it is essential to identify the vital endangered, hemodynamically, and biomechanically unstable patient early and initiate targeted and appropriate therapy.

32.1.1 Anatomy

The pelvis is an anatomically complex region. For understanding injury mechanism and injury pattern, one must keep the three-dimensional structure of the pelvis in mind. Below-mentioned you see the essential anatomic landmarks and ligaments that are crucial for pelvic stability (Fig. 32.1).

32.2 Causes and Severity of Injury

32.2.1 Causes

Severe pelvic ring and acetabular fractures usually occur in high-energy trauma. Depending on the age of the patient, it's possible to draw

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_32

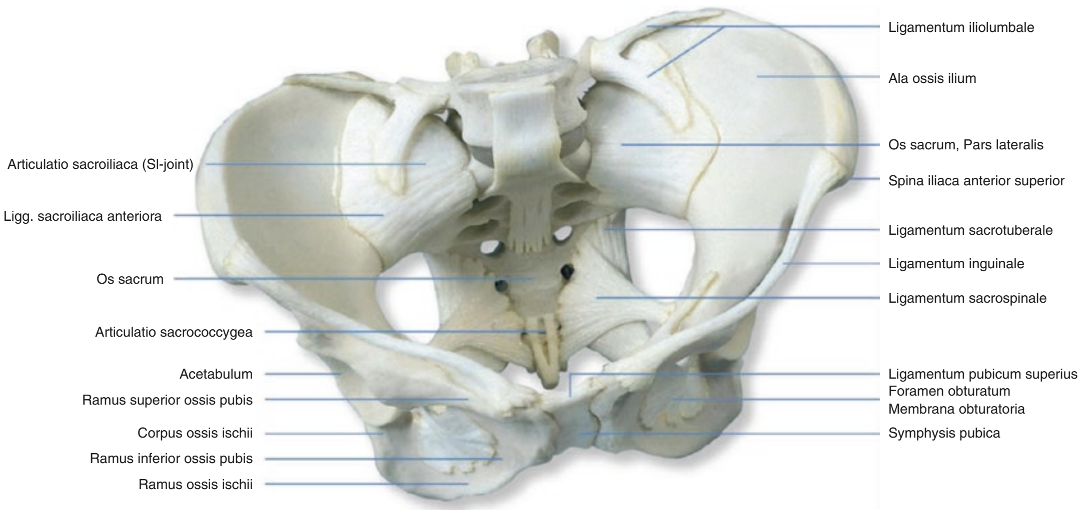


Fig. 32.1 Pelvic anatomy

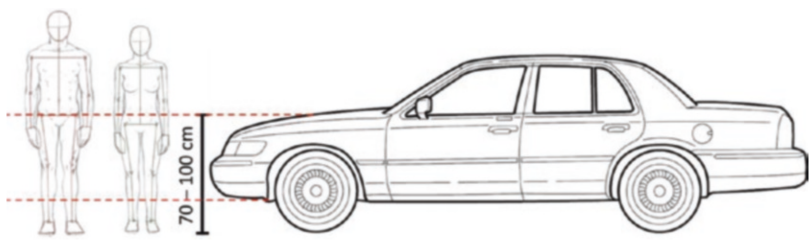


Fig. 32.2 MVA

interferences from the accident mechanism about the severity of the pelvic injury. Motor vehicle accidents and fall from great height are the most common causes of severe pelvic fractures.

32.2.1.1 Motor Vehicle Accident (MVA)

Motor vehicle accidents are the most common cause of complex pelvic trauma. One can distinguish between different accident mechanisms. Vehicle-pedestrian accidents are usually associated with low or moderate speed. There's a correlation between the speed of the automobile and the presence and severity of pelvic fracture. From a collision speed of 50 km/h (30 mph), one should consider an unstable pelvic fracture and look for it thoroughly. Besides collision speed, the collision type is a relevant and well-available hint for pelvic injuries. The risk for a pelvic injury is highest in collisions on the same side as the victim followed by head-on collision (Fig. 32.2). Pedestrians and bi-/motorcyclists have a two-time higher risk to sustain a pelvic fracture [7, 10].

32.2.1.2 Fall from Great Height

Fall from great height (>4 m) is a high-energy trauma and injury severity and pattern are positively correlated with the height. Within frequency of specific injuries, there's a difference between accidental and suicidal falls without affecting the overall injury severity. Altogether this special accident cause seldom leads to a large number of severely injured persons. But since terrorist groups commit attacks in industrialized nations, like the September 11 attacks, we also have to take this cause into consideration as a special kind of mass casualty incident. At relatively low height

(<7 m), fractures of the pelvis, upper limbs, and lower limbs and blunt thoracic trauma are the most common injuries. Above 7 m traumatic brain injuries and spinal fractures are the most frequent causes of mortality [11–14].

32.2.1.3 Crush Injury

Crush injury is a collective term for a whole range of injuries, which have a comparable mechanism and lead to compression of the pelvis. These extrinsic forces cause different injuries of varying severities, depending on the direction the force is acting. Typical crush injuries result from bruises during earthquakes, burials, and stampede.

Bruises caused by earthquakes result from collapsing houses usually with a unidirectional force. Data from Chinese earthquakes show that pelvic fractures are the second most common fracture with a share of about 20 %. Surprisingly only a small proportion has to be treated operatively (12.7 %) [15, 16].

Uproar at big events can lead to stampede within minutes with mass casualty incident. Interestingly there's a contradiction between the large number of injured persons with relatively mild injury severity and the high mortality rate in the center of the stampede. Most common causes of death are asphyxia due to thoracic compression and severe head injuries. Pelvic fractures occur regularly, but relatively rare (5 %), and are mostly moderate [17, 18].

32.2.1.4 Burials

Burials usually result from avalanches or landslides. In Europe and Northern America, approximately 150 people die of avalanches each year. The mortality is exponentially higher in completely buried (≈50 %) versus partially or non-buried (≈4 %) persons. Trauma and asphyxia are the most important causes of mortality and acute life-threatening medical problems, but the influence of major trauma as a cause of morbidity and mortality is controversial. While most frequent injuries are of the extremities (19 %), the chest (17 %), and the spine (7 %), cerebral, abdominal visceral, and pelvic trauma is rare (≈1 % each). In addition trauma is responsible for deaths of only 5–6 % avalanche victims. Most common cause of mortality by far is asphyxia (85–90 %) [19–23]. Little is known about morbidity and mortality of burials by landslides and mudslides, but it can be assumed that it is much higher compared to avalanches. Survival rate of completely buried persons is little due to heavy weight of debris that leads to compression of thorax and quick death by asphyxia. Pelvic injury is a common collateral damage, but seldom cause of death [24, 25].

32.2.2 Severity

32.2.2.1 Hemodynamic Versus Biomechanical Stability

An essential part in emergency treatment of pelvic fractures is to evaluate the injury severity to initiate suitable therapy. Injury severity heavily depends on fracture type (see also classification). One must differentiate between biomechanically stable and instable pelvic fractures.

Preclinical diagnosis is challenging since one has to rely on physical examination. If pelvic x-ray is available, the majority of pelvic fractures can be detected reliably. But fracture type is only loosely correlated with morbidity and mortality, whereas hemodynamics is the most important parameter for emergency treatment decision (see Table 32.1). Injury severity score (ISS) and triage-revised trauma score (T-RTS) are the most suitable predictors of mortality [26–28].

32.2.2.2 Triage

Triage is a complex process that is crucial for best usage of limited medical resources in mass gatherings. The main concept is to categorize injured persons into subgroups of comparable injury severity. Each subgroup is admitted to medical treatment within a different time slot, varying from immediate treatment to hours of delayed treatment. During mass casualty incidents and disasters, prehospital and field triage is essential. There are different triage systems that

Table 32.1 Criteria for stability

	Hemodynamically stable	Hemodynamically instable
Systolic blood pressure (mmHg)	>90	<90
Heart frequency (per minute)	>60 and <100	<60 and >100
Respiratory rate (per minute)	>10 and <30	<10 and >30
Hemoglobin (mg%)	≥8	<8
Lactate (mmol/l)	<8	≥8
Base excess (mmol/l)	>−5	≤−5
Glasgow coma scale	≥9	≤8

Modified after Allen et al. [26], O'Sullivan et al. [27], Smith et al. [28]

Table 32.2 Revised trauma score: it is calculated as the sum of the points for each of the three components

Glasgow coma scale	Systolic blood pressure (mmHg)	Respiratory rate (per minute)	Points
13–15	>89	10–29	4
9–12	76–89	>29	3
6–8	50–75	6–9	2
4–5	1–49	1–5	1
3	0	0	0

Champion et al. [29]

Table 32.3 Injury severity score

Body region	Abbreviated injury score	Points
Head, neck, cervical spine	Minor	1
Face, facial skeleton, nose, mouth, eyes, ears	Moderate	2
Chest, thoracic spine, diaphragm	Serious	3
Abdomen or pelvic contents, abd. organs, lumbar spine	Severe	4
Extremities or pelvic girdle, pelvic skeleton	Critical	5
External	Maximal (currently untreatable)	6

Baker et al. [30]
Calculation: *ISS* $A^2+B^2+C^2$ where A, B, and C are the AIS scores of the three most injured ISS body regions

have a common characteristic: They are not fracture specific. If a pelvic fracture is considered, a fast and reliable tool for dividing patients into low- and high-risk groups is crucial. The revised trauma score is an objective and easy to use field triage score to identify patient at high risk and is an independent risk factor associated with mortality (see Table 32.2). O'Sullivan et al. stated a boundary value of ≤8 points to identify the cohort of most risk [27].

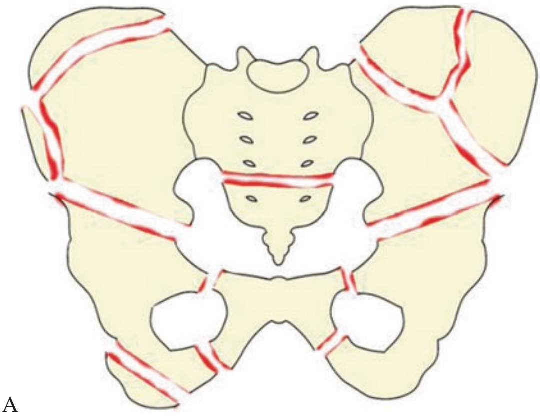
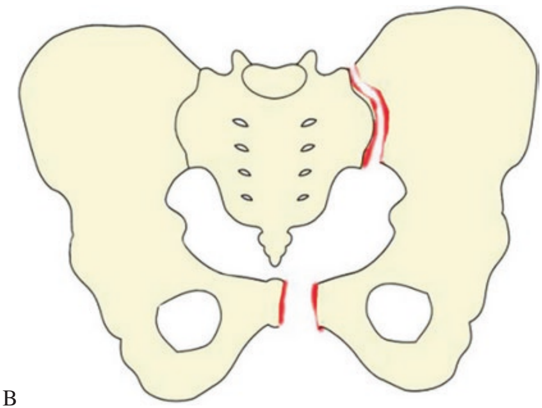
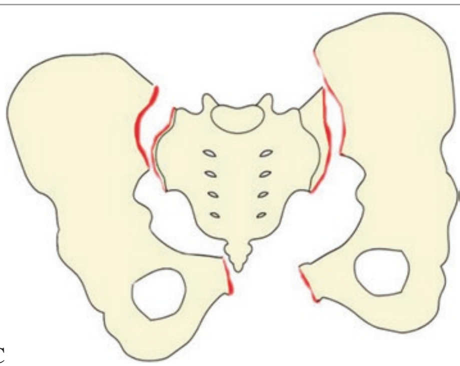
Like revised trauma score (RTS), injury severity score (ISS) (see Table 32.3) is an independent predictor of mortality and basically suitable as a decision guidance for early treatment of patients with severe pelvic fractures. But in contrast to RTS, calculations is more complicated and prehospital hardly possible due to the need of knowing all injuries. After finishing diagnostics and gathering all needed information, ISS is slightly more reliable than RTS. But its use is limited to hospital-based treatment [27].

Injury severity and pattern determine the choice of treatment. Life-threatened multiple-injured patients and those with severe traumatic brain injuries should be treated first in medical facilities that provide the best possible equipment and treatment options.

32.3 Classification

Classifications give us a chance to categorize patients according to the urgency of their disease because in the majority of cases different levels of classification are accompanied by different acuteness in orthopedic trauma surgery. Especially in disaster medicine, this is an important tool for orthopedic and trauma surgeons to gain control of the situation and to save as many people's live as possible. Like in long bones, different classifications can be found to describe pelvic fractures. In this paragraph we will focus on the most popular and helpful graduations for acetabular and pelvic ring fractures.

Table 32.4 AO classification for pelvic fractures

Type AO 61	Subtype	Description	Stability
 A	A1	Avulsion or iliac wing fracture	Stable
	A2	Stable fracture of the anterior ring which can be minimally displaced	
	A3	Transverse sacral fracture below sacroiliac joint (Denis Zone III)	
 B	B1	Symphysis rupture, incomplete rupture of dorsal pelvic ring (open book injury, external rotation)	Vertical stability, rotational instability
	B2	Symphysis rupture, lateral compression injury with overlapping anterior pelvic ring (internal rotation)	
	B3	Bilateral: B1 + B1, B2 + B2, B1 + B2	
 C	C1	Unilateral symphysis rupture and complete fracture of posterior pelvic ring	Vertical instability Rotational instability
	C2	Bilateral: type B + type C fracture	
	C3	Bilateral: type C + type C fracture	

32.3.1 Pelvis

32.3.1.1 AO Classification

Today's most common classification is the AO classification which is a modification of the classification introduced by Tile in 1984 [31, 32]. Tile's classification predicated on his work that he performed together with Pennal et al. [33]. In this study authors did present a classification for pelvic trauma according to the direction of force that produces the injury: anteroposterior compression, lateral compression with and without rotation, and vertical shear. In 1984 Tile stratified pelvic fractures for stability and classified them into types A, B, and C according to the extent of mechanical instability of the pelvic ring. This classification was again specified in the AO classification, which is based on plain radiographs. Details of the AO classification are presented in Table 32.4.

The AO classification was developed with the assistance of anterior-posterior x-rays. Therefore in modern trauma centers, sometimes confusion arises as to the correct classification comparing x-rays and CT scans. However, in the event of an orthopedic disaster with many patients suffering from an orthopedic trauma, of course the chance of x-rays being available is much higher than of CTs, especially in poor areas of the world. Moreover, even big modern cities only have limited capacities for CT scans; x-rays instead can be compiled more easily. Therefore the traditional classifications are best for triage and planning of operative interventions. In case of very limited resources, this helps to decide which patient has the best or worst chances to survive and therefore to plan who has to be operated first. An example is given in Fig. 32.3. It shows a pelvic ring fracture being classified AO 61 C1. This type of fracture pattern can be associated with severe damage to vessels and nerves.

Patients with pelvic ring fractures like shown in Fig. 32.3 are injured and life-threatened due to collateral inner injuries with, e.g., ruptured arteries or damage to the presacral venous plexus (prevalence 1:10) that can cause massive bleeding. They need quick intervention/surgery or will die fast. Using the AO classification for pelvic ring fractures, severity of injury generally increases from types A to C. Type C fractures have the highest risk for life-threatening bleeding and patients often suffer from severe further injuries because of the injury mechanisms [34].

Fig. 32.3 Pelvic ring fracture type AO 61 C1

32.3.2 Acetabulum

32.3.2.1 Classification by Judet and Letournel

The most important classification for acetabular fractures was published by Judet and Letournel in 1964 [35]. They divided the pelvis and acetabulum into two columns, an anterior and a posterior column, Fig. 32.4. Moreover they defined the acetabular walls. Based on these anatomic definitions, they reported ten types of acetabular fractures, which again can be separated into two subgroups: elementary and associated fractures. Fracture types are presented in Table 32.5.

Acetabular fractures can occur alone or in combination with pelvic ring fractures (type C pelvic ring fracture). While pelvic ring fractures offer a significant risk for mortality, it is likely low in isolated acetabular fractures [36].

Several other classifications for both acetabular and pelvic ring fractures do exist. However, we think that these two are the most important ones that will help to quickly organize resources and save as many people as possible in case of an orthopedic disaster.

Surgeons should always be aware that in case of an orthopedic disaster, classifications are only used to get an idea of how severe circumstances are and how life threatening their patients are injured to better perform triage and plan surgeries against the background of limited resources. Classifications should help to simplify and accelerate communication in between experts. Therefore, especially in the context of pelvic ring fractures, not every subitem of the classification

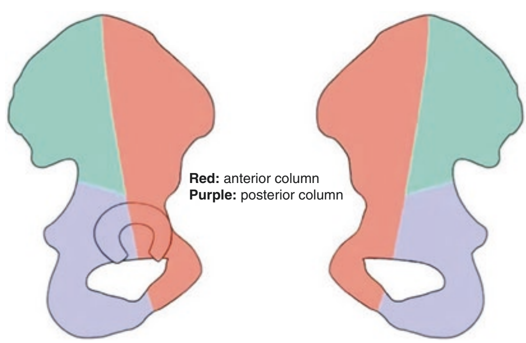


Fig. 32.4 Acetabular columns

Table 32.5 Acetabular fractures

Subgroup	Fracture type
Elementary fracture	Posterior wall
	Posterior column
	Wedge fracture of anterior wall
	Anterior column
	Transverse
Associated fractures	Posterior column and posterior wall
	Transverse and posterior wall
	T-shaped
	Anterior column and posterior hemitransverse
	Both columns

has to be known; instead, a general understanding of subtypes should exist (A, B, C). Consequently, not all subitems have been listed in this chapter.

32.4 Diagnostics

32.4.1 Preclinical

Diagnosis of a pelvic fracture in the preclinical phase is limited to anamnesis, circumstances of the accident, and clinical findings. Mortality in unstable pelvic fractures during first 24 h is caused by hemorrhage and survival of polytrauma is negatively influenced by concomitant pelvic fracture. Therefore the fast and reliable diagnosis and appropriate therapy are crucial for outcome. The emergency physician should gather all available information about circumstances of the accident. Run-over injuries, for example, are accompanied by pelvic fractures in about 80 %.

If anamnesis is possible and pelvic fracture suspected, further medical examination is necessary. One should pay attention to local signs like pain, shortening of leg, pelvic asymmetry, and others (Table 32.6). Every examination of traumatized patients should include cranio-caudal body check with checking peripheral perfusion, motor function, and sensibility and stability of pelvic ring. Therefore the examiner applies lateral, medial, and anterior pressure to the iliac crest and palpates the pubic symphysis and sacral area.

Table 32.6 Signs being suspicious for pelvic fracture

Local signs
Pain
Abrasions
Bruises
Effusions
Discolorations
Swelling
Malposition
Shortening of leg
Pelvic asymmetry
Blocking of hip joint
Acrotism
Axonal injury

Rotational instability is an indicator for pelvic ring fractures AO type B or C. Vertical instability only appears in case of unstable pelvic ring fracture AO type C with complete continuity interruption of ventral and dorsal pelvic ring. As a rule of thumb, an unstable pelvic ring fracture can be expected, if a fingerbreadth gap of pubic symphysis could be palpated and should be expected and if iliac wings could be shifted due to manual compression (Fig. 32.5).

Validity of manual stability examination is discussed controversially in literature. Shlamovitz et al. stated sensitivity and specificity of stability examination 26 and 99 % [37]. In contrast Sauerland et al. calculated a pooled sensitivity and specificity of 90 % each in a meta-analysis. But they pointed out that results were better in those studies which excluded neurologically impaired patients (e.g., GCS < 13) [38]. Pehle et al. found a sensitivity and specificity of 44 and 99 % in a prospective study on multiple-injured patients [39]. Regardless of the different sensitivities, this fast and feasible examination should be inherent part of every emergency body check due to its high positive predictive value and lack of good preclinical alternatives.

Besides examination one should pay attention to circulation, because an instability of the dorsal pelvic ring is associated with hemorrhage

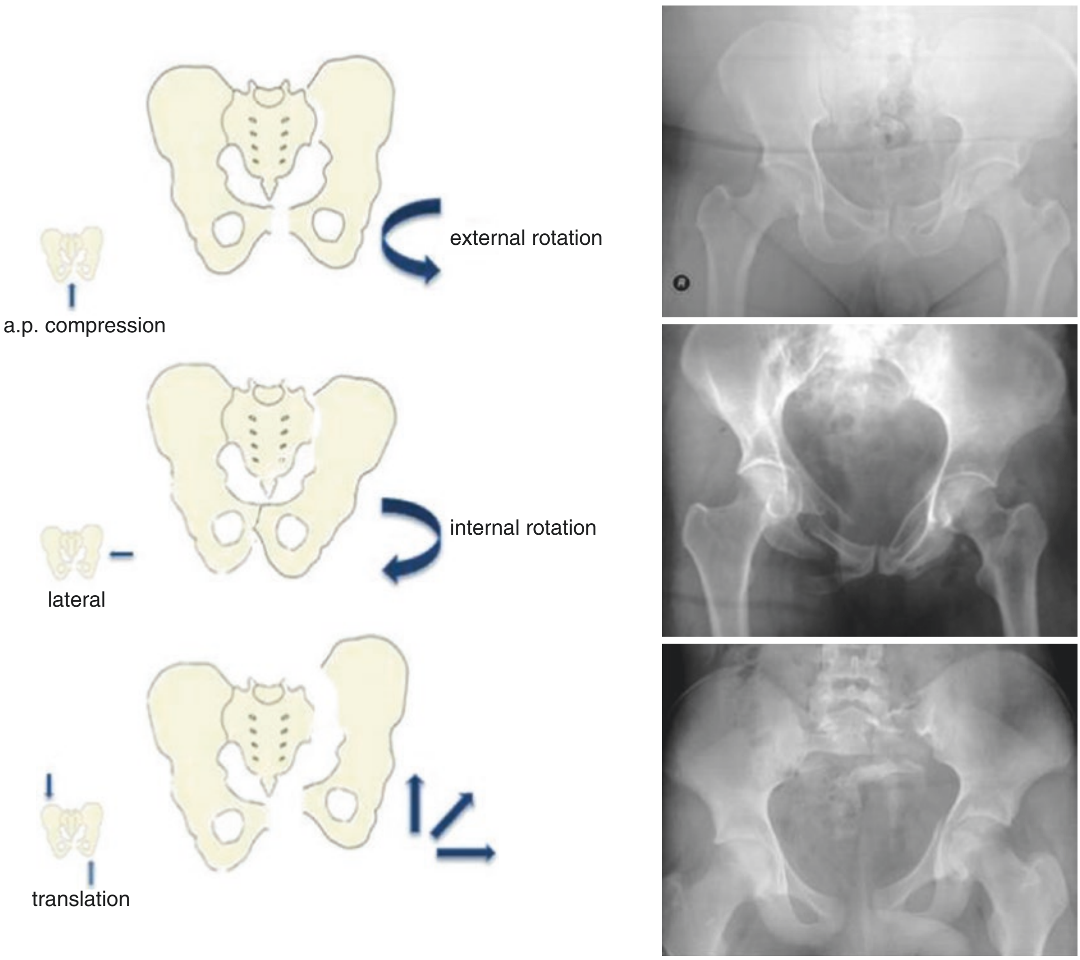


Fig. 32.5 Rotational and translational instability of the pelvis

from presacral venous plexus, perivesical veins, and fracture surfaces. Since several liters of blood can be lost into pelvis before self-limiting due to tamponade, every suspected vertical instability of the pelvic ring and every patient with suspected pelvic fracture (regardless of whether instability could be proven or not) and concomitant hemodynamic instability has to be treated like a life-threatening and unstable pelvic ring fracture until otherwise proven. Correspondingly Miller et al. stated that a non-response on volume therapy implies on relevant intrapelvic hemorrhage with a specificity of 30 %. By implication a stable systolic blood pressure >90 mmHg is a 100 % negative predictor for relevant bleeding [40].

32.4.2 Clinical

Once a patient has taken to hospital or available medical facility after preclinical examination and initial therapy, further examination and treatment follow ATLS® (advanced trauma life support for doctors) guidelines ("*treat first what kills first*"). The primary survey should follow ABCDE pattern: *a*irway, *b*reathing, *c*irculation, *d*isability, and *e*xposure. In secondary survey further examination including plain x-ray (CR) and computed tomography (CT) should gather all injuries.

32.4.2.1 Associated Injuries

Due to its complex anatomy and variety of containing organs on the one hand and the causative

Table 32.7 Serial injuries that are suspicious for pelvic fractures

Intrapelvic	
	Abdominal organs (16–55 %)
	Urogenital injuries (urethra 15 %, bladder 10–25 %)
	Pelvic nerves (L4–S2) (25–50 %)
	Pelvic vessels (up to 27 %, especially run over injury and decollement/avulsion of the skin)
Extrapelvic	
	Thoracic trauma (56 %)
	Traumatic brain injury (33 %)

high-energetic trauma on the other hand, pelvic fractures are regularly associated with intra- and extrapelvic injuries (Table 32.7). These impairments have an effect on injury severity and mortality themselves. Mortality of decollement, for example, is about 25 % due to major hemorrhage [41]. Therefore it is crucial to diagnose all concomitant injuries as early as possible to initiate a sufficient therapy.

32.4.2.2 Ultrasound

Focused assessment with sonography for trauma (FAST) is a basal part of physical examination of a trauma patient. It is a fast and noninvasive screening instrument for pericardial effusion and free fluid around abdominal organs (hemoperitoneum). Four areas are checked routinely (Fig. 32.6).

1. Perihepatic space (Rutherford-Morison's pouch)
2. Perisplenic space (Koller's pouch)
3. Pericardium
4. Pelvis (rectouterine pouch, Douglas' pouch, cul-de-sac, rectovesical excavation)

Friese et al. stated a sensitivity and specificity of FAST 26 % and 96 %, respectively. Positive and negative predictive values were 85 % and 63 %, respectively [42]. Tayal et al. found sensitivity and specificity to be 81 % and 87 % and positive and negative predictive values were 72 % and 91 %, respectively [43].

The key message is the relatively high positive predictive value. If a patient is hemodynamically unstable and FAST shows free peritoneal fluid, it is a clear indication for early stabilization of pelvic ring fracture (e.g., C-clamp) and/or diagnostic laparotomy. However one must acknowledge that a negative FAST does not exclude free peritoneal fluid, so that an additional CT is recommended.

32.4.2.3 X-Ray

A plain anterior-posterior x-ray of the pelvis is inherent part of basal medical imaging of each multiple traumatized patient. It is a fast and even in case of limited resources well-available diagnostic instrument. A fundamental understanding of radiologic anatomy of the pelvis is essential for quick and reliable assessment of pelvic x-ray (PXR) (Fig. 32.7).

Radiologic Anatomy of Pelvic X-Ray

Pelvic ring fractures usually occur at certain points. Anterior pelvic ring fractures run transsymphyseal (a), transpubic (b), or transacetabular (c) and posterior or dorsal pelvic ring fractures transiliac (1), transiliosacral (2), transalar (3), or transforaminal (4) (Fig. 32.8).

Sensitivity of PXR is discussed controversially in the literature due to partially disparate findings. Chmelová et al. estimate the overall sensitivity of plain x-ray images in the diagnosis of pelvic ring injury, when compared to CT scans, at 83 % [44]. Guillamondegui state sensitivity and specificity of PXR 68 % and 98 %, respectively [44]. Berg et al. calculated sensitivity for detecting pelvic instability from PXR taken in a trauma room setting 74 % [45]. Edeiken-Monroe et al. found that pelvic stability was accurately evaluated on PXR in 88 % of cases [46].

The role of pelvic x-ray as part of a trauma series is changing. While benefit in hemodynamically unstable and neurological diminished patients is clear, the impact of PXR in stable blunt multiple trauma patients, who required CT scan for full evaluation of the abdomen and pelvis, is questionable in hospitals where multidetector CT is available [47–49].

Anyway one should gain experience in assessing PXR (Fig. 32.9). Basic assessment includes checking osseous continuity for displaced fractures, especially linea arcuata (1). But without

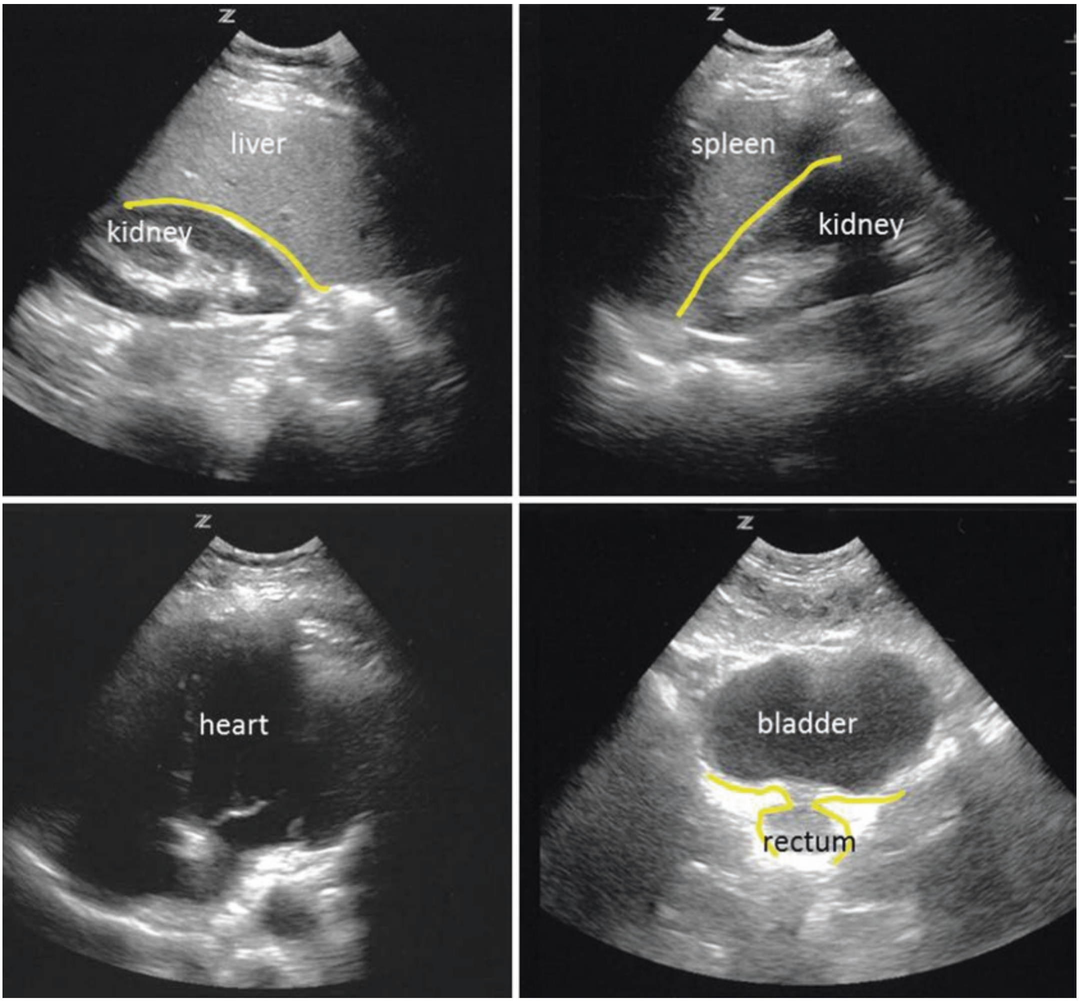


Fig. 32.6 Representative images from FAST (focused assessment with sonography for trauma); *yellow lines* mark perihepatic (u.l.) and perisplenic space (u.r.) and rectouterine pouch (d.r.)

reasonable care, one could miss a fracture easily. Searching for pelvic ring fractures, one should focus on symmetry. If pubic symphysis projects onto an imaginary line through spinous processes, each side of the pelvis is a mirror image for the other side and both iliac wings should have comparable shape. If one iliac wing displays wider or narrower, one must expect a rotational instability (2). Next step is to look for parallelism of clearly recognizable anatomic landmarks: iliac crest (a), basis ossis sacri (b), caudal sacroiliac joint (c), and cranial and caudal pubic symphysis (d, e). Width of pubic symphysis (3) and sacroiliac joints (4) reveals a ligamentous disruption. Following these simple steps, one could identify most of the unstable pelvic ring injuries.

Combination of PXR and CT has largely replaced inlet and outlet as well as ala and obturator radiographs. But one should keep these in mind, if in case of limited resources CT is not available. In this particular case, the combination of anterior-posterior pelvic x-ray and inlet/outlet or ala/obturator radiographs is yet more sensitive than PXR alone.

32.4.2.4 CT

Computed tomography angiography (CTA) or multidetector computed tomography (MDCT) is

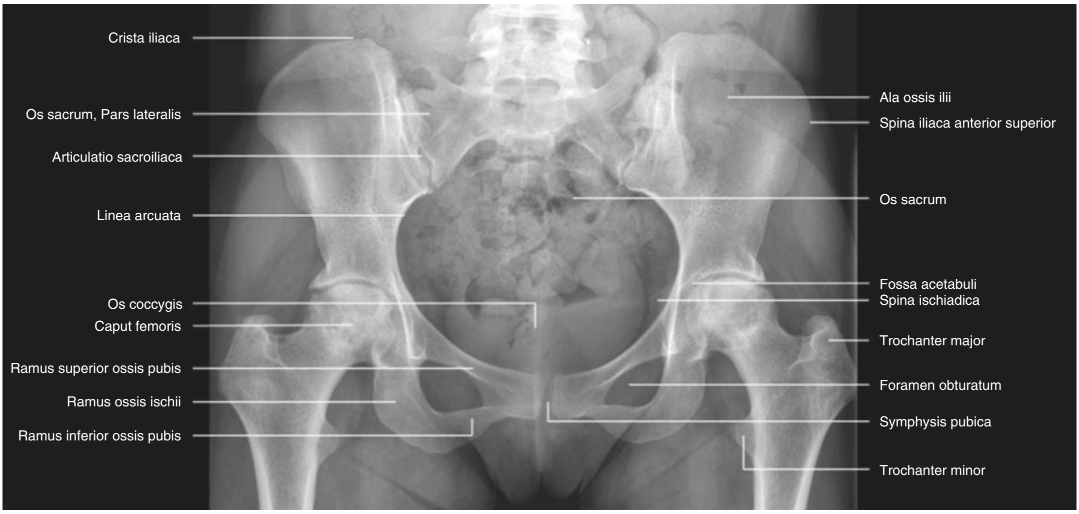


Fig. 32.7 Radiologic anatomy of the pelvis

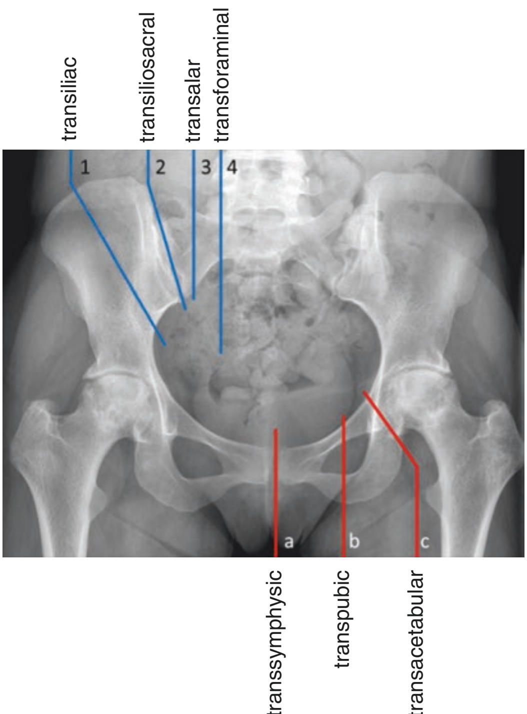


Fig. 32.8 Common fracture lines of the pelvis

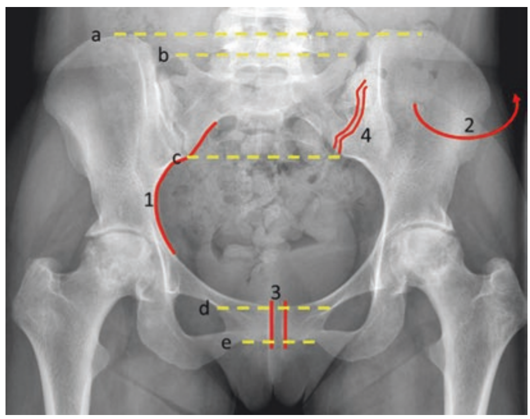


Fig. 32.9 Basic assessment of the pelvis after trauma

gold standard in diagnosis of pelvic fractures [48]. If possible one should use multiplanar reconstruction (MPR) for better assessment of imaging. This increases sensitivity of pelvic fracture detection compared to axial slices. In addition modern software allows non-orthogonal (oblique) reconstruction, which is best suitable for identifying sacral fractures. Besides CT is helpful in detection of pelvic hemorrhage (sensitivity about 90 %) [50]. Blackmore et al. state that the risk ratio for severe bleeding due to fracture-related angiorrhexis is 4,8 in patients with more than 500 ml extravasate compared with patients with less than 500 ml. Thus one should assume a relevant hemorrhage in patients with more than 500 ml of intrapelvic fluid. By implication one can exclude relevant hemorrhage in patients with less than 200 ml of intrapelvic fluid with 95 % certainty [51].

32.4.2.5 MRI

Compared to MDCT magnetic resonance imaging (MRI) reaches a significantly higher sensitivity in detection of especially sacral fractures, which is beneficial for elderly patients and insufficiency fractures [52, 53]. But due to time-consuming imaging and poor availability, MRI plays no role in early diagnosis of pelvic fractures in multiple-injured or unstable patients.

32.5 Therapy

32.5.1 Indication

In this chapter we will only report therapeutic interventions being needed to save as many lives as possible in case of a disaster during the first 24 h. Therefore final reconstructions of acetabular and pelvic ring fractures are not described.

Little is known as to the optimal treatment for pelvic fractures in disasters. Basically we think that the indication for therapy of pelvic fractures during the first 24 h is the extent of injury. Biomechanically and hemodynamically stable uncomplicated fractures do not need direct treatment, except analgesia. However, unstable fractures that effect hemodynamic stability should be treated immediately to prevent life-threatening blood loss, e.g., from the presacral venous plexus which is often injured in severe pelvic ring fractures. Fast intervention is mandatory in these cases as mortality becomes much higher, the longer patients with severe pelvic ring fractures have to wait for initial treatment [54]. Nevertheless, in case of a disaster dozens of patients with pelvic fractures can present in this situation and surgeons have to decide about the proper sequence of patients and interventions. This also includes the decision that maybe some patients cannot be helped and are let to die. Therefore the indication for therapy has to be defined consciously that resources (human and technical) are maybe limited and that severity of injury does differ in between patients. Especially in case of associated injuries, triage can become difficult.

Significant bleeding is the most important complication of pelvic ring injuries. In most times it derives from the presacral venous plexus which can be torn easily in pelvic ring disruption as it is very close to the bone and iliosacral ligaments [55–59].

Anteroposterior compression traumatic mechanisms have a high risk for external rotation of one or both hemipelvis [60]. In this situation the inner pelvic volume expands which triggers bleeding in case of ruptured vessels. Therefore one strategy to get control of severe life-threatening bleeding in pelvic fractures is to again internally rotate an externally rotated hemipelvis. Different techniques have been published (internal rotation, antishock sheet, pelvic c-clamp, external fixator). A general demand is that these techniques have to be fast and easy and should result in temporary pelvic ring stability. A reference value for the need of application is mechanical instability of the pelvis in combination with low hemoglobin (<8 mg/dl) [61]. Moreover techniques like pelvic packing or embolization can help to stop bleeding. Important aspects of therapy are listed in Table 32.8.

Whereas pelvic ring fractures are of high risk for severe bleeding and hemodynamic instability, isolated acetabular fractures are of relatively low risk to become life threatening. Consequently, the following mechanical stabilizations are mostly for pelvic ring fractures.

Table 32.8 Therapeutic options during the first 24 h

Therapy
Compression
Internal rotation
Circumferential pelvic antishock sheet
Prehospital volume therapy
Pelvic c-clamp
External fixator
Pelvic packing
Embolization
Clotting management

32.5.2 Initial and Emergency Therapy

32.5.2.1 Compression

Sometimes pelvic fractures are associated by severe soft tissue wounds (open pelvic fractures). These can be accompanied by severe bleedings that can be life threatening themselves. In this situation, compression should be applied to stop bleeding. Afterward sterile dressings should be put on.

32.5.2.2 Internal Rotation

Internal rotation of the legs is the most simple method to try to internally rotate the externally rotated hemipelvis. The patient has to be placed supine with the legs stretched. Now the legs have to be internally rotated; the feet sometimes have to be crossed. This way, an internal rotation force is applied to the pelvis and the pelvic ring can be closed. For fixation in internal rotation, tape can be used. It is most easy if lower extremities are healthy; however it can also be applied if lower extremities are splinted. The tape should not be applied too long to protect soft tissues; moreover it should not be applied circumferentially [62].

32.5.2.3 Circumferential Pelvic Antishock Sheet

Again the patient is positioned supine. Any sheet can be placed under the patient's pelvis. Rescuer has to ensure that the antishock sheet is placed directly under the pelvis. Afterward the pelvis is wrapped in the sheet. The ends of the sheet have to overlap anteriorly and have to be tensed afterward. Wrinkles should be avoided to protect the soft tissues. The circumferential pelvic antishock sheet can be secured using clamps [63]. Another option would be to twist the sheet anteriorly of the pelvis to compress it and to secure it in this position.

32.5.2.4 Prehospital Volume Therapy

Prehospital volume therapy is widely discussed. Hemorrhage causes decreased perfusion and consequently hypoxia in several organs. Volume therapy therefore should try to improve microcirculation. It has been published that prehospital volume therapy does not affect morbidity and mortality [64]. Some authors even advised against prehospital volume therapy due to increased mortality rates. These studies however deal with thoracic and abdominal bleedings and fast surgery is recommended [65–72]. In case of injured extremities, recommendations as to optimal prehospital volume therapy differ slightly [73–77]. Reviewing the literature however, it is recommended to perform a reduced volume therapy with the circulation being stable at low level with the systolic blood pressure being as high as 90 mmHG [78–81]. Normotensive patients however do not need any volume therapy. Crystalloids should be preferred, especially Ringer's lactate. Isotonic NaCl solutions should not be administered [82, 83].

32.5.2.5 Pelvic C-Clamp

The pelvic c-clamp is another option to reduce dislocated pelvic ring injuries. A pelvic c-clamp is supposed to apply compression to the posterior pelvic ring to close the diastasis. The patient is placed supine. Stab wounds are made at the entry points: These are 3–4 finger breadths anterolateral to the posterior superior iliac spine (PSIS) along a line drawn between the PSIS and the anterior superior iliac spine (ASIS). An alternative to find the correct entry point is to draw a curved line in the axis of the femur and a vertical line from the ASIS. The crossing will mark the entry point. Steinmann pins are fixed in the bone using a hammer. Afterward they guide the pelvic c-clamp which can be closed by compression with subsequent compression of the posterior pelvic ring to close the diastasis. Cranial displacement of the pelvis has to be corrected by traction at the unilateral leg before fixation of the clamp. Dorsal displacement can be corrected by a T-handle that can be placed in the ASIS. Whenever applying a c-clamp, it is helpful to internally rotate the legs. It should not be used for distinct comminution of the ilium near the SI joint. Moreover only venous hemorrhage can be controlled whereas arterial hemorrhage does remain most times [55, 61]. Figure 32.10 shows a patient who was treated with a pelvic c-clamp in the emergency room for a C-type pelvic fracture.

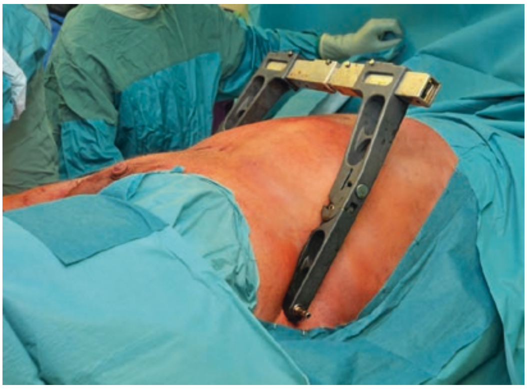


Fig. 32.10 The pelvic c-clamp

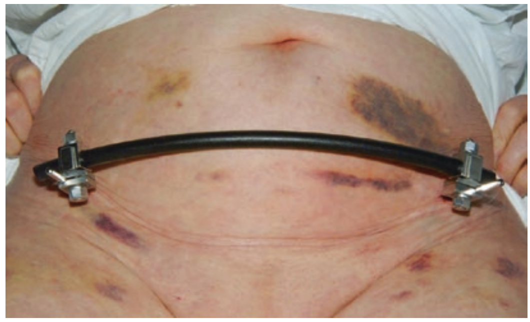


Fig. 32.11 The supra-acetabular external fixator

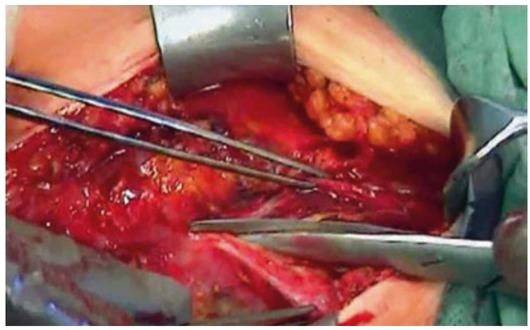


Fig. 32.12 Pelvic packing. The linea alba is incised

32.5.2.6 External Fixator

Another method for fixation is the use of an external fixator, placed in the anterior pelvic ring. Like the pelvic c-clamp, this intervention is easy and fast to perform. Schanz screws should be placed in the supra-acetabular region and aim for the SI joint; they should be directed 30° cranially and 70° medially in supine position, starting supra-acetabulary. External fixators are effective in patients with anterior pelvic ring disruption with a closed posterior pelvic ring. In case of isolated posterior instability, however they are not as effective as pelvic c-clamps to reduce the pelvic volume for hemorrhage control [84, 85]. Figure 32.11 shows a supra-acetabular external fixator.

All these methods are emergency procedures that can be performed fast without much preparation. Especially the methods of internal rotation and the application of a circumferential pelvic antishock sheet can be performed outside in a disaster area. Patients that received a pelvic c-clamp or external fixator can be left with these for days before final fixation.

32.5.2.7 Pelvic Packing

In case of pelvic ring fractures, massive hemorrhage can occur in the pelvis. Most times these bleedings are venous and related to the presacral venous plexus; however infrequently they can also be arterial (10:1). In case of hemodynamic instability despite mechanical redression by, e.g., a pelvic c-clamp, pelvic packing is indicated. The linea alba is incised; the peritoneum is left intact but pushed free. Pelvic organs are pushed laterally so that the posterior pelvic ring can be seen. Arterial bleedings should be clipped or sutured whenever possible. Afterward at least three radioopaque swabs should be put into the pelvis on both sides of the organs [86, 87]. Pelvic packing is known to significantly reduce mortality. The swabs compress bleeding vessels, the consequence being that patients improve hemodynamically and need less blood transfusions [87]. The incision for pelvic packing with the linea alba being incised can be seen in Fig. 32.12.

32.5.2.8 Embolization

In former times there were always discussions whether embolization or pelvic packing would be best for hemorrhage control. Angiographic embolization is performed to find the bleeding vessel and to specifically stop this bleeding by embolization. However, only arterial bleedings can be embolized which is important as the majority of bleedings result from the presacral venous plexus. Angiographic embolization takes much longer than pelvic packing and is much more complicated to perform (human and technical resources). Moreover recent studies did show better results in pelvic packing compared to angiographic embolization [88].

32.5.2.9 Collateral Injuries

Pelvic fractures are often associated with further injuries apart from the bone; almost every abdominal organ as well as the soft tissue layers can be affected. Collateral injuries include genitourinary injuries, torn or ruptured lumbar plexus, or severe soft tissue wounds like Morel-Lavallée lesions. The perineal region can also be injured. Therapy of all these injuries is manifold. It is important to distinguish in between all these different possible injuries. Some injuries have to be treated immediately: Intestine perforations as well as vesical perforations and severe urethra injuries have to be treated immediately to prevent urine and feces to leak into the abdomen or inner pelvis. Moreover intra-abdominal bleeding, dependent on its severeness and source, has to be operated immediately. However, other injuries, that do not cause death as fast as beforehand mentioned injuries, can be treated later. These injuries include soft tissue wounds, ruptured lumbar plexus, or little intra-abdominal bleeding. Generally, collateral injuries to pelvic trauma involve other disciplines than orthopedics as well, e.g., urology or abdominal surgery. Therefore we need an interdisciplinary approach to treat these patients. Collateral injuries that can be seen frequently are listed in Table 32.9.

Table 32.9 Common collateral injuries to pelvic trauma

Common collateral injuries
Further fractures
Soft tissue wounds
Genitourinary injuries
Ruptured lumbar plexus
Lacerated perineal region
Intestine perforations
Liver ruptures
Spleen ruptures Blunt thoracic trauma
Traumatic brain injury

32.5.2.10 Clotting Management

In multiple-injured patients which represent the patient cohort that is often also suffering from pelvic fractures, clotting is known to be impaired regularly [89]. This coagulopathy aggravates bleeding [90]. Patients with a deranged coagulation are of higher risk for complications during recovery such as renal failure or multiorgan failure [91, 92]. High hematocrits (30 %) are supposed to help to control bleeding [93]. If clotting management is done by application of fresh frozen plasma (FFP), the relation of FFP and red blood cell units should be 1:2 to 1:1. Fibrinogen should be replaced if it is <1.5 g/l. In case of hyperfibrinolysis, antifibrinolytics such as Tranexam (2 g) should be given first [94]. Moreover aspects like body temperature and pH should be optimized.

Conclusion

Pelvic fractures are common in multiple-injured patients and associated with high mortality up to 30 %. Half of all decedents die within the first 24 h due to fatal hemorrhage. The other 50 % die within days and weeks after trauma due to multiorgan failure. Main causes of pelvic ring fractures are motor vehicle accidents and falls from great height.

In the preclinical phase, one has to confine on focused examination and hemodynamic assessment. Hemodynamically unstable patients with suspicion of pelvic injury should be treated like unstable pelvic ring fracture until opposite is proven.

Classifications are important for the triage of pelvic trauma patients. They facilitate communication and help surgeons to estimate clinical severeness. However, in disaster medicine classifications should be reduced to the essentials. Type B and C pelvic ring fractures are of high risk for fatal hemorrhage whereas type A fractures are of low risk.

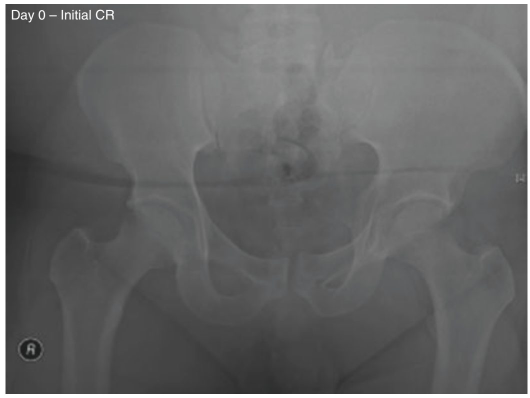
Clinical emergency diagnostic should involve plain pelvic x-ray and focused sonography (FAST) as well as computed tomography whenever possible in case of suspected pelvic ring fracture.

The therapy of pelvic trauma during the first 24 h has to be fast and easy to perform. We did present different techniques. Whereas pelvic binders and the internal rotation technique can be used outdoors, the pelvic c-clamp and also the external fixator can best be implanted in clinic. However, at least the pelvic c-clamp can also be adjusted outdoors at the side of injury. Collateral injuries also have to be taken care of; however not all need emergency treatment. Volume therapy and clotting management are key aspects in the management of severe injured patients, who, e.g., suffer from pelvic ring injuries. However, details of management are complex and widely discussed. Volume therapy should be initiated at the side of injury. Crystalloids, e.g., Ringer's lactate, are preferred solutions. The systolic blood pressure should be kept stable at low levels like 90 mmHg.

32.6 Case Reports

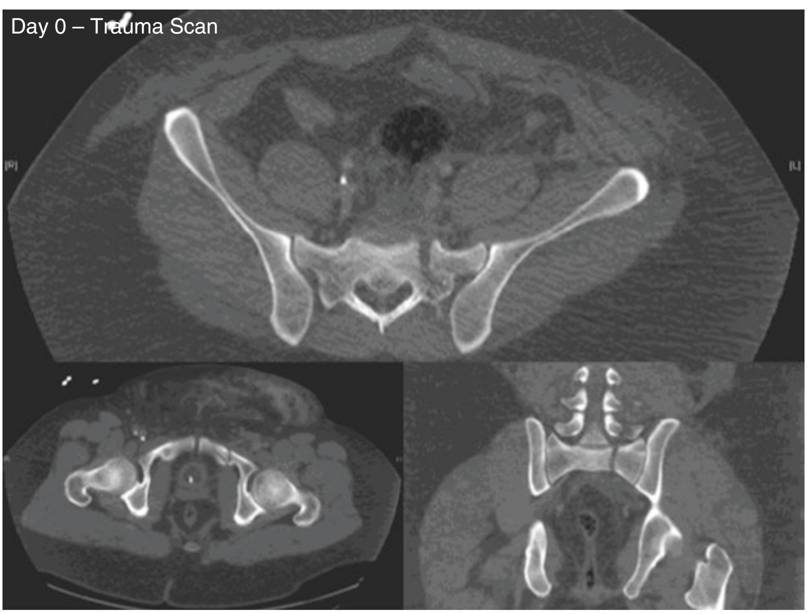
Case 1
Preclinical Situation

- Twenty-five-year-old male person
- Rear-end collision with high speed
- Jammed in the car for 30 min
- Initial GCS 15
- Abdominal and spinal pain, both legs with reduced sensitivity
- Preknown factor V Leiden mutation
- Transport to the ER

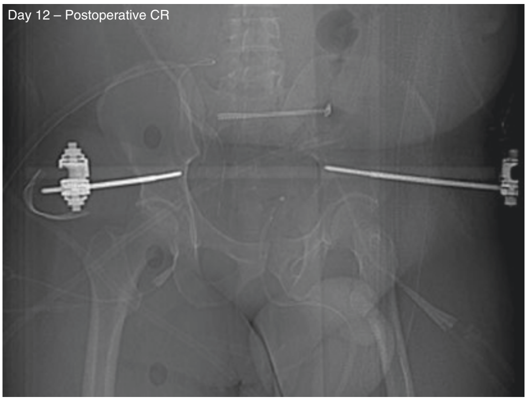


Emergency Room

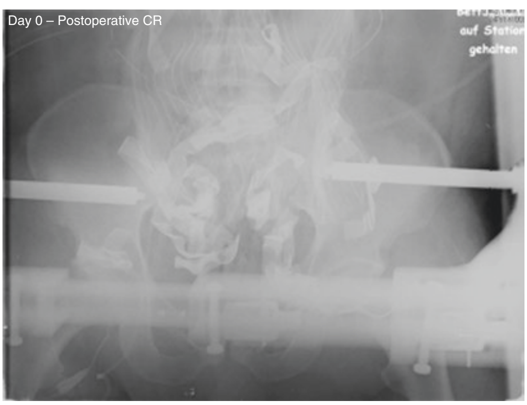
- Awake, hemodynamically stable, with Hb 13 g/dl
- Bleeding out of nose
- Supple abdomen and no free fluid in FAST
- Pelvic pain, uncertain test of pelvic stability due to obesity
- Pain of the lower spine
- Multiple superficial wounds of the lower limb



Trauma Scan
- Type C pelvic fracture (transforaminal sacral fracture), transpubic fracture left and lower pubic fracture right, acetabular fracture right
- Distinct hematoma dorsal of the M. rectus abdominis with intra-abdominal bleeding and rupture of the bladder
- Bilateral pulmonary contusion
- Nasal bone fracture



Clinical Course
- 2:40 am car crash
- 3:40 am arrival at ER
- 4:34 am finishing trauma scan
- 5:58 am incision OR and C-clamp
- 8:00 am CPR responsibility and presacral packing → hemodynamic stabilization
- Twelve days later external fixator + SI screw joint



Case 2
Preclinical Situation
- Sixteen-year-old male person
- Cyclist strucked by a lorry
- Initial GCS 4
- Unstable type C pelvic fracture
- Hemodynamically unstable with intubation and ventilation
- Transport to the ER

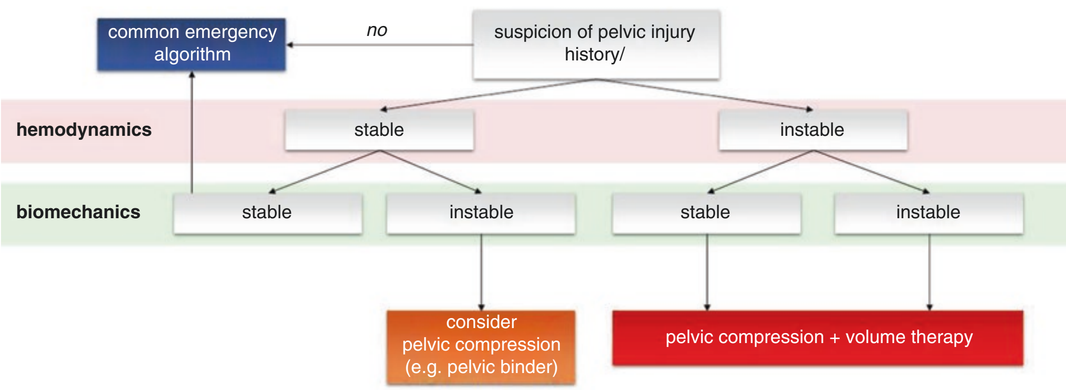
Emergency Room
- No free fluid in FAST
- Implantation of C-clamp and hemodynamic stability
- Transport to trauma scan

Trauma Scan

- Type C pelvic fracture (transsymphyseal instability, acetabular fracture left)
- Fracture of C2, Th9-11
- Sternal fracture with pulmonary contusion
- Retroperitoneal and abdominal hematoma
- Petrous bone fracture

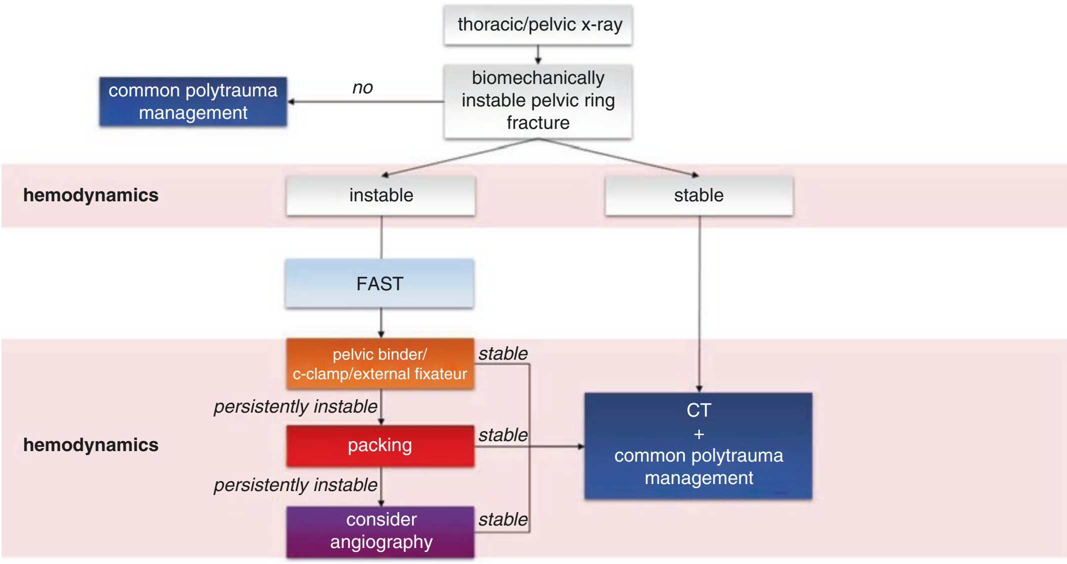
Work Flow

Preclinical

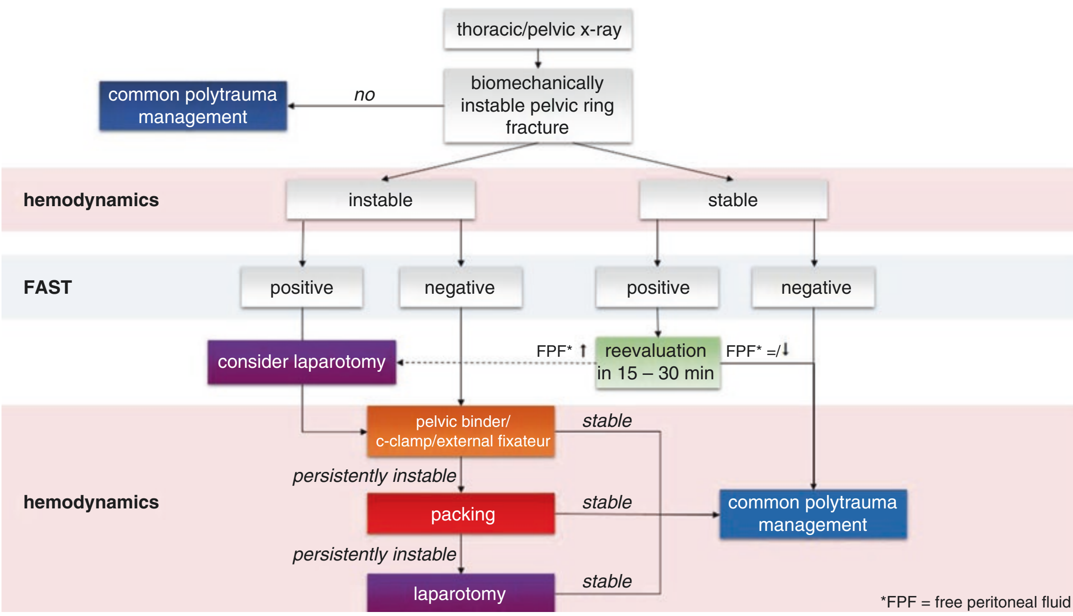


Clinical

CT available in emergency room or in hospital within few minutes:



CT not available:



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33 Amputations in Disasters

Nikolaj Wolfson, Moris Topaz, Alexander Lerner, and Eric S. Weinstein

33.1 Introduction

Mass casualties related to either natural or man-made disasters are a reality of our lives, affecting large populations happening in both developed and developing countries. The earthquake that hit Haiti on January 12, 2010, caused around 237,000 deaths and nearly 300,000 wounded and left about 1 million homeless—revealing just how unprepared most countries are to deal with mass casualties and disaster-related injuries. A large percentage of the injuries typically seen in these situations are to the limbs [1, 2]. An overwhelming number of casualties; delayed presentation; crush injuries and crush syndrome; lack of adequate medical facilities and sometimes expertise, regional and cultural; and other factors influence the decision to amputate, to save lives, or to preserve function.

Despite improvements in both orthopedic and vascular reconstructive surgery, including the introduction of new technologies [3, 4] over the last 50 years, amputation is often the necessary treatment for severe extremity trauma. While limb-salvage techniques have lowered the rate of amputations in noncombat civilian and combat military situations, the current amputation rate of war-related amputations is now twice that experienced by military personnel in previous wars [5, 6]. The rise in amputation rate is likely due to the improvements made in soldier's protective equipment.

Both mass casualty injuries in civilian population, caused predominately by either crash or high-speed accidents, and military trauma often due to a blast require damage control approach. The choice to perform an amputation and save patient's life is one of the most important and challenging decisions facing the civilian and military surgeon. Given our current geopolitical situation, it is likely that surgeons will continue to be confronted with these complex patients.

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_33

As a rule, making the difficult decision for amputation should not be seen as a failure of treatment but rather as a life-saving or function-preserving operation. The approach used is multidisciplinary and takes into consideration medical, surgical, and psychological factors, the availability of postoperative care, continuation of care, rehabilitation and prosthetic resources, and community reintegration. It is of major importance to have the patient and patient's family involved in the decision-making process and obtaining informed consent, with documentation, when possible. Participation of the local medical community and if available local religious and cultural representatives or social service staff versed in the provision of relief care to assist the patients and their family in making life-altering treatment decisions.

In 2011 HAS Amputation Following Disasters Working Group developed conclusions and recommendations in the areas of amputation management in disasters. The goals of the group were to come up with best practice recommendations in the areas of team planning, operative technique, pain management, rehabilitation, medical records, and outcome tracking. This initiative can be great platform for developing optimal care in disasters [7].

The following chapter will review the subject of amputation during natural disasters and mass casualties with emphasis on a staged approach to minimize postsurgical complications, especially infection.

33.2 History

The history of amputation is as old as human kind.

Hippocrates, who stated that war was a "proper school for surgeons," was one of the first to describe amputation. He recommended performing amputation within the insensate necrotic area of the extremity for the purpose of minimizing pain and bleeding [2, 8, 11]. In contrast, in the first century BCE, Celsus recommended amputation within the healthy part of the extremity, dividing the bone above the level of the soft tissue incision. He also advocated the usage of ligatures for the purpose of hemostasis [3].

The introduction of gunpowder in the thirteenth century and its later extensive use in the fifteenth and sixteenth centuries were a major turning point in battlefield surgical procedures [4, 9]. Open fractures and severe damage to the soft tissues were common, which necessitated a more extensive surgical approach to amputation. In 1536, Ambroise Paré, a military surgeon, [5], rediscovered Celsus' principles: amputation through viable tissue and the use of the ligatures. While running out of boiling oil, which was used at that time for wound cauterization and sterilization, Paré learned that cold, not heat, is more beneficial for the control of wound bleeding. Pare is also credited with inventing artery forceps.

In 1588, William Cloves described the first successful above-knee amputation and, in 1593, Fabry, in his monograph on gangrene, reported the first amputation through the thigh [5].

The introduction of Morel's tourniquet in 1674 (the Spanish windlass) and Petit's tourniquet in 1718 were significant steps in the control of hemorrhage and allowed for a better technique of amputation and the creation of more functional stumps [10].

The Napoleonic Wars led to further improvements in battlefield surgery. Jean Dominique de Larrey, of France, is considered one of the founders of military medicine. A legendary surgeon in Napoleon's army, he designed horse-drawn carts called "flying ambulances" to carry surgeons and medical supplies into the field of battle. Larrey [12] and Guthrie of Great Britain advocated early primary amputation. They found that early amputation was associated with a lower incidence of infection and less hemorrhage. Larrey, who was the first in 1803 to disarticulate the hip, amputated 200 limbs and disarticulated 11 shoulders one night in 1812 in the battle at Berezina River.

Another French surgeon, J. Lisfranc de St. Martin, in 1815 published a book on partial foot amputation. He also popularized the formation of flaps for better coverage of the amputation stump. In 1844, James Syme described ankle disarticulation.

The introduction of ether anesthesia in 1846 and the subsequent development of antiseptics led to more precise surgery and a lower risk of wound infection.

Nikolai Ivanovich Pirogoff (1801–1881), the most renowned military surgeon in Russian history, performed hundreds of amputations during the Crimean War (1853–1856), in which France, the United Kingdom, the Kingdom of Sardinia, and the Ottoman Empire fought against Russia. The inability to provide ankle disarticulation to his soldiers, who required Syme's amputation (which he admired), led him to come up with what is known as the "Pirogoff amputation" [95]. The Pirogoff amputation is a surgical salvage procedure for the complex injuries of the forefoot, where there is considerable loss of the osseous and soft tissues. Part of the calcaneus together with the fat pad is rotated and fused to the tibial plafond, which allowed for a longer stump, eliminating the need for below-knee amputations, and allowed for weight bearing. Pirogoff also introduced nurses on the battlefield and published the *Atlas of Human Cross-Sectional Anatomy* based on sawed frozen sections.

During the American Civil War (1861–1865), the approach to amputations evolved further [13]. General anesthesia was available for the surgeons. There were nearly 55,000 amputations performed during the war. At the beginning of the war, surgeons learned, based on experience from the Napoleonic Crimean wars, that timing plays a crucial role in the outcome of amputations. Primary amputations were performed early after the initial injury, in crush injuries, gunshot fractures with extensive comminution, open fractures, partial or complete amputations, combinations of fracture and open joint injury, and fractures associated with nerve or vessel injury. An indication for secondary amputation was an infected wound. Later in the war, indications for amputations became more refined: gunshot fractures to the femur were not an indication for primary amputation and the use of splints helped to treat long bone fractures non-surgically.

World War I (1914–1918) brought artillery into the battlefield, which caused over 7 million deaths, 19 million wounded, and half a million amputations. Fitzmaurice-Kelly [14] in 1916 reported on a method for skin incisions, which was made as distally as possible in order to allow it to retract with the subcutaneous tissue, while the muscle and bone were divided more proximally. This facilitated the preservation of the residual limb length and the prevention of infection and secondary hemorrhage. This procedure was called a "Guillotine" amputation, since the muscle and bone were cut at the same level. It was subsequently replaced with the construction of the flap, which after being left for some time facilitated a better closure of the wound.

World War II (1939–1945) was plagued with heavy civilian casualties from massive aerial bombardments. The use of more modern medical support (blood and plasma transfusions and antibiotics) as well as surgical advances (arterial repair), early evacuation, and better splinting made the salvage of many limbs possible.

While the mortality rates of the subsequent wars have significantly decreased, the amputation rate has remained high (~13 %), which is likely due to more destructive weapons. In contrast to above-knee amputations carried out during World War I, below-knee amputations predominated during World War II. In 1943 Norman T. Kirk indicated that guillotine amputations in a war setting should be performed as distally as possible and completed later under calmer conditions.

Recent advances in the field of amputation include new ways of wound debridement and decontamination, tissue presentation, wound coverage by regulated negative-pressure-assisted wound treatment (RNPT), and fracture reduction and stabilization with minimally invasive devices and new techniques in vascular reconstruction. Based on extensive experience with vast number of combat casualties treated during armed conflicts and mass casualty incidents of the second half of the twentieth and beginning of the twenty-first centuries, these techniques combined with improved prostheses and rehabilitation programs have greatly improved the outcome for amputees.

33.3 General Principles

33.3.1 Introduction

The decision to perform an amputation is made to save the patient's life or preserve extremity function.

The general principles of trauma care, including rapid triage, application of the principles of Advanced Trauma Life Support [15] care of life-threatening injuries, and early stabilization of the affected extremity, are applied. In the case of exsanguinating hemorrhage from the extremities, hemostasis with the use of tourniquets is the highest priority. The appropriate resuscitation is performed and the adequate antibiotics and tetanus toxoid (as part of the Tdap vaccine) are administered prior to wound management.

War extremity wounds are characterized by high-energy injury, extensive soft tissue damage (Fig. 33.1), and prolonged injury to operation time. The mechanism of crush injuries, specifically after earthquakes, is more of a prolonged low energy trauma with extensive soft tissue damage and often late (>12 h) presentation (Fig. 33.2). These factors lead to an increased risk of infection and inevitably higher amputation rates [16–18].

A multidisciplinary approach to this type of injuries may ultimately improve an outcome and maximize functional rehabilitation but unfortunately often not possible.

Fig. 33.1 Extensive soft tissue damage

Fig. 33.2 Late presentation

33.3.2 Crush Injury

Crush injuries may lead to *compartment syndrome* with or without associated skeletal injury [19]. In this situation the pressure within closed myofascial compartment is increased to an extent that microcirculation is compromised leading to compromised function [20]. If released timely, by performing fasciotomy, these changes can be reversed. When an injured extremity is exposed to substantial crushing force for a prolonged period of time and the volume of the compressed, crush tissue is substantial, and irreversible changes can take place, including muscle cell death and systemic manifestations. This is known as *crush syndrome*.

The *crush syndrome* may develop after 1 h in a severe crush situation, but usually requires 4–6 h of compression for the systemic manifestations to occur. At the early stages, there are very subtle local changes. When the extremity is trapped under rubble for prolonged periods, depending on the muscle mass and other circulatory factors, the venous return from the involved compartment is impaired and some of the toxic metabolic products are not part of the systemic circulation. Restoration of perfusion can lead to reperfusion injury with associated cardiac, renal, and circulatory manifestations. For this reason treatment of the crush syndrome is primarily focused on preservation of the patient's cardiac, renal, metabolic, and circulatory fluid volume with IV hydration and administration of IV $NaHCO_3$ in advance of the release of the entrapped extremity or extremities and thereafter until sufficient urine output is maintained and clinical evidence that rhabdomyolysis is improving. This treatment of crush syndrome is different from the treatment of acute compartment syndrome [21, 22].

There is well-reported evidence from different disasters showing a high rate of infection leading to an increase in deaths and associated secondary amputations when fasciotomies were performed in the presence of crush syndrome [6, 16, 17, 21, 23–28]. In hypoxic tissues, the body's inherent infection control and healing are impaired increasing the risk of infection and decreasing appropriate wound healing compared to other traumatic injuries.

Fasciotomy is not indicated in treatment of the crush syndrome unless the peripheral circulation is absent or severely compromised and directly observed to be working over a 1–3 h time frame. In this specific instance, compartment decompression is done to reestablish peripheral blood flow. Another indication for fasciotomy is with unique open fractures.

Only when damage to the extremity is significant and risk of reperfusion-related systemic changes is significant should amputation be performed to save the patient's life. An instance may be if the patient is to undergo another lengthy operative procedure or procedures and the ability to directly observe the injured limb or limbs is lost.

Amputations in this situation should be done in a stage fashion. As much limb length as possible should be preserved. Wounds should be well debrided and covered with a dressing allowing discharge fluid to be drain. Any obstruction to the wound discharge may lead to major complications, both local and systemic with significant risk to patient's remaining limb and life.

33.3.3 Blast Wound Amputation

Blast-related injuries create a wide zone of soft tissue injury with gross contamination of materials brought into the wound from the environment. Land mine blasts create an "umbrella effect" (Fig. 33.3a, b) with the tearing of the soft tissues, stripping them off the bone, and extending proximally away from the visible site of the injury [29–31].

After general trauma care is initiated (ATLS), the initial local extremity care is centered over bleeding control utilizing rapid tourniquet placement above the site of bleeding. Applied in the field it has been shown to have lower mortality rate compared to when applied in the emergency room [20, 32]. Vascular injuries of the affected extremities can be subtle. It has been shown that in the absence of vascular changes on physical examination, up to 25 % of patients demonstrate positive findings on the angiography assessment [33]. Meticulous wound care is of primary importance. Thorough irrigation and debridement, even of small wounds, is essential to clean deep contamination and devitalized tissues. Wound care in blast injuries requires stage approach and can be very challenging. The wounds are left open and the patient returns to the OR in 24–48 h for a second inspection, further debridement, and possible closure [34]. Coverage of trauma wounds with new-generation negative-pressure technology (RNPT), regulated negative-pressure-assisted wound therapy, and regulated, oxygen-enriched negative-pressure-assisted wound therapy has showed beneficial effects in treating the soft tissue blast injury in comparison with the gauze dressing therapy in swine [35].

Compared with gauze dressing treatments, RNPT reduces bacterial load more efficiently, initiated granulation tissue formation earlier, and increased the inflammation faster. Negative pressure ranging from −10 to −25 kPa on the RNPT group showed beneficial effects in treating the infected soft tissue blast injury.

Safety precautions should be taken in treatment of blast injuries due to the wide area of injury with high susceptibility to major and profuse bleeding. To avoid uncontrolled bleeding, treatment should be deferred until bleeding control has been achieved, vacuum pressure should be maintained at the low level of the efficacy range (50–70 mmHg), fluid collection should be controlled and restricted by the device to limit uncontrolled hemorrhage (blood loss), and dressing should allow visible detection of bleeding.

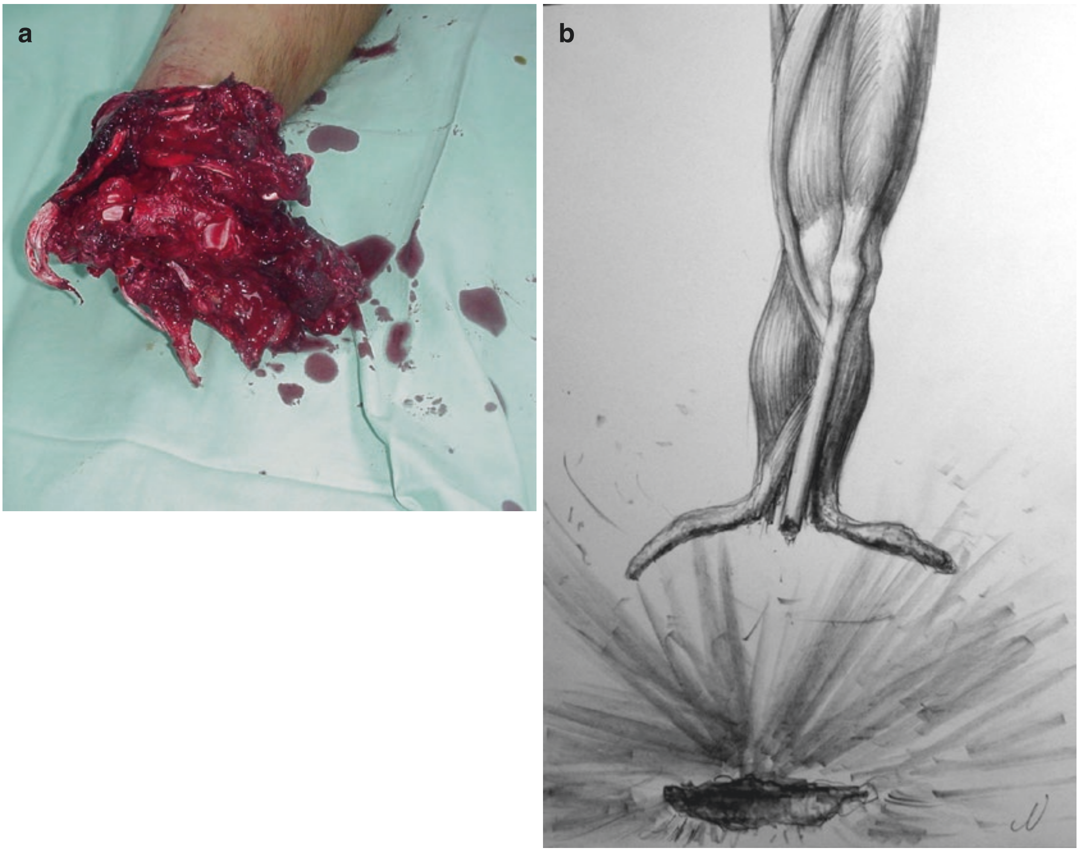


Fig. 33.3 (**a**) Blast amputation. (**b**) "Umbrella" effect

Immediate skeletal stabilization is essential [36]. Wound coverage is performed as soon as soft tissue condition allows. Rotational flaps are favored in a disaster setting over free flaps due to multiple factors. There is a high risk of infection with blast injury. In the case of suicide bombings, transmission of bacteria or viruses is introduced by penetration of biologic material contaminated with hepatitis B or C into the patient's extremity [37] or from the environment [38].

33.4 Anesthesia

In preparation for deployment to the disaster zone, it is of major importance to have appropriate equipment, medications, and adequate manpower. Lessons learned from 2010 disaster in Haiti [39] support optimization of the patient's condition prior to the amputation and appropriate antibiotics administration rather than rushing with procedures that can have devastating complications. No amputation performed in a field hospital should be done without appropriate pain management [40]. Type of anesthesia is based on the patient's condition and resources available. Total intravenous anesthesia (TIVA) and ultrasound-based regional anesthesia (USRA) can be ideal techniques for patients in disaster settings. It is much easier to control patient's pain after the amputation if regional, epidural, or spinal anesthesia is used [32, 41, 89]. This approach proved itself in the field [32, 42, 43]. Use of continuous peripheral nerve blocks has been used successfully for pain management during amputations and the immediate postoperative recovery phase [42, 44]. Management of perioperative somatic pain and phantom limb pain (PLP) is of major importance.

33.5 Indications for Amputations

The ultimate goals of treatment of extremity wounds are the preservation of life and maximizing extremity function. In this context, the decision-making process for the patient considered for amputation is based on multiple factors.

In situations of high-energy penetrating trauma and where the damage to the affected extremity is beyond salvage, completion of the amputation is the only option.

When vascular injury is irreparable, the amputation is to be performed.

Indications for amputation are based not only on patient's factors but also on surgeon's or facility factors and their ability and availability to provide care that will determine what option to choose: to amputate or to salvage injured extremity.

33.5.1 Patient Related

In certain situations the need for amputation is obvious. When the patient's general condition is at risk, the safest approach is used. When the situation permits addressing the patient's mangled extremity in a more comprehensive way, multiple factors are considered. Patient's age, immune status, and comorbid conditions, preinjury functional status of the currently injured extremity, and other extremity and concomitant injuries will have important impact in the decision to amputate or salvage.

Different scores have been used to establish objective criteria in decision-making process to amputate or to salvage [45–51]. The Ganga Hospital Open Injury Score described by Rajasekaran et al. [52, 53] to specifically address the question of salvage in open Gustilo-Anderson III-B injuries while not yet widely accepted seems to have very promising use.

Local healthcare systems and sociocultural factors ultimately play role in decision-making process when amputation is considered. Informed consent should be obtained, time and circumstances permitting; family of the affected patient should be informed and involved in this very challenging process. While in some countries and cultures, the life of an amputee can be reasonably maintained with appropriate artificial prosthesis, in others, the loss of limb may create functional, social, and mental handicaps. When operating in foreign countries, an international medical team facing difficult treatment dilemmas should always have local medical and cultural authorities involved in some of these life-altering decisions.

33.5.2 Surgeon and Facility Related

The surgeon's skills, level of the facility where the surgical care is provided, and the ancillary services are among the factors that will determine the surgical approach and outcome. An error is to ignore the factors related to the event itself, since a large number of casualties (demand) with a lack of qualified, credentialed healthcare providers (supply) would create an imbalance. Choices will have to be made to allocate time and resources in a manner different than if there were ample providers from multiple specialties that matched or exceeded the number of casualties, where the individual patient's needs can be attended in a more comprehensive way. The dual loyalty in a disaster is to do the most good for the most casualties while trying to do the most for the individual cannot be understated. After a disaster and during ongoing rescue and recovery efforts which may be hampered by sporadic weather and other factors, the geography of the area will impact the timing and mode of transportation of the injured to an appropriate medical facility and will determine how fast and how many can receive most optimal care.

33.6 Surgical Technique

33.6.1 General

The surgical management of the extremity is carried out in a staged fashion after the initial airway and breathing are secured and patient is appropriately anesthetized. The following steps are to be followed:

33.6.2 Hemostasis

If significant bleeding is encountered, immediate direct pressure at the site of the bleeding is applied in order to control the hemorrhage. This is followed by the rapid placement of a tourniquet above the site of the bleeding. The use of a tourniquet is necessary to ensure that the amputation is not compromised. The combat application tourniquet system (CATS) used in the prehospital setting by the US Army has improved survival by 23 % relative to application in the emergency department [54–56]. A sterile hemostatic dressing is then applied.

33.6.3 Secondary Examination

A secondary examination is then performed to exclude other injuries. A careful examination of the neurovascular function, bone, and soft tissues of the injured extremity is essential. If an X-ray assessment is possible, it is performed in order to evaluate the integrity of the bone and the presence of radio-opaque or space occupying foreign bodies, especially in the case of blast injuries.

33.6.4 Wound Care

In the case of blast or crush injury, all viable tissues should be preserved since the exact extent of the tissue damage cannot be immediately established.

Wound care is of utmost importance following life and limb salvage. Effective wound management can determine later need for reamputation or even life salvage. Wound infection is a major factor determining the outcome of blast and crush injuries. It affects the late viability of soft tissue as well as bone infection and will determine the future complexity of the wound healing and rehabilitation.

Negative-pressure technology, one of the most important non-pharmacological platform technologies, has been developed for the wound management field and has been used over the last two decades [3]. This treatment modality *should be used cautiously* to avoid increasing blood loss.

In situations such as trauma, mainly in blast and crush injury and heavily contaminated combat injuries, when tissue oxygen concentration is reduced, the anaerobic indigenous flora can multiply quickly and induce fast spread of local infection and sepsis. The presence of aerobic or facultative infections creates a habitat that supports growth of anaerobes by reducing the oxygen concentration in the infected tissue. This may be of greater significance when applying occlusive dressings, creating an airtight sealed environment, as in RNPT.

The open length-preserving amputation (in the past open circular amputation) [56] does not preserve length [57] and might be challenging as far as residual limb healing and rehabilitation are concerned. Early aggressive debridement, usually within 2 h, is performed with a skin incision made as distal as possible through the skin and fascia. All viable tissue is preserved for use during definitive reconstruction when, and if, needed. Wound edges are secured [3] to avoid further damage to the skin flaps by the retaining sutures. Wound should be irrigated with normal saline. Preferably it should be warm, low-pressure pulse irrigation or simple low-pressure flow through sterile tubing. To avoid cell damage and due to the lack of evidence of the antibiotic containing solutions, we recommend normal saline if available, or in a resource constrained, austere environment, tap water has been proven to be as efficacious under 0.46–0.54 PSI [7].

The next debridement is performed within 48–72 h and repeated again as needed. The definitive soft tissue flaps are fashioned in the later stages, since the degree of soft tissue viability is difficult to assess at the initial stage. After the initial debridement, the wound is not closed primarily but rather covered with light sterile dressing. *A wound is not to be covered with occlusive dressing that may lead to an increase in ischemic changes and infection* (Fig. 33.4a, b). Fasciotomy and revascularization, if needed, using shunts or definitive vascular reconstruction, as well as skeletal stabilization with either internal or external fixation, are carried out based on the level of care available.

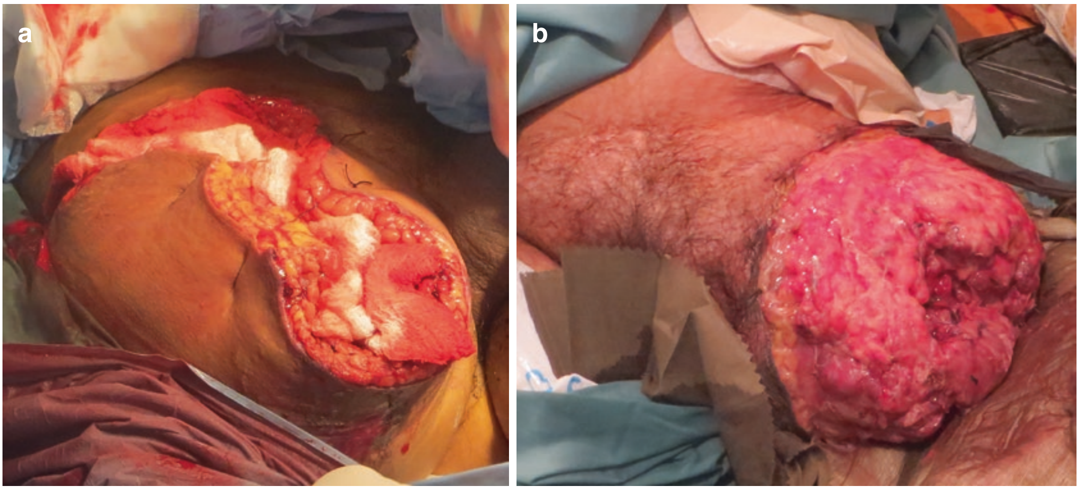
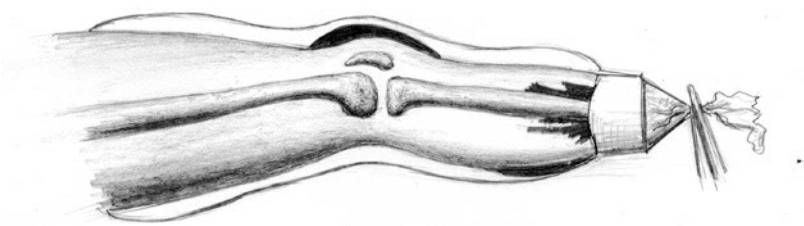


Fig. 33.4 (**a**, **b**) Occlusive dressing and its local sequelae

Fig. 33.5 Skin traction



Skin traction (Fig. 33.5) used in the past to prevent skin retraction and transportation casts [57] is no longer commonly used because of improvements in wound management and transportation times. Various wound coverage techniques can be used, including local flaps [58–63], free tissue transfer [64–66], and split-thickness skin grafts [67, 68], and some new technologies like top closure tension-reduction system and others [69] may be applied as a second choice for method of closure. Multiple surgical debridements are the rule prior to definitive delayed wound closure.

33.6.5 Level of Amputation

The following are the factors to be considered when deciding at what level to perform a lower extremity amputation:

It should be carried out at the level of viable tissues. In the acute setting, skin vascularity is sometimes assessed by a trial skin incision [17]. Most of the time, the decision of the level of the amputation is based on clinical factors: skin color and temperature, presence of peripheral pulses, extent of the skeletal damage, and gross infection. When definite amputation is performed in a more delayed fashion, other diagnostic modalities, such as ankle/brachial index, transcutaneous PO_2 measurements [70], arterial Doppler studies, Xenon 133, laser Doppler, and thermography, have been used to predict the healing potential of the amputation wound.

Bone cutting is carried out in consideration of the soft tissue coverage, so that when the closure of the wound is performed, the skin is not under tension.

Stripped of soft tissue attachments comminuted and devascularized bone fragments should be removed to avoid future local infection due to sequestrum formation. Large bone fragments with soft tissue attachment and preserved blood supply should be stabilized using either external or internal fixation, to allow preservation of the longest optimal amputation stump.

33.6.6 Soft Tissue Management

Quality of the soft tissue management is the key for successful care of amputation. Initial approach should be based on comprehensive but careful debridement of amputation wound and better if done in a stage fashion. While often used in civilian and vascular trauma, myoplasty and myofascial closures [71–73] are not recommended in the treatment of combat-related injuries [74]. Myodesis is the preferred method of soft tissue stabilization [39, 75]. To perform myodesis, muscular fascia is either sutured to the periosteum or reattached to the bone by drilling holes in the bone cortex. This technique allows to stabilize the muscle layer of the soft tissue envelope making it more stable and well padded. Myofascial closure and myoplasty may then be used to supplement primary myodesis.

33.6.7 Arteries

Initial bleeding control should be accomplished using direct pressure and tourniquet in acute presentations. Double ligation of transacted arteries, however, is often advocated as an early solution to secure bleeding from the larger vessels.

33.6.8 Nerves and Tendons

During initial wound care, both nerve and tendon length should be preserved as much as possible to allow for future reconstructions. When the level of amputation is determined and wound closure is to be performed, the level of neurotomy proximal to the wound can minimize risk of symptomatic neuroma formation. Their ends should be tagged with nonabsorbable sutures.

When a large nerve is to be cut, it is recommended to do ligation prior to transaction to minimize bleeding from the vasa vasorum.

33.6.9 Skin Management and Wound Closure

Wound closure is performed only when initial soft tissue inflammatory response to the trauma is passed and there is no angry, inflammatory tissue reaction. Closure of the wound is done in variety of ways. The important basic principle is not to complete skin closure under skin tension.

Pallor of the skin layer will be indicative of skin being overstretched. Inappropriate wound closure may result in skin necrosis leading to infection and possibly sepsis Fig. 33.6.

The unique skin-stretching technology and device may apply both stress relaxation and mechanical creep for delayed primary closure of large skin defects which otherwise would have required closure by skin grafts, flaps, or free tissue transfer (Fig. 33.7) [99]. These types of devices employ distribution of dynamic, selective, vector-oriented forces over a wide area of attachment, continuously or cyclically, in both noninvasive and invasive attachment to the skin, so that surrounding skin can be stretched, allowing safe primary closure of wound margins by conventional methods. The notable advantages of using this system for external skin stretching include:

1. The application of both acute intraoperative stress relaxation and pre- and postoperative mechanical creep for high- and low-tension wound closure, respectively.
2. It serves as a topical tension-relief platform for tension sutures, alleviating the typical tearing and scarring inflicted by tension sutures.
3. Undermining of the skin edges and adjacent tissue can be avoided, minimizing compromise to skin viability and reduce the risk of infection.
4. Skin can be further approximated as a bedside procedure by mechanical creep.
5. Surgical technique is simplified.

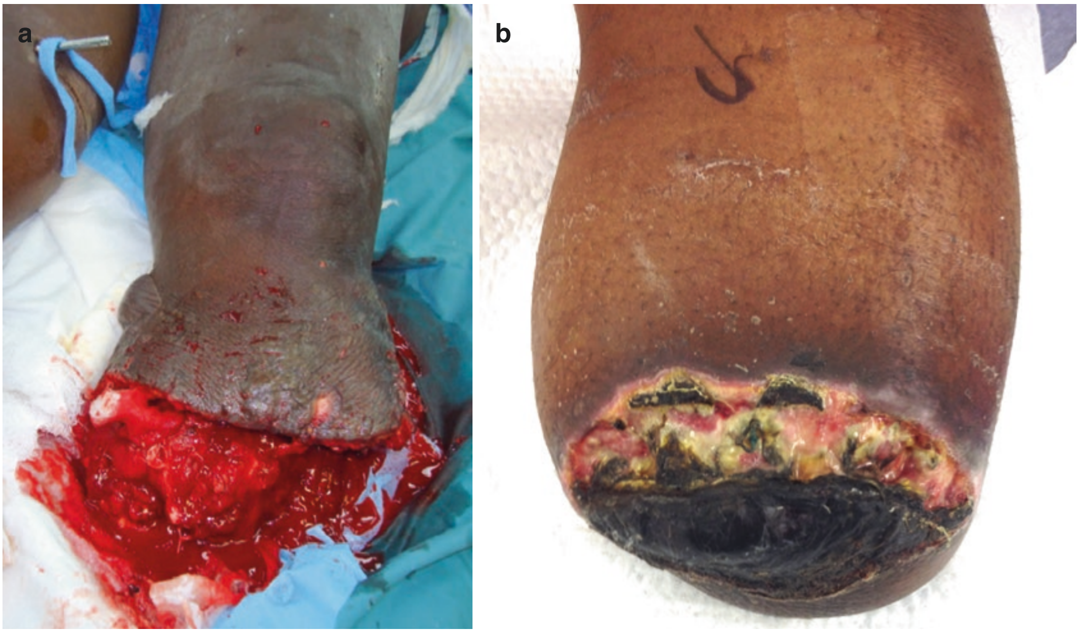


Fig. 33.6 (**a**, **b**) Amputation wounds closed prematurely dehisced, necrotic, and infected

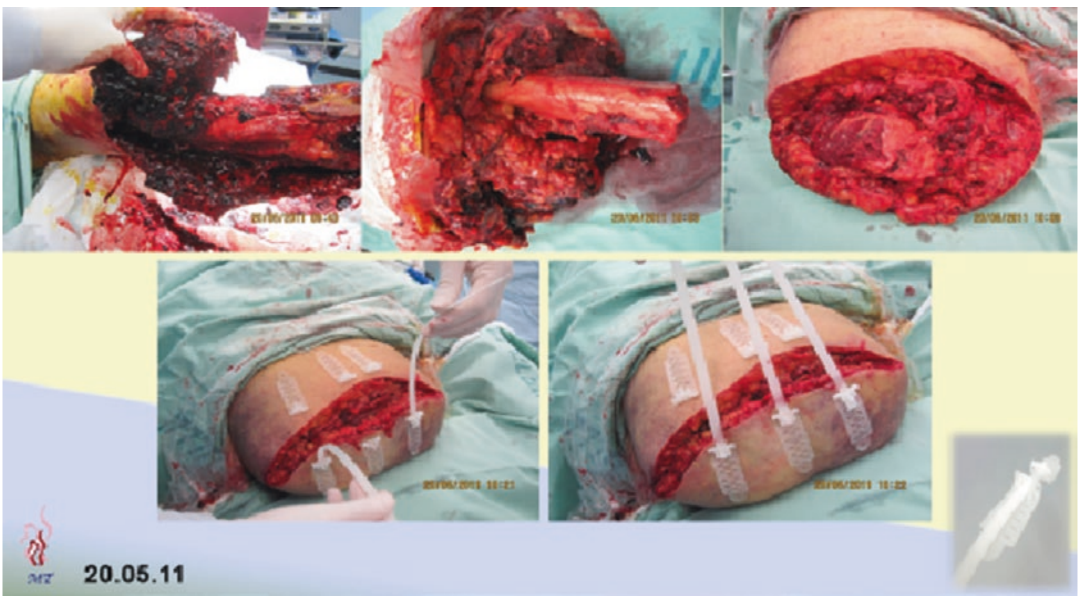


Fig. 33.7 Gradual primary wound closure

6. Drainage of hematoma or infection can be easily performed bedside together with dressing change and delayed closure of the wound.

The weight-bearing area of the residual limb should be sensate and actively controlled.

Scars should not be located in the weight-bearing areas of the residual limb.

Avoidance of significant *flexion contractures* should be taken into account.

33.7 Upper Extremity Amputations

Salvage of the upper extremity versus amputation has paramount importance in patients with severe injury. While planning upper extremity amputation, the surgeon should aim for a pain-free functional extremity. Preservation of maximal limb length is a key.

33.7.1 Finger and Ray Amputations

33.7.1.1 Fingertips

Based on the pattern of the injury, the fingertip is either left to heal by secondary intention or soft tissue coverage achieved by either local flap or skin graft (Fig. 33.8a, b).

33.7.1.2 Digits

Index Finger

Distal to PIP Joint: tissue is debrided, digital nerves are identified and allowed to retract proximally, and bone is shortened to allow to close skin preferably on the dorsal surface of the digit.

Proximal to PIP joint amputation: consider either similar to distal to PIP joint approach or, if no finger prosthesis will be available, perform index ray amputation transecting second metacarpal. This will improve hand function.

In case of multiple finger injuries, an attempt should be made to salvage affected digits.

33.7.2 Wrist Disarticulation

Between transradial amputation and wrist disarticulation, priority is given to wrist disarticulation.

The main reason is preservation of pronation and supination.

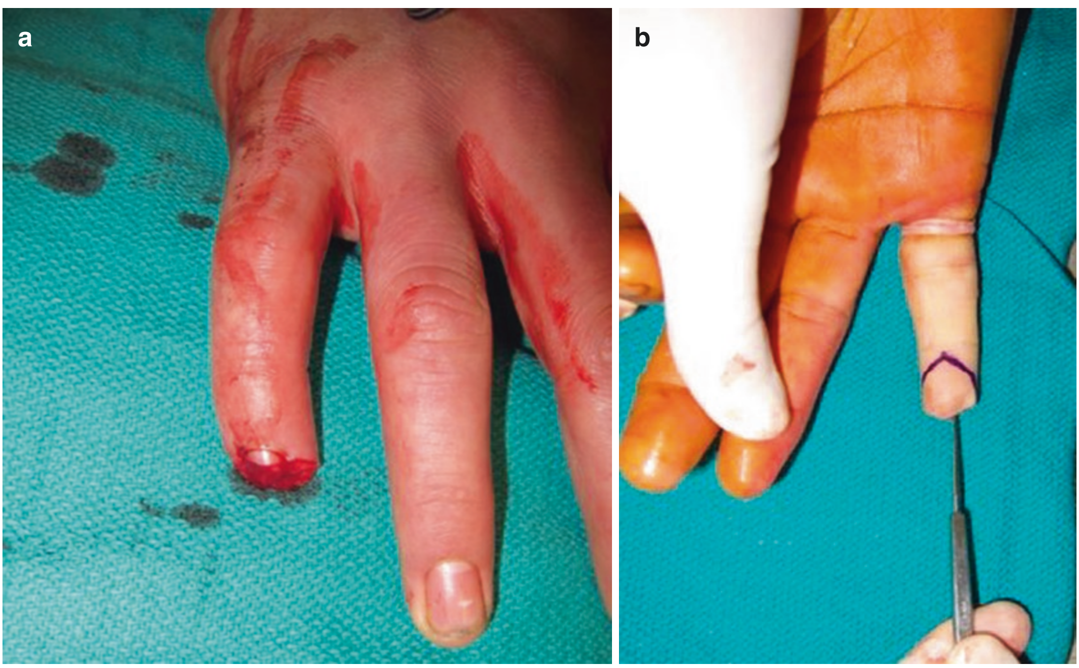


Fig. 33.8 (**a**, **b**) Fingertip amputation

The following are the steps:

1. Prep and drape arm as high as axilla.
2. Tourniquet is used and applied to appropriate level of pressure (100 mmHg above systolic pressure).
3. Longer palmar and shorter dorsal flaps are created (2:1). Radial and ulnar arteries should be identified and double-ligated proximal to the level of wrist. Radial, ulnar, and median nerve should be identified, infiltrated with local anesthetic, and transected as proximal as possible. All tendons should be transected at the wrist level.
4. Radial and ulnar styloids are excised.
5. Hemostasis is performed.
6. Wound closure. Drain is used and skin closed with 2.0–3.0 Nylon
7. Dressing: Petroleum-based dressing is applied on the incision site, followed by a gauze and then bandage in a snug but not very tight fashion to prevent swelling but not to create excessively painful compression to the stump. Drain is removed in 24–48 h and sutures in 14–20 days.

33.7.3 Forearm Amputation

The longer the stump, the better range of motion.

The steps are similar to the wrist except the flaps are equal in length. Fishmouth incision is made.

Flexor digitorum superficialis (FDS) flap is then fashioned long enough to be carried around bone ends. Other muscles sectioned at the level of the bone. FDS is sutured to the dorsal fascia.

Ulna is left slightly (1–3 cm) longer than radius in the proximal forearm, while radius is left longer than ulna in the distal forearm.

Similar technique for the wound closure and dressing is applied.

If appropriate microvascular expertise is available, replantation is performed. Elbow function is of highest priority. At least 4–5 cm of the ulna is needed for the elbow function (Fig. 33.9a–g).

33.7.4 Transhumeral Amputation

As much of the length of the humerus as possible is preserved. Humerus is amputated at least 4 cm proximal to the elbow joint to allow appropriate prosthesis placement. Posterior and anterior fishmouth skin flaps are created. Posterior triceps muscle is cut about 4–5 cm distal to the humerus cut, while anterior muscle flap is about 1.5 cm distal. After thorough debridement, vascular ligation and nerve cuts wound is covered with sterile non-obstructive dressing. It is then closed in a staged fashion.

33.8 Lower Extremity Amputations

When an amputation is performed above the ankle, the transtibial below-knee amputation is considered to be the most effective compared to transfemoral amputations. This is carried out for the preservation of the knee joint, adequate oxygen consumption [16], and reduced perioperative mortality [76].

Attempts should always be made to preserve the lower limb at the lowest possible level. The shortest length for below-knee amputation should be at the level of the tibial tubercle, so that the extensor knee mechanism is preserved. When performing the definitive closure of the amputation, better stump shape and easier prosthetic fit are achieved with a residual tibial length of 15 cm or less [60, 77].

If prosthetic service is available following amputation, below-knee amputation is the preferred option. If there is no access to prosthetic fitting and injury is to the foot while the hindfoot plantar skin is preserved, the choice is between Pirogoff, Syme, and Chopart amputation [93]. This may allow patients to ambulate and weight bear without a prosthesis [95].

Fig. 33.9 (**a**–**g**) Forearm replantation

33.8.1 Below-Knee Amputation

33.8.1.1 General Principles

This the most common type of trauma-related lower limb amputation, both on the battlefield and in civilian life. Blast, mainly from a land mine or booby trap, is one of the most common mechanisms. In natural disasters it is often a crush injury and mangled extremity with open fracture/fractures.

Because of the nature of the battlefield and wounds caused by blast injury, a guillotine amputation was commonly used in the past. Experience of the recent years both in the military settings and during natural disaster does not support this method of amputation in disasters [7]. Wound complications following this technique are high due to different reasons, including soft tissue retraction, exposed bone, and others.

The following is required to have below-knee amputation leading to functional lower extremity [67]:

1. A functional knee joint with no more than 20° loss of extension
2. A proximal tibia with a patellar tendon attachment
3. An adequate soft tissue envelope with the mobile muscle covering distal end of residual limb
4. Full-thickness skin covering load transfer areas

In some instances, when the proximal tibial fragment is short and/or there is soft tissue deficiency to cover the distal stump, osteoperiosteal grafts that have been harvested from the removed limb can be used in the case of primary amputations. An unstable proximal tibiofibular joint in the case of a short residual limb can lead to the lateral displacement of the fibula due to the pull of the biceps femoris, which may cause prosthesis wear difficulties. This is addressed by the arthrodesis of the proximal tibiofibular joint. Another way of creating a more sturdy and even "end-bearing" stump is by making a distal synostosis between tibia and fibula, which is a technique modernized and popularized by Ertl [78], Dederich [79], and others [80, 81]. In recent years, the "Ertl's technique" has gained more popularity mainly due to the stable weight-bearing platform.

33.8.1.2 Amputation Technique

The level of amputation is determined mainly by the extent of the soft tissue injury. All reasonable attempts should be made to save tibial tubercle, so that active knee motion will be possible. Modern prostheses take advantage of the longer residual limb.

Different techniques are use to performed below-knee amputation. We prefer technique described by Burgess [99].

No matter what type of amputation is performed, the skin flaps must be created with enough length to avoid closure under the tension. We prefer long posterior flap about 7 cm longer than limb diameter (Fig. 33.10).

A muscular cut is made approx. 5–7 cm distal to the bone transection, which allows for appropriate padding or bone coverage and myoplasty (suturing muscle, fascia to the anterior tibial cortex, via either periosteal layer or drilling holes through the cortex of the tibia for suture placement). By creating a myodesis effect (where the antagonistic muscles and fascia groups are sutured together), the triceps surae retraction risk is minimized. Posterior flap consists of medial and lateral gastrocnemius and soleus. Soleus debulking might be required to facilitate approximation of the wound edges.

No redundant soft tissue, neither "dog ears," nor crevices are created at the final closure of the wound.

The skin should not adhere to the underlying bone, and there will preferably be no scar formation in the areas of the prosthesis contact.

A bone cut is made with either a cooled power saw or Gigli saw. An approximately 45° bevel is made in the anterior tibial cortex and the cortical edges are smoothly contoured by using a bone file to prevent skin breakdown with prosthetic use. No periosteum is striped off the bone. No periosteum should be removed in order to prevent the formation of ring sequestra or bone overgrowth.

A fibular cut was traditionally made approximately 1 cm proximally to the tibial cut with proximal laterally facing facet. The creation of distal tibiofibular bridging may require this approach to be changed.

The major blood vessels are dissected and separately ligated by using double ties in order to prevent the development of arteriovenous fistulas and aneurysms.

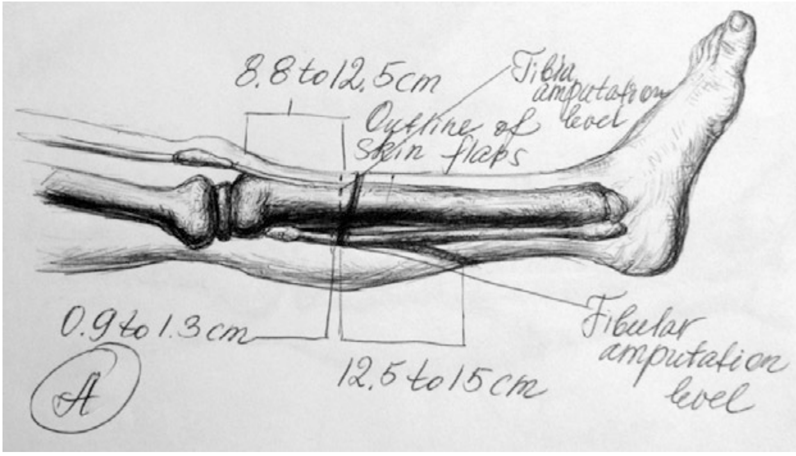


Fig. 33.10 Below-knee amputation with posterior flap

Tibial, superficial peroneal, deep peroneal, saphenous, and sural nerves should be transected 3–5 cm proximal to the level of amputation. The nerve ends are often injected with long-lasting anesthetics to reduce postoperative pain (Fig. 33.11). If bleeding from vasa nervorum is encountered it should be cauterized.

Different techniques had been introduced to overcome a problem of wound closure (Fig. 33.7) [96–98].

Prior to wound closure or the application of the dressing, the tourniquet is taken down and hemostasis is performed. The wound is irrigated with an irrigation solution of choice. A drain is placed for the prevention of hematoma. Nylon #3.0 or #2.0 sutures are used to close the skin. It is usually done is a stage fashion (Fig. 33.11a–c). After a sterile dressing is applied, the extremity is placed in plaster splints in extension, making sure that the patella is free of pressure [100]. Plaster is marked with the date of the surgery and any other instructions that might be needed (Fig. 33.12). The dressing and splint are changed between 2 and 10 days following surgery based on the condition of the wound at the time of closure.

33.8.1.3 Postoperative Management

As soon as the wound condition permits, a rigid light dressing is applied up to the mid-thigh while keeping the knee in extension. Adequate pain management is of major importance and a multidisciplinary team is needed to provide comprehensive care. For more specific types of flaps and types of amputations, we recommend the *Atlas of Amputations and Limb Deficiencies: Surgical, Prosthetic, and Rehabilitation Principles*, ed. 3 AAOS, [13].

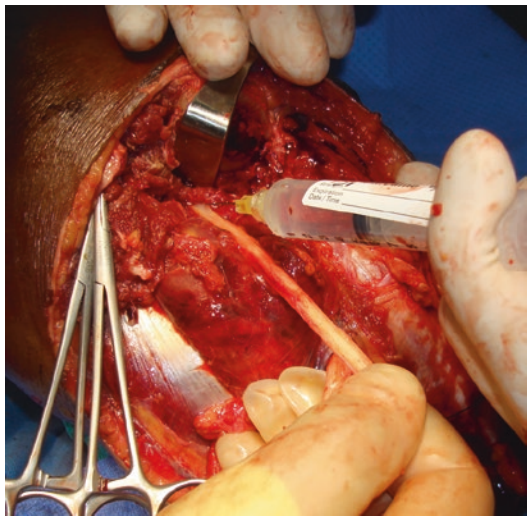


Fig. 33.11 Injection of tibial nerve with long-lasting anesthetic

33.8.2 Knee Disarticulation

Superior weight-bearing properties and better energy consumption favor knee disarticulation compared to above-knee amputations. However, difficulties with soft tissue coverage make this type of amputation challenging. More proximal reamputation is often required. Different surgi-

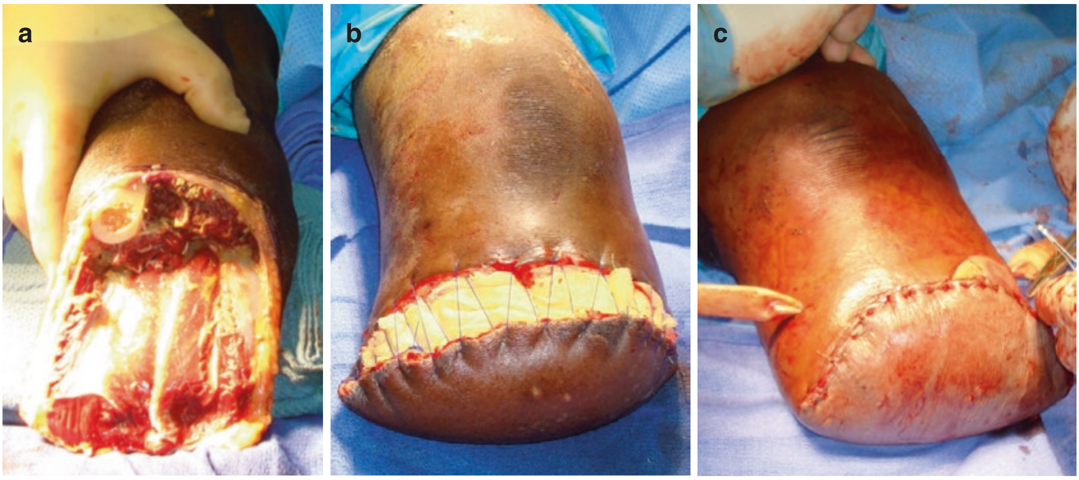


Fig. 33.12 (**a**–**c**) Staged wound closure

cal techniques [67, 68, 82–84] addressed the size and shape of the amputation stump and its coverage, so that an appropriate prosthesis can be used. This procedure is not used as often as transfemoral amputation due to inability to cover the distal femur with sufficient soft tissue. For this reason, the muscle-balanced transfemoral amputation is preferred. Application of the Circular cast with a window to accommodate potential knee swelling (Fig. 33.13).

Fig. 33.13 Application of the Plaster of Paris with open patella and mark of the operation date

33.8.3 Above-Knee (Transfemoral) Amputation

33.8.3.1 General

When the extent of the injury to the bone and soft tissues below the knee is so severe that it is impossible to reconstruct the residual limb, an above-knee transfemoral amputation is indicated. The velocity and cadence of the gait and increased energy expenditure make this type of amputation inferior to more distal amputations.

33.8.3.2 Level of Amputation

Preservation of maximal residual length is important for optimal prosthesis fit and function. If a more proximal amputation is required, the trochanteric part of the bone is saved to enable a better prosthetic fit. Muscle atrophy in a transfemoral amputation is a common occurrence and is related to both the residual limb length [85, 86] and the quality of the muscle stabilization [87]. The preservation of adductor magnus is important to maintain adduction strength and muscular balance.

33.8.3.3 Amputation Technique [88]

As in a transtibial amputation, the surgical approach is staged: after the initial surgery, the wound is left open and is definitively closed only when the soft tissue conditions permit.

If the femoral shaft is fractured, it should be reduced and fixed prior to the final closure.

The patient is positioned supine and the hip is flexed while supporting the thigh with a rolled sterile blanket.

A tourniquet is used but is deflated prior to final soft tissue closure in order to assure proper hemostasis.

A skin cut is performed in a way that no suture line and corresponding healing scar are placed at the distal end of the stump, which may interfere with the prosthesis use. We prefer "fishmouth" incision (Fig. 33.14a–c). The subcutaneous dissection is minimized to preserve perforating the fascial blood vessels.

The major blood vessels are dissected and separately ligated by using double ties in order to prevent the development of arteriovenous fistulas and aneurysms. They are cut at the level of bone cut.

The sciatic nerve is dissected, and if bleeding from the central vasa nervorum is encountered, it is either cauterized or ligated together with nerve as far as proximal as possible. Infiltrating the sciatic nerve with a long-acting local anesthetic may minimize postoperative pain [88]. Smaller nerves are dissected and cut proximal to the bone cut.

Muscles: The quadriceps femoris is cut at the tendinous portion just above the patella, and the adductus magnus is detached from the adduction

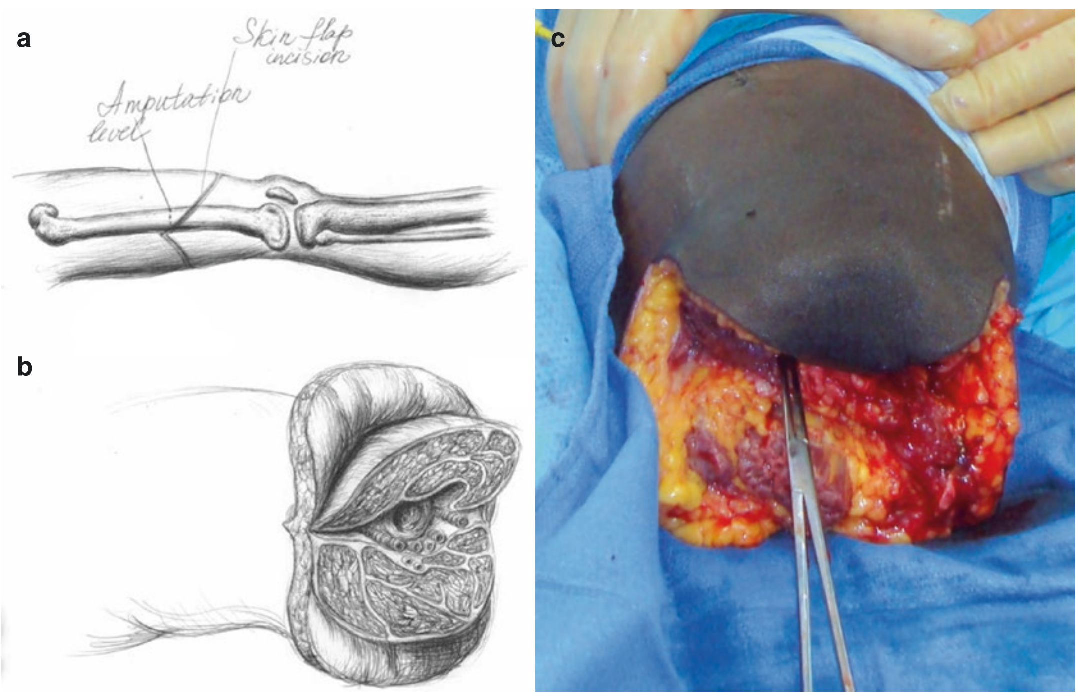


Fig. 33.14 (**a**–**c**) "Fishmouth" incision

tubercle and, if needed, from the linea aspera in order to allow for its transfer to the lateral cortex of the femur where it is anchored under slight tension. Hamstrings and posterior muscles are divided slightly distal to the bone section, while the tensor fascia is cut at the level of the bone section.

The myodesis and myoplasty of the adductor muscle are performed keeping the appropriate muscle tension. This is carried out by reattaching the adductor magnus to the lateral femoral cortex (Fig. 33.15a, b).

The bone edges are smoothened with a rasp and the wound is well irrigated after the tourniquet is deflated and final hemostasis is performed.

Based on the mechanism of the limb injury, closure of the wound is then addressed.

If the limb is damaged by a blast or crush injury, or patient is presented with delay and wound is either contaminated or infected, wound closure is then performed in stages. If treatment is in the austere environment and transfer to medical facility is delayed, skin traction may be used.

When closure is performed, the quadriceps is then wrapped around the distal femur and sutured posteriorly to the posterior deep fascia.

A drain is placed under the muscle flaps and brought lateral and proximal to the planned site of skin closure.

A sterile dressing is then applied. While a variety of dressings are available, we prefer to use semirigid dressing, utilizing a heavy plaster splint, which minimizes hip flexion and helps control swelling (Fig. 33.16a, b). The sutures are removed 2–3 weeks after the surgery. Temporary prosthesis fitting is carried out 5–8 weeks after the amputation.

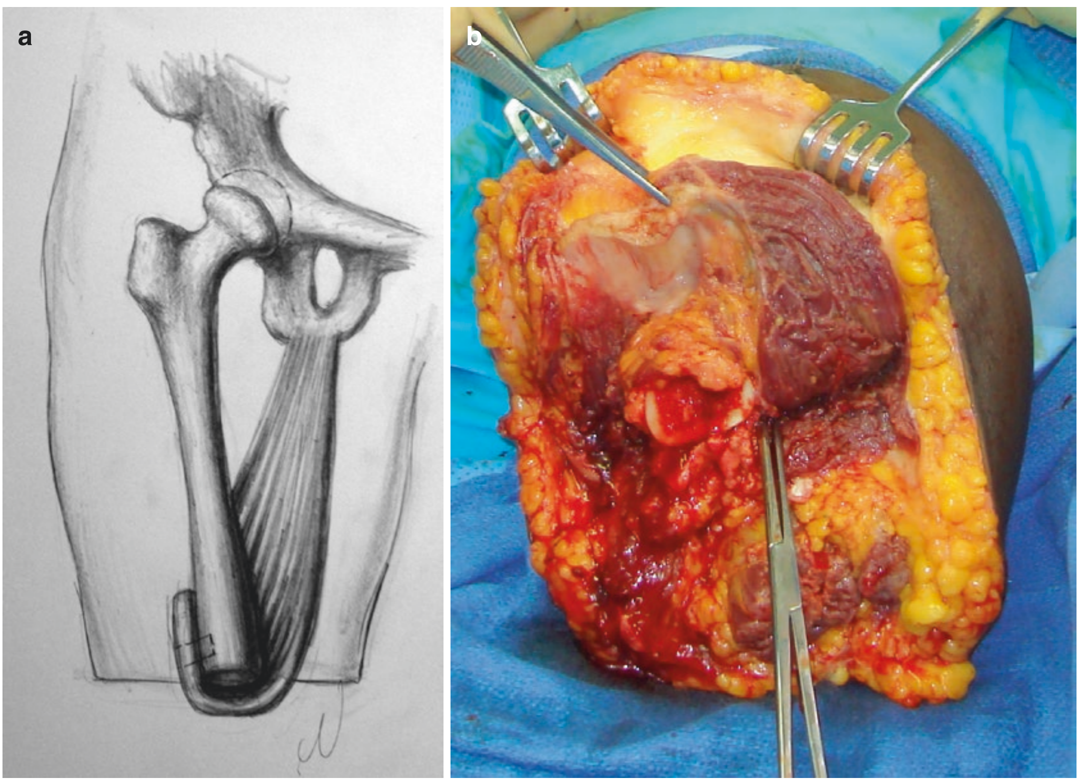


Fig. 33.15 (**a**, **b**) Reattaching the adductor magnus to the lateral femoral cortex

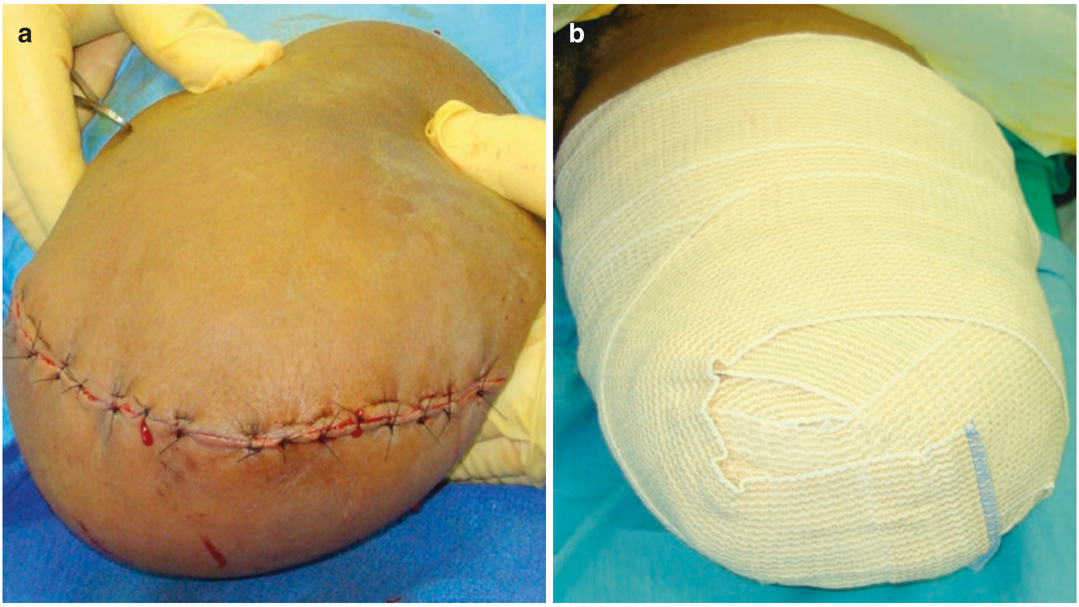


Fig. 33.16 (**a**, **b**) Semirigid dressing with heavy plaster splint

33.8.4 Hip Disarticulation

In a battlefield setting, or in an austere environment, this procedure can be required in case of a life-threatening hemorrhage or infection. It is usually performed in the regional center by a well-experienced and skilled team. There is very high risk of mortality when procedure is performed in the field hospital. For more detailed coverage of this particular subject, we recommend the *Atlas of Amputations and Limb Deficiencies: Surgical, Prosthetic, and Rehabilitation Principles*, ed. 3 AAOS, [13].

33.9 Complications

Hemorrhage and infection are complications common to all operations. Amputations also have certain unique complications.

33.9.1 Early Complications

The early complications of amputation are delayed hemorrhage, skin flap breakdown, and infection [90].

33.9.1.1 Delayed Hemorrhage

Postoperative bleeding at the stump site occurs due to a missed vessel, which retracts into the surrounding tissues, vasospasm, or failed suture ligation of arteries. When postoperative bleeding is noted, it is imperative to remove the dressing in order to visualize and suture the bleeding vessel. The wrong decision is to reinforce the dressing, which only serves to cover the offending vessel.

33.9.1.2 Skin Flap Breakdown

Skin flap breakdown is due to technical error or poor blood flow to the flap (Fig. 33.17). The technical errors include closing the stump under tension, aggressive handling of skin edges with instruments, and excessive use of the cautery device when achieving hemostasis. To avoid technical errors when performing definitive amputations (as opposed to a guillotine amputation), great care must be taken to plan the incision to allow for adequate skin flaps and to close the wound in multiple layers of absorbable suture to minimize tension at the skin level. Please refer to the section on amputation technique for a description of the process. In young trauma patients, such as those who suffer devastating extremity injuries in war zones, perfusion to the skin is

Fig. 33.17 Skin flap breakdown

rarely a challenge, but in elderly patients who undergo amputation for peripheral vascular disease, crush injury to the skin with aggressive use of instruments leads to necrosis at the approximated skin edges. Minimal or no use of forceps on the skin edges will help avoid this complication. Excessive cauterization near the wound edges causes focal areas of necrosis, which lead to skin breakdown. A lack of adequate skin coverage is at times a problem when trying to salvage a below-knee amputation. Microvascular free tissue transfer techniques are available to allow for myocutaneous free flap coverage of the distal tibia when primary wound closure cannot be achieved. It allows for adequate tissue coverage to avoid revision to an above-knee amputation [91].

33.9.1.3 Infection

Early surgical infection is a risk in all blast and crush amputation wounds (Fig. 33.18). Gas gangrene and necrotizing fasciitis are dreaded complications. Gas gangrene is caused by the alpha-toxin produced by *Clostridium perfringens*.

Fig. 33.18 Infected amputation stump

The alpha-toxin has been identified as phospholipase C confers the virulence to *G. perfringens* [25]. The recommended treatment of necrotizing fasciitis is intravenous wide-spectrum antibiotics, penicillin and clindamycin, and surgical debridement with supplemental hyperbaric oxygen treatment (HBO). One of the alternative ways to substitute for HBO in cases where HBO is contraindicated or not available is RO-NPT [26].

33.9.2 Late Complications

The late complications of an amputation include stump instability, ulceration, neuroma, heterotopic ossification, phantom limb pain, and contractures.

33.9.2.1 Stump Instability

Stump instability is due to an excess amount of muscle tissue left at the weight-bearing surface of the stump. The excess muscle acts as an unstable platform within the prosthesis, ultimately decreasing the utility of the prosthesis. Management of this complication is surgical excision of the excess muscle tissue followed by a repeat course of rehabilitation and prosthesis fitting.

33.9.2.2 Ulceration

Ulceration after surgery is a result of pressure on the skin at the stump from either immobility or from pressure in the prosthesis. Immobility pressure ulcers are usually the result of being bed bound. The posterior aspect of the stump ulcerates due to constant pressure. This may be avoided by floating the stump off the bed on pillows. Other methods to avoid immobility pressure ulcers include specialized pressure relieving mattresses and adjusting the position of the bed every 2 h. Prosthesis pressure ulcers occur because of (1) changing of the size of the stump over time and (2) lack of adequate tissue to cushion the tibia.

33.9.2.3 Neuroma

Neuroma formation after amputation is a debilitating complication that may prevent the patient from achieving maximum mobility [91]. The initial therapy is neuroma prevention, which is achieved through careful surgical technique and avoiding excessive stretch of the nerve and use of electrocautery on the nerve itself. The treatment of neuroma formation is a surgical excision or ultrasound-guided regional nerve blockade. Ultrasound guided peripheral nerve blockade with bupivacaine and methylprednisolone has been described with good results [21].

33.9.2.4 Heterotopic Ossification

Heterotopic bone formation is a well-described phenomenon that causes pain in the amputated limb [27]. The first descriptions of heterotopic osseous formation are from the American Civil War [28]. The presence of heterotopic bone in the adult population has been brought to the fore by the wars in Iraq and Afghanistan. In one study, 64 % of those patients who underwent an amputation for high-energy trauma developed heterotopic ossification [23]. Heterotopic bone formation may cause stump breakdown by causing pressure ulceration within the prosthesis. The treatment of heterotopic bone includes rest, refitting of stump sleeve, and ultimately excision of the heterotopic bone.

33.9.2.5 Phantom Limb Pain

Phantom limb pain for greater than 6 months occurs in up to 65 % of all patients who undergo an amputation. At 2 years, phantom pain was present in 59 % of patients [24]. In patients with existing pain, the limb pre-amputation has been found to have a higher incidence of postoperative phantom limb pain [24]. Fifty to eighty percent of American servicemen requiring amputation due to war-related injuries experience phantom limb pain [6]. A novel treatment approach is the use of mirror visual feedback therapy, which works to “shrink” the size of the phantom limb and ultimately the pain associated with the amputated limb [92].

33.9.2.6 Contractures

Contractures after an amputation are due to improper surgical technique leading to a muscular imbalance in the patient’s stump, a lack of proper fixation of the extremity in extension during the initial postoperative phase, and/or a lack of adequate physical therapy and rehabilitation [94]. Contractures are a severe problem because inability to fit the prosthesis may make it impossible to walk. A maximum of 20° angulation is allowed to achieve ambulation with below-knee prosthesis.

Conclusion

Choosing an amputation over a limb-sparing procedure should not be considered a failure of treatment, depending on the time of presentation to the treatment team a life-saving, function-preserving operation or a reconstructive operation. It is one of the most challenging decisions orthopedic surgeons face. Given the current geopolitical situation, it is very likely that surgeons will continue to be confronted with these complex decisions. The functional outcome following amputation is affected by the severity of injury, the quality of medical, surgical, rehabilitation, and prosthetic care, as well as psychological and social services support. Development of a team approach with each of these disciplines represented is recommended by the World Health Organization “classification and minimum standards for medical teams in sudden onset disasters."

After a sudden-onset disaster, in certain resource constrained, austere environment settings, for many severe extremity injuries, amputation is the most effective method to rapidly return the patient to an active and productive life. Time-permitting, exhaustive efforts should be dedicated to involve the patient if available, the family, and local religious and cultural authorities in the decision to amputate with long-term consequences of living as an amputee discussed and accepted.

The increased incidence of devastating extremity injuries due to high-velocity missile and blast injury and the widespread use of body armor continues to mandate amputation in the management of combat casualties. Aggressive debridement and careful attention to detail during the definitive amputation revision optimize the chances for successful rehabilitation. Advanced technologies such as RO-NPT together with TRS have been recently employed in order further reduce wound infection and allow for better tissue management for both avoiding amputation and downgrading complexity of the amputation surgery. More field experience and data are required to establish role of these new developments for a regular practical use.

Technical, cultural, facility, and surgical skill factors should all play significant roles in the decision-making process when amputation is considered. Given what we have learned to date, a staged approach to amputation should be implemented whenever possible to minimize the risk of local and systemic infection. Since field amputation is an evolving medical skill set that will inevitably grow with the increasing incidence of disaster, education from medical school through residency, and subsequent CME certification courses, in its purposes, techniques, planning, and approaches should be of critical importance to all orthopedic surgeons.

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Nonunion and Osteomyelitis Following Fractures

34

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34.1 Introduction

Natural disasters generate often high-energy trauma, leading to fractures of the bones and significant damage to the surrounding soft tissues. Bone is the only tissue that can heal without scar formation; however, this prerequisites optimum conditions. The higher the energy of the trauma, the less optimum conditions for healing occur. Knowledge of normal bone healing and the reasons for nonunion and osteomyelitis may help the surgeon to better plan the management of these complications. The lack of a normal healing process during the inflammation phase leads to an atrophic nonunion, whereas it leads to a hypertrophic nonunion if it occurs during the bone healing repair phase.

A fractured bone needs mechanical stability, biological sufficiency, and contact between properly aligned fragments for healing to occur. Bone defects or severe displacement of the fragments, infection, insufficient local blood supply, usage of steroids and nonsteroidal anti-inflammatories [1], radiotherapy, soft tissue problems, and atrophic muscles and contractures may negatively impact the healing process.

Delayed union is a term used for a fracture that has not united within a period of time that is considered adequate for bone healing; the union is slow but will eventually occur without additional surgical or nonsurgical intervention. Thus, delayed union is mainly a clinical diagnosis [2]. According to the FDA, a diagnosis of nonunion may be established "when a minimum of 9 months has elapsed since injury and the fracture shows no visible progressive signs of healing for 3 months." The time frame, however, is different for different fractures. A fracture of the tibial shaft is not considered a nonunion until at least 9 months, whereas a fracture of the femoral neck can be defined as a nonunion after just 3 months. Tibial diaphyseal fractures that do not exhibit sufficient bridging callus to achieve clinical stability by 16 weeks are considered to be delayed union fractures [3]. On the other hand, nonunion refers to a fracture that will not unite without additional surgical or nonsurgical intervention (usually by 6–9 months). Of the long bones, the tibia is the most common site for nonunion development.

Bone necrosis, damage to adjacent tissue, and penetration of bacteria are the prominent

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_34

etiological features associated with the onset of osteomyelitis. Thus, patients with infected nonunion usually have had numerous previous surgical interventions, resulting in bone defects and soft tissue compromise. Beginning with Papineau, many treatment modalities have been described for the treatment of osteomyelitis [4, 5]. Current knowledge depicts that the only cure for osteomyelitis can be obtained with radical debridement until reaching live and bleeding bone [6].

34.2 Classification

34.2.1 Classification of Aseptic Nonunions

The most widely used classifications are the Weber–Cech system [7] (Figs. 34.1 and 34.2), Ilizarov's classification, and Paley's nonunion classification. The nonunion is classified according to radiographic appearance, which correlates with the fracture biology.

- *Hypertrophic* nonunions are characterized by abundant callus formation. These nonunions are hypervascular and offer excellent healing potential given the right environment (Fig. 34.3). They result from insufficient mechanical stability caused by insecure fixation, insufficient immobilization, or premature weight bearing.
- *Atrophic* nonunions are characterized by an absence of callus and atrophic bone ends, which may be tapered and osteopenic or sclerotic (Fig. 34.4). Bone vascularity is deficient, and the bone suffers from poor healing potential. If there is a fibrous capsule around a freely mobile nonunion, filled with a viscous fluid and creating the appearance of a joint, then it is referred to as a *pseudarthrosis*. Atrophic nonunions result from insufficient blood supply to the bone fragments. It has been shown that the number of blood vessels in atrophic nonunions reaches the same level as in healing bone but at a later timepoint. Diminished vascularity within the first 3 weeks, but not at a later timepoint, may prevent fractures from uniting [8].

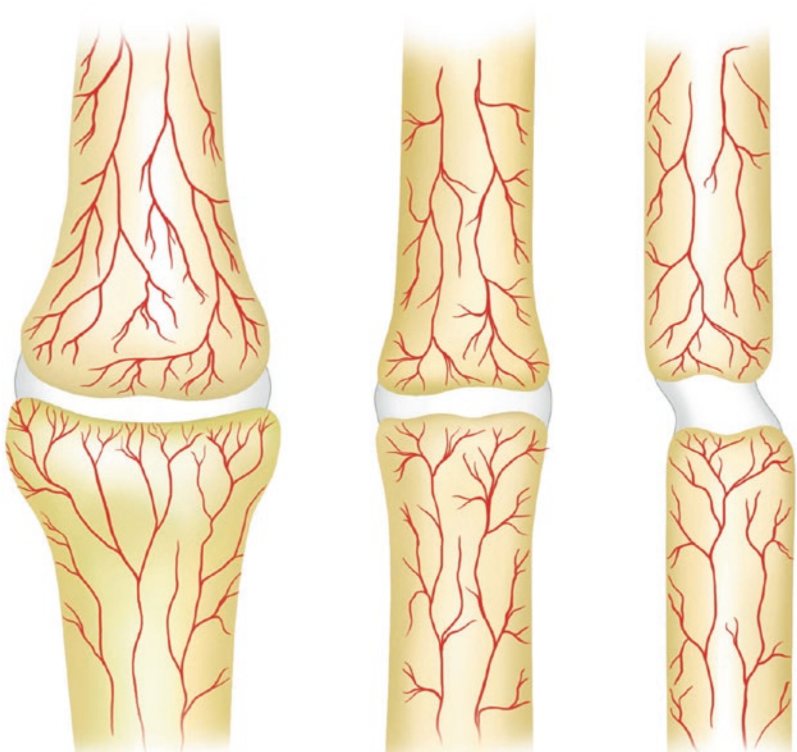

Fig. 34.1 *Vascular nonunions according to the Weber–Cech Classification*: "elephant foot," "horse hoof," and oligotrophic nonunion (from *left to right*)

Fig. 34.2 *Avascular nonunions according to the Weber–Cech Classification*: torsion wedge, comminuted, defect, and atrophic nonunion (from *left to right*)

Fig. 34.3 A patient x-ray showing hypertrophic nonunion of the femur

Fig. 34.4 A patient x-ray exhibiting atrophic nonunion of the humerus

- *Normotrophic* nonunions share the characteristics of both atrophic and hypertrophic nonunions. The bone ends exhibit moderate healing potential (Fig. 34.5).

Ilizarov classified nonunions into two categories: lax and stiff. Lax nonunions have radiologically apparent atrophic bone ends, they exhibit pathological movement at more than 7°, and they exhibit shortening of more than 2 cm. On the other hand, stiff nonunions feature hypertrophic bone ends, pathological movement of less than 7°, and shortening of less than 2 cm [9].

Another recent classification for tibial nonunions was described by Paley and Herzenberg in terms of clinical *mobility*, which roughly correlates with the three categories of Weber–Cech Classification (Fig. 34.6). Although initially described only for tibial nonunions, this classification may be applied to nonunions of other bones. In this classification, there are two major types: type A, bone defect of less than 1 cm, and type B, bone defect of more than 1 cm.

Fig. 34.5 A patient x-ray exhibiting normotrophic nonunion of the femur

A1: Lax (mobile) (Fig. 34.7)
A2: Stiff (nonmobile)
  A2-1: No deformity
  A2-2: Fixed deformity
B1: Bone defect and no shortening
B2: Shortening and no bone defect
B3: Bone defect and shortening

34.2.2 Classification of Chronic Osteomyelitis

In 1985, Cierny and Mader developed a staging system for adult patients with osteomyelitis based on the anatomical type of osteomyelitis and physiological class (Table 34.1) [10]. Host factors may be modified with medical or adjuvant surgical treatment, such as soft tissue flaps, and such alterations may positively influence the outcome of the treatment.

34.3 Evaluation

34.3.1 Clinical Evaluation

Clinical evaluation of the nonunited segment includes an inspection for gross deformity, overall alignment, venous stasis, and lymphedema. A complete neurovascular examination must be carried out, documenting the peripheric pulse status. The motor function and the sensitivity of the skin of the affected limb are checked.

Table 34.1 The University of Texas medical branch staging system for adult osteomyelitis

Anatomic type	Physiological class
Type I: Medullary osteomyelitis	A host: Good immune system and delivery
Type II: Superficial osteomyelitis	B host: Compromised locally (B^L) or systemically (B^S)
Type III: Localized osteomyelitis	C host: Requires suppressive or no treatment; treatment would cause more damage than the disease itself
Type IV: Diffuse osteomyelitis	–

Fig. 34.6 Tibial nonunion classification described by Paley: Lax (A1), stiff without deformity (A2-1) and stiff with fixed deformity (A2-2) (upper row, from *left to right*). Bone defect without shortening (B1), shortening without bone defect (B2), and bone defect with shortening (B3) (lower row from *left to right*)

Fig. 34.7 A patient with a lax humeral nonunion

- Obtain arteriogram, if there are signs of local malnutrition.
- Obtain electromyography to evaluate and document the neurological status when needed.
- Check for limb length discrepancy.
- Inspect the skin for the presence, location, and healing status of previous wounds and incisions (Fig. 34.8).
- Establish the location of pain.
- Assess the pathological motion produced by the manual stress test applied to the nonunion site.
- Check and document any contracture at the adjacent joints.
- Photographic documentation is very useful for treatment planning (Fig. 34.9).

All systemic and local factors that compromise wound and bone healing should be investigated [10] (Table 34.2).

34.3.2 Radiological Evaluation

- Obtain true anteroposterior and lateral x-rays of the affected limb segment.
- Orthoroentgenogram helps to document and measure limb length discrepancy and deformity (Fig. 34.10).
- Stress x-rays are helpful to document motion across the nonunion site (Fig. 34.11a, b).

Fig. 34.8 A patient's tibia with trophic changes and fistule caused by osteomyelitis

Fig. 34.9 A patient's clinical picture showing the deformity and shortening

- Obtain a computerized tomography (CT) for subtle nonunions (Fig. 34.12).
- Bone scanning will identify increased uptake in viable nonunions but decreased uptake in nonviable nonunions (Fig. 34.13). Synovial pseudarthrosis typically appears as a cold spot on bone scans. Indium-labeled leukocyte scanning may help to distinguish between infected and noninfected nonunions [11, 12]. Currently, NaF (natrium fluoride)-enhanced PET (positron emission tomography) is used for this purpose [13].
- If there is a sinus tract, a sinogram will help to determine whether it communicates with the nonunion site.
- A magnetic resonance imaging study is most helpful to show the presence of osteomyelitis and the status of the ligaments at adjacent joints. In addition, skip abscesses within the

Table 34.2 List of systemic and local factors that may compromise wound healing [10]

Systemic factors	Local factors
Malnutrition	Chronic lymphedema
Renal/liver failure	Venous stasis
Alcoholism	Major vessel compromise
Immunodeficiency	Arteritis
Chronic hypoxia	Extensive scarring
Malignancy	Radiation fibrosis
Extremes of age	–
Steroid therapy	–
Diabetes mellitus	–
Tobacco use	–

Fig. 34.10 Orthoroentgenogram of a patient with a femoral nonunion, causing deformity and shortening

medullary canal are properly displayed by an intravenous contrast-enhanced MRI, thus staging the extent of infection (Fig. 34.14).

- Ultrasonographic evaluation of callus formation is a useful alternative technique when an abnormal healing process is encountered. It allows for the evaluation of bone formation during the first 4 weeks, during which radiograms are not appropriate for this purpose. Because the ultrasonographic exam does not involve radiation, it can be repeated often and routinely [14].

34.3.3 Laboratory Studies

- Total blood count
- Erythrocyte sedimentation rate
- Quantitative CRP levels
- Total protein and albumin levels

Patients with low albumin and lymphocyte levels may need parenteral nutritional aids in addition to a high protein and high calorie diet.

34.4 Treatment

The process and outcome of bone repair is determined by the magnitude and interaction of the anabolic (bone forming) and catabolic (bone resorbing) responses [15]. Anabolic treatments can be mechanical (e.g., distraction osteogenesis, ultrasound), biological or pharmacological (e.g., bone morphogenetic proteins, parathyroid hormone), graft based (e.g., autologous bone graft, allograft), and cell based (e.g., bone marrow or mesenchymal stem cells, platelets, gene therapy). Anti-catabolic treatments are usually pharmacological, for example, the administration of bisphosphonates to inhibit resorption of osteoclasts.

Early referral to a tertiary center is recommended, since this may reduce the morbidity and duration of time off work for some patients [16].

As with the treatment of malignant tumors, one has to decide between specific local and systemic therapies [17]. In general, the treatment protocol should lead to:

- Local and systemic eradication of the infection
- A stable limb with a normal alignment
- Normal muscle function
- Normal joint motion

Principles of treatment for osteomyelitis can be incorporated in a staged protocol, often implemented by a multidisciplinary team consisting of an orthopedic surgeon, an infectious disease specialist, a plastic/microvascular sur-

Fig. 34.11 Stress x-rays of a humerus showing motion across the nonunion site **a** – valgus stress, **b** – varus stress applied

geon, and preferably a hyperbaric oxygen treatment specialist.

34.4.1 Debridement for Infected Nonunion

Radical debridement of all dead tissue, including skin, soft tissue, and bone, is required. An intraoperative injection of methylene blue dye into the fistula is performed (Fig. 34.15). Debridement is done until until bleeding and alive tissue is seen at the resection margins, to ensure that all foci of infection are removed [18, 19]. Viable bone is characterized by punctate bleeding, known as the "paprika sign" (Fig. 34.16). While using a high-speed burr for a thorough debridement, continuous cooling irrigation should be performed to prevent heat necrosis. This procedure should not be limited by concerns about the osseous and soft tissue defects. Specimens of purulent fluid, soft tissue, and bone from the infected area should be sent for aerobic and anaerobic cultures; it is also important to perform cultures for fungi and granulomatous infections in immunocompromised patients. The wound should be irrigated with a copious amount of saline solution, and antibiotics may be added to the terminal liter of the irrigation fluid [19]. After irrigation, all gowns, gloves, drapes, and instruments should be changed with a new, clean setup (double setup) [20].

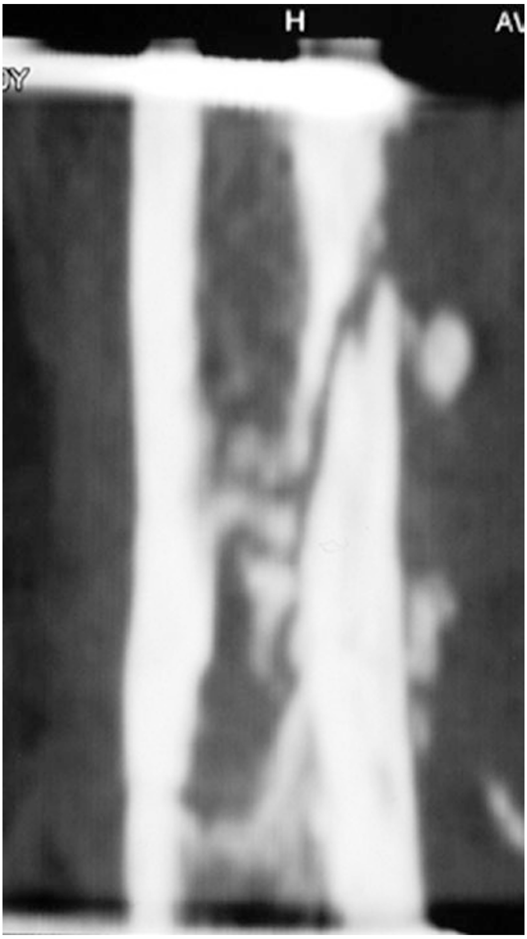

Fig. 34.12 A CT scan of the femur, confirming a subtle nonunion

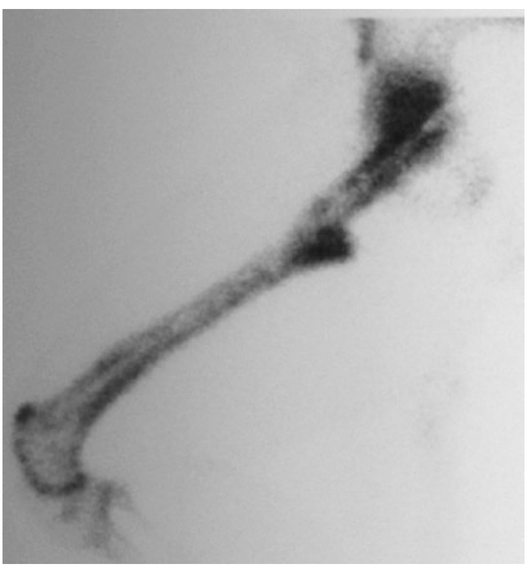

Fig. 34.13 Bone scan of a femur with nonunion showing increased uptake at the nonunion site

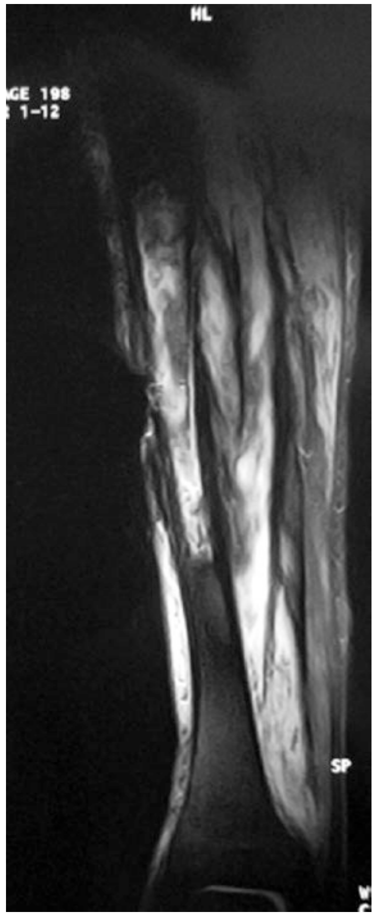

Fig. 34.14 Magnetic resonance imaging study shows the extent of the infection

Fig. 34.15 Perioperative injection of methylene blue through the fistule

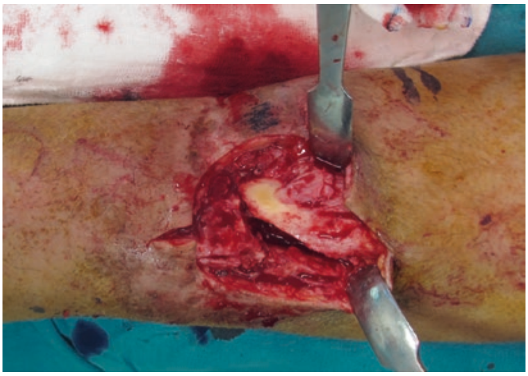

Fig. 34.16 The paprika sign: live bone is differentiated from the dead bone by the presence of punctate bleeding on the live bone

Fig. 34.17 Antibiotic beads placed into the dead space following resection

34.4.2 Antibiotic Beads

The dead space that results from debridement is filled with physician-made polymethylmethacrylate antibiotic-impregnated beads (Fig. 34.17). The pathogen must be susceptible to the eluted antibiotic. If wound closure is not possible, the wound containing antibiotic beads is sealed with a semipermeable membrane so that the eluted antibiotic remains in the involved area to achieve a high local concentration [21].

When a nonunion or bone defect is associated with infection, subsequent procedures for wound management and bone defect bridging are planned, and the beads can be removed at the time of final reconstruction.

34.4.3 The Existing Hardware

The decision to retain or remove implants from the site of an infected fracture must be individualized and depends on the time since the fracture fixation, bone healing status, stability provided by the hardware, and fracture location [18]. If the fracture has healed, the internal fixation device should be removed. However, if the fracture has not healed, the internal fixation device should be left in place as long as it is stabilizing the fracture. Loose hardware that is not providing stability should be removed. If the fracture has not healed and the hardware is removed, the fracture should be stabilized with another device; preferably, an external fixator should be utilized for nonunions in the tibia and nonunions with a bone defect.

34.4.4 Soft Tissue Consideration

In cases with an adequate soft tissue envelope, delayed or primary closure can be performed depending on the extent of infection. If soft tissues are compromised, coverage should be achieved with local or free muscle flaps. A new approach is to utilize negative pressure wound coverage techniques (NPWT) with a V.A.C device (KCI, San Antonio, TX). NPWT is often used because of its ability to reduce excess moisture in the wound, reducing bioburden and exposure to associated toxins. NPWT also increases cell proliferation (including proliferation of granulation tissue) and perfusion in the wound bed. NPWT also aids in contraction of the wound edges by gently stretching the skin [22]. This adjuvant in wound treatment aims to carry the soft tissue reconstruction procedure one step down in the reconstructive ladder, thus allowing a simpler technique, like allowing a local muscle flap instead of a free flap (Fig. 34.18a–c). The VAC Instill (KCI, San Antonio, TX) differs from

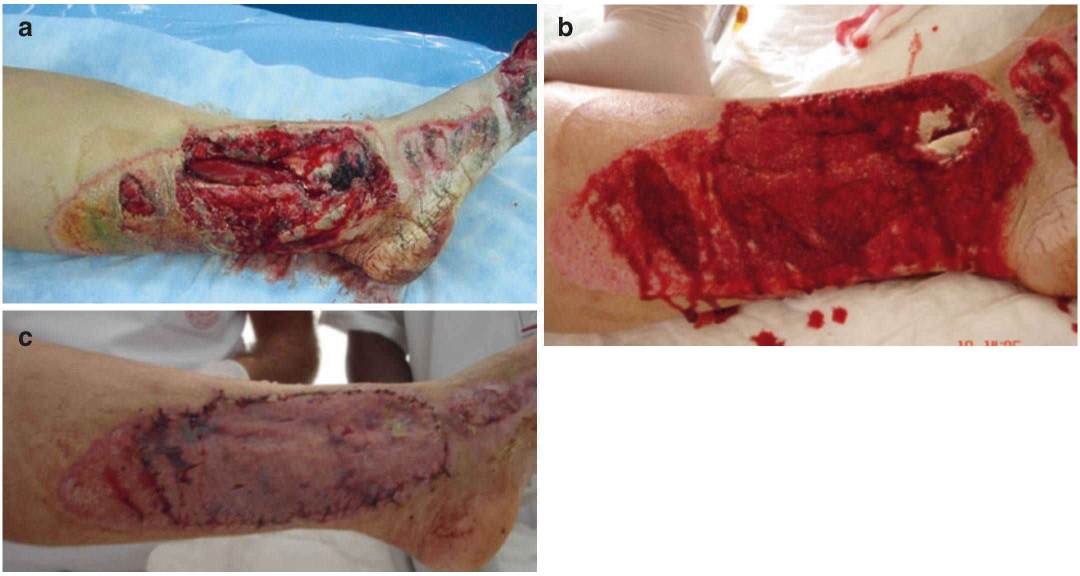

Fig. 34.18 Severe crush injury of the foot and ankle (**a**). The wound after VAC treatment (**b**). VAC treatment allowed for skin graft coverage in 14 days (**c**)

traditional VAC therapy because it allows the clinician to add solutions to the wound as well as apply negative pressure.

Depending on the size of the defect subsequent to radical debridement, type of soft tissue reconstruction is determined, ranging from split skin graft to free vascularized myocutaneous flaps. According to Heppert, soft tissue coverage options will depend on the following criteria [23]:

- The type of osteosynthesis
- The position and size of the soft tissue defect
- The local vascular status
- Patient compliance

34.4.5 Hyperbaric Oxygen Treatment

Another valuable adjuvant is hyperbaric oxygen treatment (HOT) [6]. HOT can be applied in some cases preoperatively along with systemic antibiotics, when there is severe inflammation with acute infection flare-up for 2–3 weeks. The operation can be delayed until a considerable drop of elevated white blood cell count, CRP (C-reactive protein), and ESR (erythrocyte sedimentation rate) levels. In patients who have been heavy smokers and who have a history of radiation treatment to the infection area and in patients with macro- or microangiopathies, HOT is continued for 30–40 sessions postoperatively.

34.4.6 External Fixation Modalities

Ilizarov asserted that distraction alone may be a potent stimulus, at least for nonunions of hypertrophic type. This assertion has been confirmed in the literature [24, 25]. It is possible to achieve stable fixation with the Ilizarov frame, even in the presence of osteopenia or bone defects. The newer hexapod external fixator systems are quite modular with the virtual hinge concept and guide the treatment with the help of an Internet-based software for precise correction (Smart Correction, Gotham Medical LLC, NJ, USA; Taylor Spatial Frame, Smith and Nephew Inc., Memphis, Tennessee, USA).

34.4.6.1 Monofocal Distraction

Monofocal distraction is most suitable for hypertrophic nonunions because they exhibit callus-

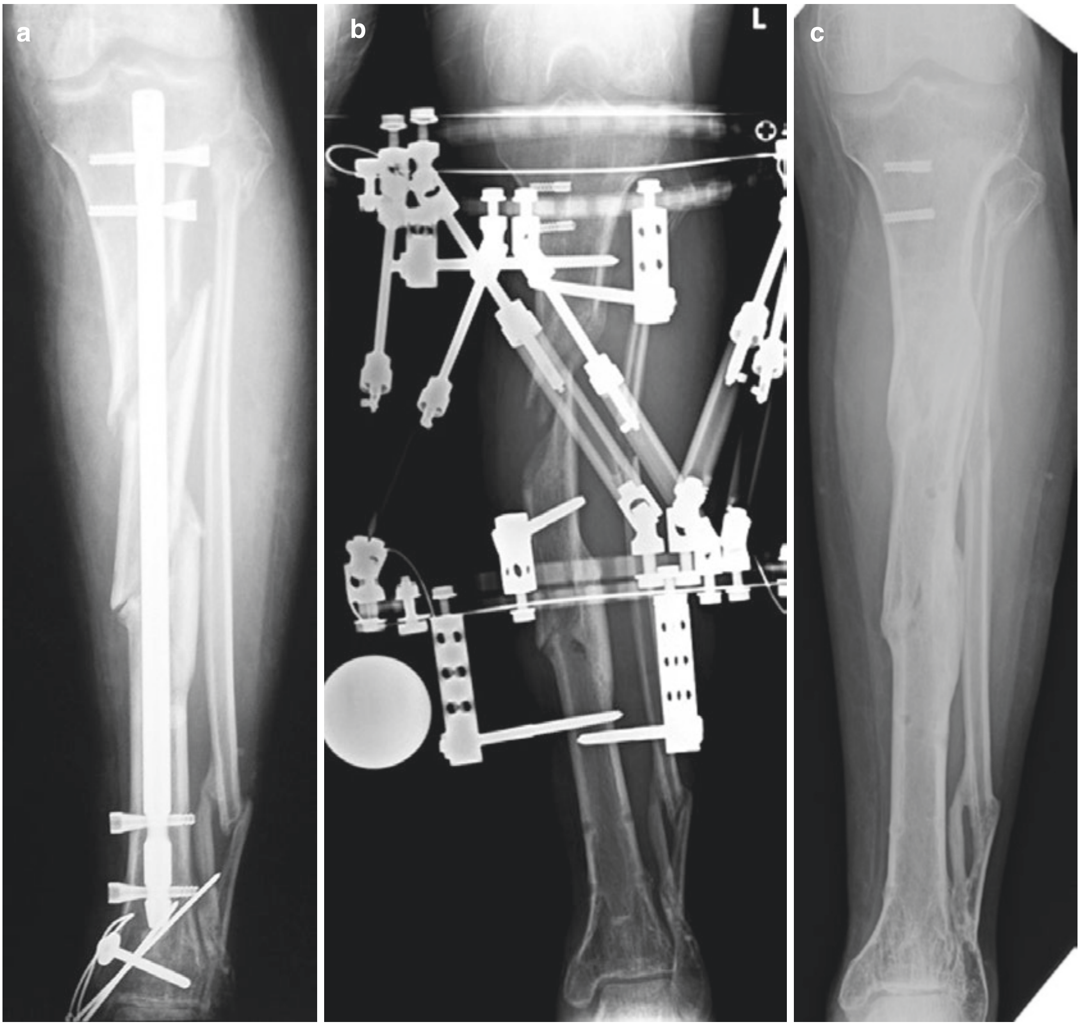

Fig. 34.19 Nonunion of the tibia following intramedullary nailing (**a**). Monofocal distraction using a hexapodal external fixator (**b**). Excellent healing was obtained following monofocal distraction (**c**)

forming capacity. If there is an angular deformity, eccentric distraction may be performed until the deformity is corrected, followed by longitudinal distraction until the desired amount of lengthening is achieved [26, 27] (Fig. 34.19a–c).

34.4.6.2 Consecutive Monofocal Compression Distraction

This method consists of alternating short periods of progressive distraction with periods of compression, which is also known as "callus massage" or the "accordion technique" [28, 29]. Raschke et al. recommend 0.5 mm of distraction per day for 7 days, followed by 1 mm compression per day for 7 days over a 4-week period. Our preference is distraction at a rate of 4 × 0.25 mm per day for 10 days, followed by a latency period of 10 days and compression at a rate of 2 × 0.25 mm for 20 days thereafter. These sequences may be repeated three times until bone healing is complete (Fig. 34.20a–e).

Monofocal compression distraction using external fixators can be appropriate for the treatment of humeral shaft nonunions, especially after failed plate fixation or in cases with severe shortening [30].

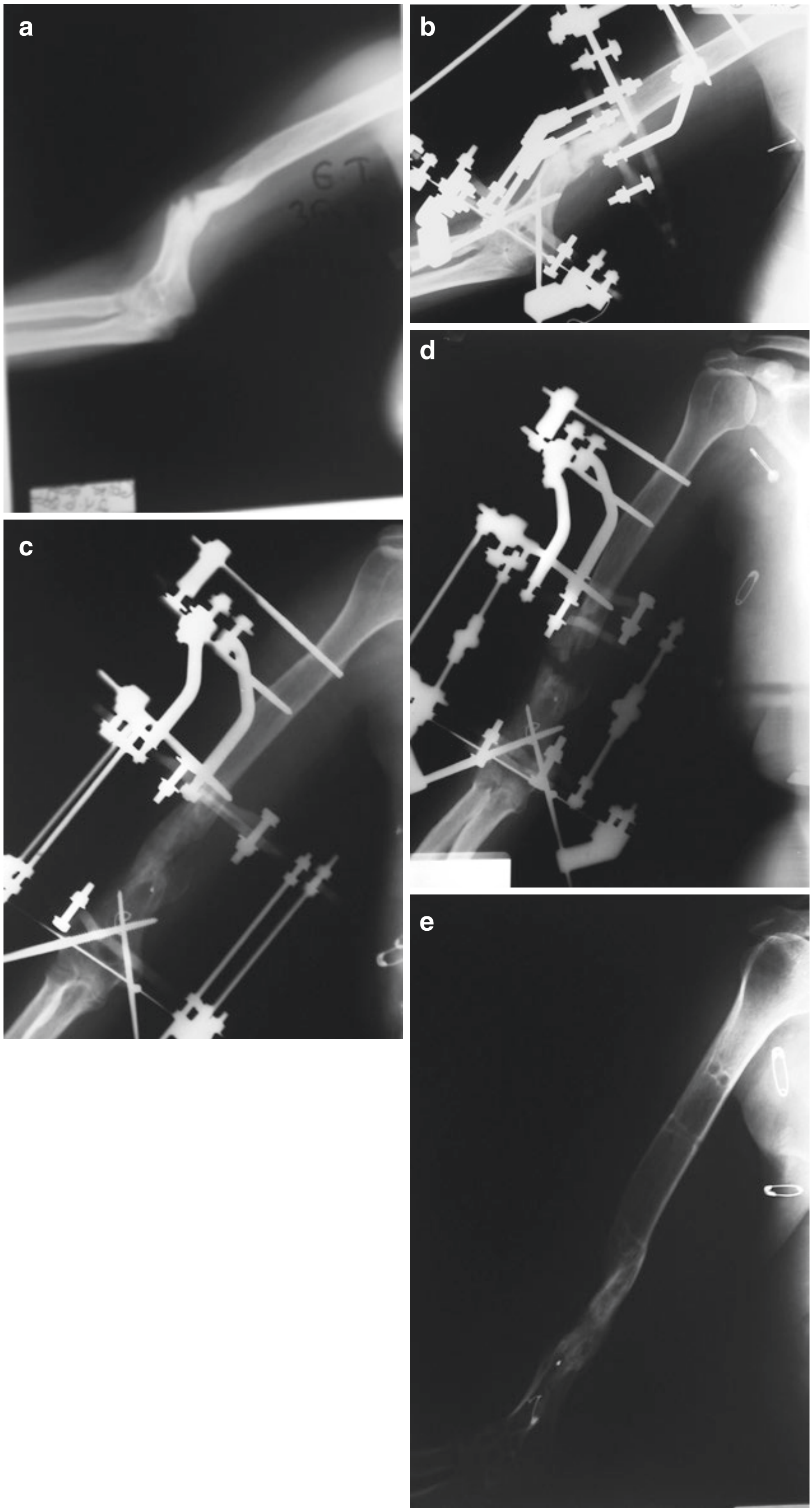

Fig. 34.20 A humeral nonunion (**a**). The deformity is corrected gradually by the use of a circular external fixator (**b**). Consecutive monofocal distraction (**c**) and compression (**d**) is applied (accordion technique). (**e**) X-ray at the end of the treatment

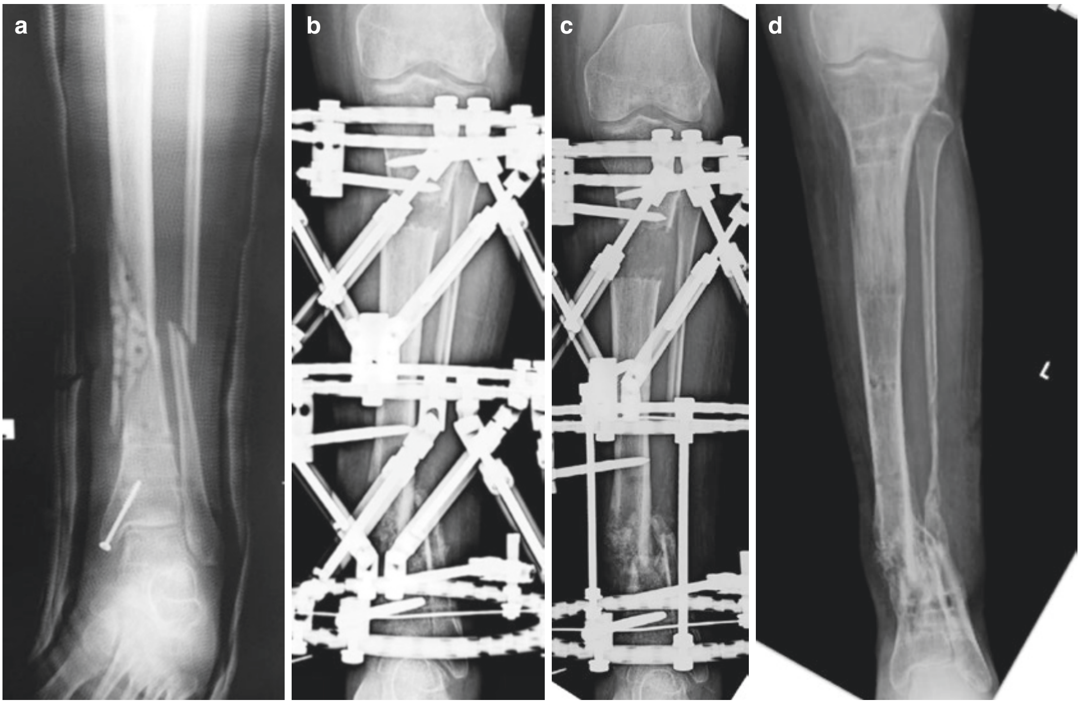

Fig. 34.21 A nonunion with sequestration at the tibia (**a**). The dead bone was removed, the defect was closed by acute shortening, and a proximal osteotomy was performed for gradual lengthening (**b**). Through lengthening at the proximal osteotomy site, the limb acquired its original length, and the docking site distally has healed (**c**). X-ray at the end of the treatment (**d**)

34.4.6.3 Bifocal Strategy: Acute Shortening and Gradual Lengthening

In cases with bone loss, acute shortening until the gap is closed followed by gradual lengthening through another osteotomy may be performed [27]. Our experience indicates that the safe limits for acute shortening are up to 4 cm in the tibia and 6–7 cm in the femur. If additional compression is required, it must be performed gradually at a rate of 2 mm/day. During the surgery, the arterial pulses of the foot, a Doppler ultrasound evaluation, capillary refill time, and oxygen saturation of the hallux help evaluate the circulatory status of the extremity. If these parameters deteriorate, the distraction must be reversed until normal circulatory status is achieved (Fig. 34.21a–d).

34.4.6.4 Fibula Transport

An alternative use of external fixation to bridge large tibia defects is transfer of the ipsilateral fibula transversely, using a circular external fixator and protecting its vascular pedicles. This technique should be applied with expertise in external fixation surgery. The technique is used in patients with massive defects of the tibia and an associated active infection (Fig. 34.22a–e). Complications are nonunion, shortening and anterior bow, and a stiff ankle joint [31].

34.4.7 Internal Fixation

34.4.7.1 Plate Osteosynthesis

Plate osteosynthesis provides stability and compression, which in turn minimize the motion and reduce the gap at the nonunion site. Several types of plates can be used to treat nonunions. Metaphyseal and specifically located aseptic nonunions with excellent soft tissue envelopes are the best indications for plate fixations (Fig. 34.23a, b).

Fig. 34.22 A tibial nonunion with hypertrophied fibula (**a**). Circular-type external fixator was applied, and the fibula is started to be transported distally (**b**). X-ray at the end of distal transport of the fibula (**c**). Then, proximal tibia was connected to the fibula by an intramedullary nail (**d**). X-ray at the end of the treatment (**e**)

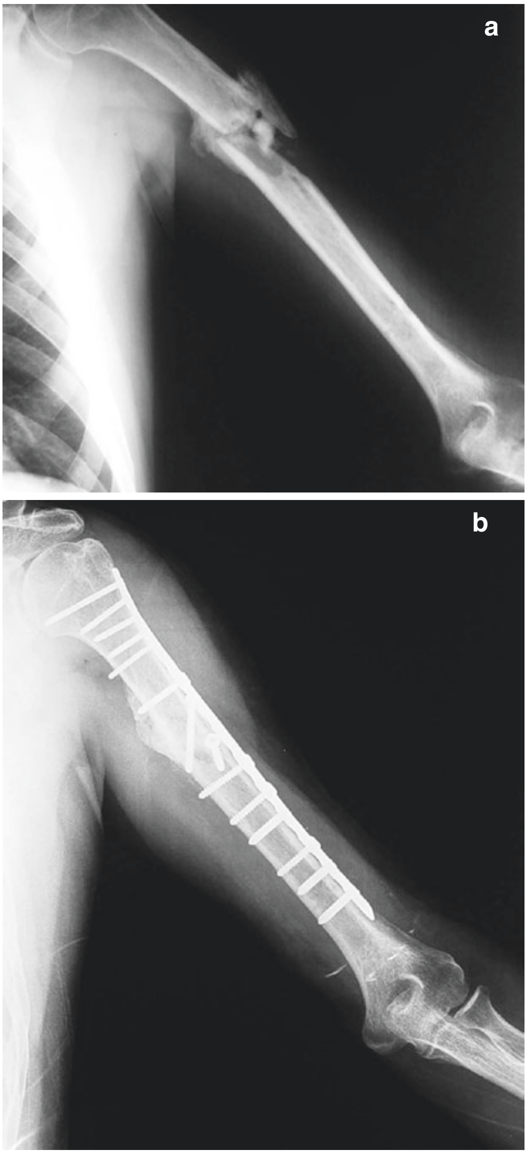

Fig. 34.23 A humeral fracture that failed to heal after conservative management (**a**). Plate fixation was performed (**b**)

A wave plate has been recommended by various authors, as it has a contour bent into its midportion so that it stands away from the bone at the abnormal area, thus providing biological and mechanical advantages; the local blood supply is preserved by reducing the amount of dissection and the area of plate–bone contact, and there is more space for autogenous bone grafts on the lateral cortex [32, 33]. Wave plates can be used in the presence of a complete segmental defect, as it will not fail until the bone graft consolidates because cyclic loading is distributed over a wide area rather than at a local fulcrum (Fig. 34.24).

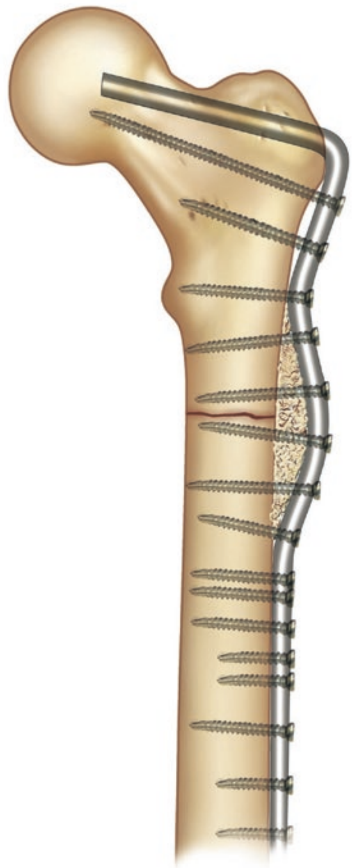

Fig. 34.24 Wave plate. Note that grafting was possible under the wave plate to the nonunion site

34.4.7.2 Exchange Nailing

Nonunion can occur following intramedullary nailing of the long bones in the lower extremities. Of note, it is more common if unreamed intramedullary nailing is used in femoral shaft fractures. Concerns about reaming include disruption of the cortical blood flow, thermal necrosis of the cortical bone, marrow immobilization due to elevated intramedullary pressure, and increased consumption of coagulation fac-

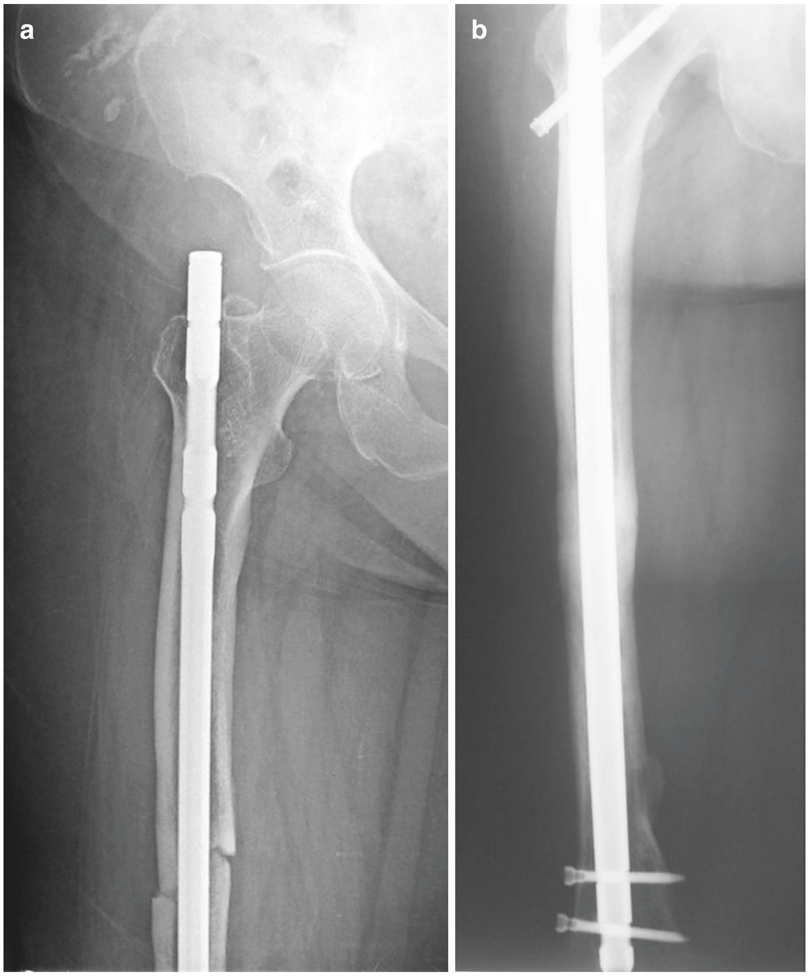

Fig. 34.25 A femoral shaft fracture was initially treated with intramedullary nailing (**a**). Exchange nailing resulted in union of the femur (**b**)

tors [15, 34–36]. Despite these concerns, clinical success of reamed intramedullary nailing has been confirmed by several studies [37–39]. Exchange nailing is a good choice for the nonunions of the long bones, which may be initially treated using an intramedullary nail (Fig. 34.25a, b).

The major technical details are as follows:

- Remove of the current intramedullary nail.
- Ream the canal: this provides internal grafting effect, increases periosteal blood circulation, and enables exchanging with a larger nail.
- Place a larger diameter intramedullary mail: this provides increased stability (higher bending rigidity and strength).

Main indications for exchange nailing:

- Aseptic diaphyseal femoral nonunions
- Proximal tibial nonunions
- Tibial shaft nonunions
- Distal tibial nonunions
- Lower extremity nonunions with angular or rotational deformities

Exchange nailing is not recommended for the treatment of humeral shaft and very distal femoral nonunions.

Failure to heal the nonunion may occur even following exchange nailing. In such patients, we prefer to remove the locking screws that are associated with the intramedullary nail and then to compress using a circular external fixator.

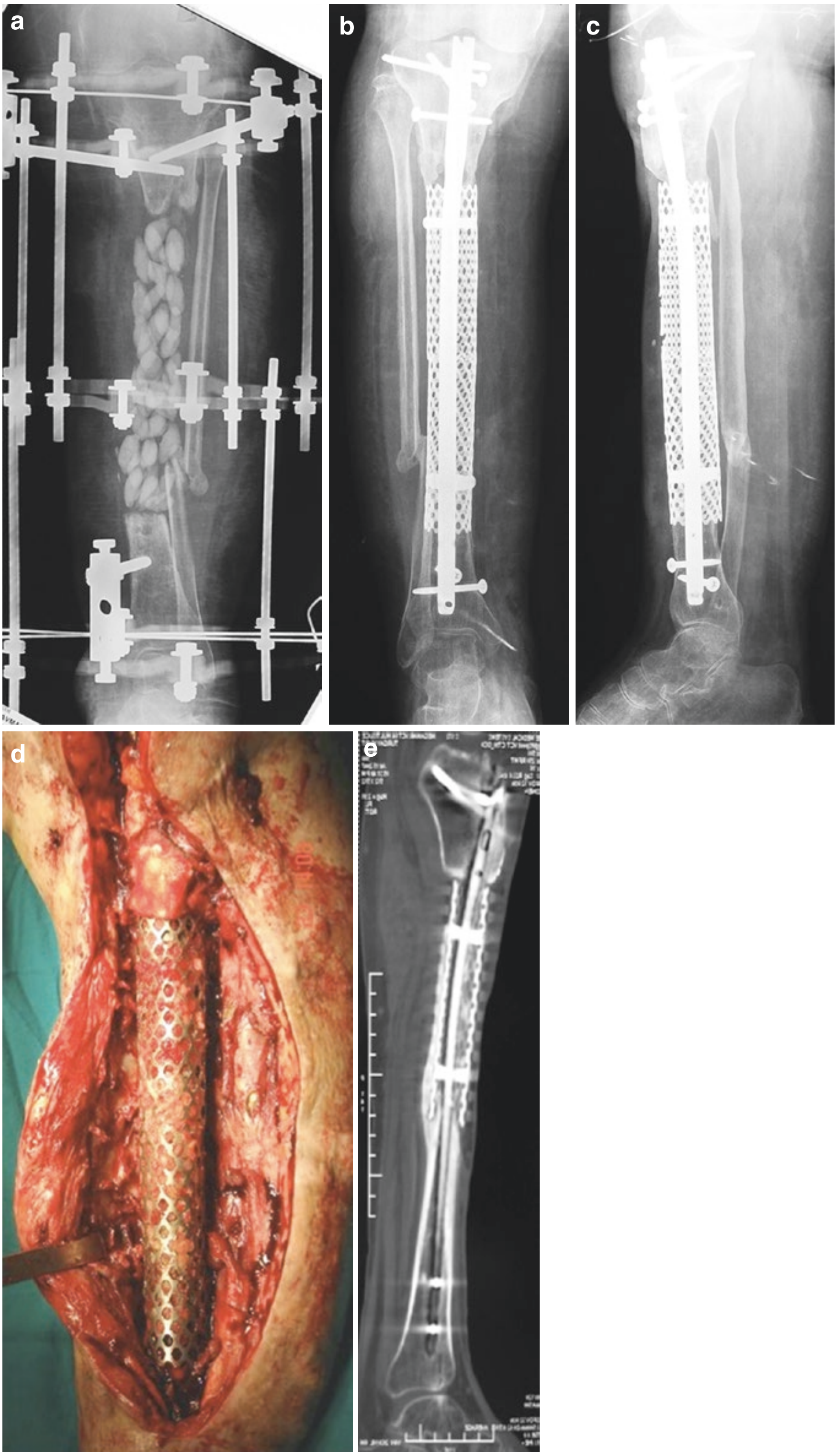

Fig. 34.26 A 33-year-old male patient with a C-M type IV-BL lesion presented with a 14-cm bone defect following Gustilo–Anderson GIIIB open tibia fracture after a car accident. (**a**) Radical debridement, temporary external fixation, and antibiotic-loaded PMMA beads. (**b**) Insertion of a titanium cage filled with DBM and cancellous autograft, fixed by a locked intramedullary nail (AP view). (**c**) Insertion of titanium cage filled with DBM and cancellous autograft, fixed by a locked intramedullary nail (lateral view). (**d**) Intraoperative view. (**e**) Postoperative sagittal CT scan at 1 year, displaying new bone formation around the cage

Fig. 34.27 A patient with an infected tibial nonunion. (**a**) Initial x-rays showing nonunion and deformity. (**b**) Photograph showing deformity, shortening, and fistule. (**c**) All infected dead bone is resected. (**d**) Antibiotic rod is inserted. (**e**) Antibiotic-impregnated beads are placed. (**f**) X-ray showing the antibiotic rod and beads in place. (**g**) Bone transport over nail technique: a proximal osteotomy is utilized and the middle segment is transported over an intramedullary nail with the help of a circular external fixator. (**h**) X-ray at the end of the treatment

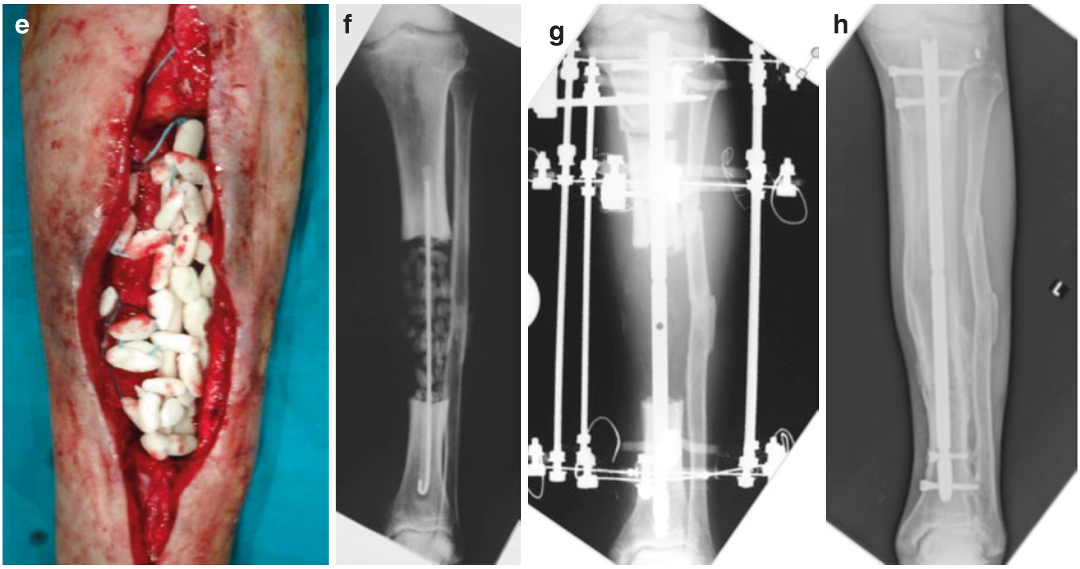

Fig. 34.27 (continued)

34.4.7.3 Titanium Cage and Grafting for Defect Nonunions

This technique is recently reported in the literature with short-term results [19, 40]. The prerequisites are a sterile bone defect exceeding 10 cm with a healthy soft tissue envelope. It these series, patients gained excellent limb alignment, and bone healing with bony ingrowth occurring through the cage was demonstrated with computed tomography. This technique may be a reasonable alternative in the treatment of segmental bone loss of long bones. Excellent bone formation through the cage can be evaluated with computerized tomography (Fig. 34.26a–e). However, it is possible that the patient gets reinfected, where an external fixation protocol might be needed for tandem bone transport.

34.4.8 Combination Techniques

The latest medical advances not only offer a shortened treatment time but also guarantee increased patient comfort. Combined techniques that utilize external fixators and internal fixation modalities (intramedullary nails, plates) combine the advantages of both techniques, with a decrease in external fixation time of almost 50 %. By decreasing the external fixation time, patient comfort increases and the rate of external fixator-related complications decreases, including pin track infections and joint contractures. The internal fixation hardware left in place after removal of the external fixator guarantees stability, inhibiting refracture or the recurrence of deformity, and enabling accelerated rehabilitation. Many combination techniques are described in the literature. Fixator-assisted acute femoral or tibial deformity corrections and consecutive lengthening over nails allow surgeons to address the deformity together with the limb length discrepancy. This technique may also be applied in the case of a nonunion associated with a deformity – this is known as the monofocal compression–distraction technique combined with deformity correction. Combined techniques are satisfactorily used for nonunions with defects and/or infections [27, 41, 42].

Bone transport is used for defect nonunions. Three methods exist:

- Internal bone transport.
- External bone transport.
- Bone transport over nail (BTON) (Fig. 34.27a–h). Bone transport with the use of an external fixator is known to be a reliable solution that leads to success-

ful outcomes. The time spent in an external fixator (the external fixation time) depends on the length of distraction required and does carry a risk of complication. When the distraction phase is complete, the consolidation phase (which often lasts more than twice as long as the distraction time) becomes difficult for the patient to tolerate. Removal of the external fixator before satisfactory consolidation is associated with fracture, deformity, and shortening through the distracted callus [5]. Older frames often required repeated adjustment to prevent misalignment of the docking site. The usage of the intramedullary nail in addition to the external fixator served to help avoid misalignment of the docking site, leading to significant decreases in external fixation time together with better maintenance of anatomical length and alignment [43].

Alternatively, minimal invasive plate osteosynthesis (MIPO) may be used to confer similar advantages [44]. Bone transport may also be accomplished through the use of fully implantable intramedullary lengthening devices, such as internal lengthening nails.

For defects between 5 and 12 cm, we prefer the BTON technique. The contraindications of the BTON technique are vascular disease, diabetes mellitus, and active infection. Bone defects larger than 12 cm and tobacco abuse are relative contraindications.

34.4.9 Biological Stimulation

As a principle, following debridement for atrophic nonunions, bone grafting should be performed ideally from the posterior iliac crest which is rich in bone marrow elements (Fig. 34.28).

34.4.9.1 Vascularized Bone Grafts

Vascularized bone grafts are indicated when the skeletal defect is longer than 6 cm [45, 46]. Fibular osteocutaneous, composite rib, and iliac osteocutaneous flaps are the most commonly used VBG clinically. Vascularized bone fills a large dead space; overpasses considerable bone defects; enhances tissue healing with a living, biological, infection-resistant composite tissue; and serves also to cover soft tissue defects. Reported success rates range from 80 to 95 % [45, 46]. Complications include anastomosis failure, nonunion, graft fracture, and donor site problems. This technique is preferred in patients with a healthy vascular tree needing both bone and soft tissue bridging and most importantly an experienced microvascular team. Our experience involves two cases, one with tibial bone and soft tissue loss and the other with femoral bone defect exceeding 12 cm (Fig. 34.29). Both patients healed uneventfully, and the VFGs became hypertrophied after 14 and 8 months, respectively.

Fig. 34.28 X-ray showing a humeral nonunion with the bone grafts at the nonunion site

34.4.9.2 Central Bone Grafting for Tibial Nonunions

Central bone grafting is an operative technique that uses a lateral approach, anterior to the fibula and the interosseous membrane, whereby a central compartment is created for autologous cancellous bone graft placement, thereby achieving a tibiofibular synostosis. The central

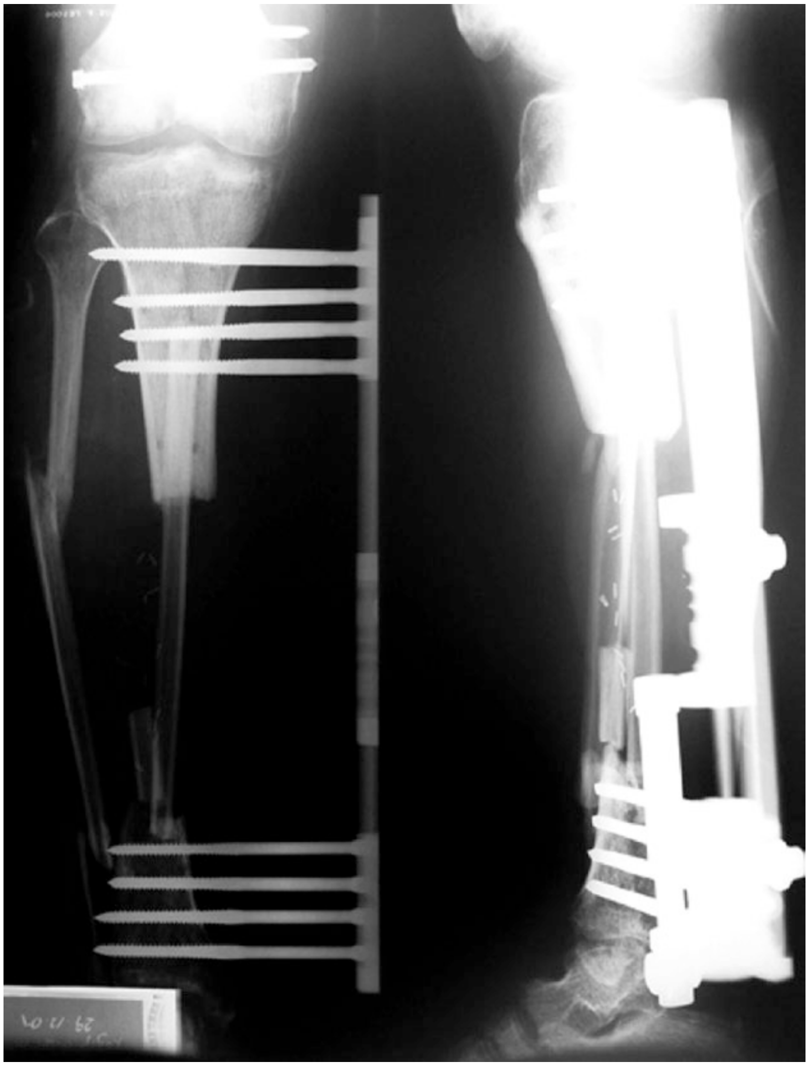

Fig. 34.29 Vascularized bone grafting (fibula) for a defect nonunion at the tibia, AP view (*left*), lateral view (*right*)

bone mass and the fibula consolidate into a tubular bone that is sufficiently strong for weight bearing. This technique is a relatively simple and safe method for the treatment of tibial nonunions compared to posterolateral bone grafting, bone transport, and rib or free vascular fibula grafts [47, 48]. It heals faster, requires fewer operations, and achieves similar rates of union in comparison to traditional posterolateral bone grafting. Central bone grafting may be used for bone defects of up to 5 cm, without previous infection, or in patients with previous infection exhibiting a defect of up to 2 cm after debridement.

34.4.9.3 Electrical Stimulation

The use of electrical energy for the treatment of nonunions started back in the 1950s. It was pioneered by Yasuda, who demonstrated new bone formation around the cathode in a rabbit femur. Today, three devices are approved for use with humans [49]:

1. Direct current stimulator supplied by Zimmer (Warsaw, Indiana, USA)
2. Inductive coupling system from Electro-Biology, Inc. (Fairfield, New Jersey, USA)
3. Direct current stimulation using a completely implantable system supplied by Telectronics Proprietary Ltd. (Milwaukee, Wisconsin, USA)

Fig. 34.30 A patient with a tibial nonunion (**a**). Partial fibulectomy and elastic intramedullary nailing resulted in tibial union (**b**)

34.4.9.4 Partial Fibulectomy

The application of a partial fibulectomy is controversial for the treatment of tibial nonunions. It has been recommended on the basis that the intact fibula may hold an ununited tibia in distraction (Fig. 34.30a, b).

34.4.9.5 Bone Marrow Injection

Bone marrow contains osteoprogenitor cells that are key elements in the process of bone formation and fracture healing. Autogenic bone marrow grafting is a useful technique in the treatment of delayed unions and nonunions. Percutaneous technique is preferable as it expedites the operative procedure and eliminates wound healing difficulties. Using specific needles for iliac punctures, a bone marrow volume of 50 ml is aspirated under fluoroscopic control and immediately injected into the nonunion site (Fig. 34.15). Because of the short interval between aspiration and injection, an anticoagulant (e.g., heparin) is not needed. Heparin usage is associated with potential impairment of bone healing. Repeat injections may be performed when no healing is observed on follow-up x-rays.

34.4.9.6 Platelet-Rich Plasma Injection

It has been shown in animal experiments that the use of platelet-rich plasma (PRP), alone or in combination with other bioactive components, may be an effective approach to augment the ability of porous biomaterial scaffolds to repair orthotopic defects [50]. Recently reported in human study showed safe and efficient combined use of PRP injection with demineralized bone matrix and iliac crest bone marrow aspirate in the treatment of tibial fractures [51].

34.5 Future

Bone tissue engineering offers significant potential in the management of refractory nonunions. There are only a few reports of its successful use in the literature. Thus, the translation into clinical practice remains limited at this time. Recent advances in stem cell therapy, cell biology, and biomaterials science are promising, and some bone morphogenetic proteins and growth factors are commercially available; however, further studies are needed to promote clinical application.

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Part V

Treatment of Orthopaedic Injuries: Pediatric Injuries

35 An Overview: Pediatric Trauma During Natural and Man-Made Disasters

Leonid M. Roshal

35.1 Introduction

This chapter is based on our experience in providing medical care to children after earthquakes in Armenia (1988), Iran (1990), Georgia (1991), the USA (San Francisco, 1991), Egypt (1992), Japan (1995), Russia (Neftegorsk, Sakhalin, 1995), Afghanistan (1998, 2002), Turkey (1999), India (2001), Algeria (2003), Pakistan (2005), Indonesia (2006, 2009), Haiti (2010), and Nepal (2015). Medical assistance in these countries was provided by the Russian specialized medical pediatric team which included medical specialists of the Clinical and Research Institute of Urgent Pediatric Surgery and Trauma. There is no other team like this in the world. In many countries, it is known as Doctor Roshal's Brigade. This brigade provided medical assistance to thousands of injured children all over the world [1–7]. Our chapters in this book were written by the immediate participants of these events. Based on our data, mortality and disability rate in children drops by half when medical assistance is provided by pediatric surgeons, compared to doctors for adults. Adult surgeons are more likely to do amputation surgeries than pediatric ones.

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35.2 Specifics of Pediatric Medical Care

Besides obvious anatomical and physiological differences, as well as differences in types and dosage of medications, child psychological trauma becomes an issue of great importance. Horrific events that the child has lived through affect their psyche. Some children lose their parents, which aggravates their psychological condition. Thus, children need additional attention and loving care. Participation of psychologists and volunteers is extremely important [8–14].

Another issue of vital importance is that rehabilitation of children after trauma [16], as we believe, is a process that might take a few years. Doctors who work with children in a disaster zone are supposed to know about local infections typical for the children in this locality, as well as about specifics of their nutrition. Also, they should take into account the importance for children, especially girls, of the cosmetic aspect of the surgery. Doctors should keep in mind that every scar tissue caused by the surgery that was performed on a little child will be growing along with the child. Such scar can become huge as the child grows and cause bad deformity of the face

N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_35

or other open body parts. So, the rule for the doctors is to use organ-preserving surgeries on children whenever possible.

In the countries where earthquakes happen often, special disaster planning measures, including care for children, are taken in preparation for natural disasters [15].

Considering the specifics of pediatric medical care, we initiated and promoted a Declaration about providing medical assistance to children. This Declaration was adopted in 1998 at the Pan-American Congress on Disaster and Emergency Medicine in San Jose (Costa Rica) and later approved at the WADEM Congress:

Declaration of the First Pan-American Congress on Disaster and Emergency Medicine

We delegates of the first Pan-American Congress on Disaster and Emergency Medicine recognize that children who are victims of disasters require special care delivered by persons at the scene of the catastrophe who are specially trained to provide this unique form of medical care.

We further recognize that most persons who deliver care to children during disasters may not be aware of the peculiarities associated with this important segment of the population during disaster conditions, and as a result, some children die or are permanently disabled who potentially could recover from their physical and or psychological injuries.

Therefore, be it resolved that the members of this Congress support the concept that there should be educational initiatives focused on children following disasters, which include life-supporting first aid training of the general population and the training of emergency medical services personnel in prehospital pediatric care. The definitive care of children in disasters is provided best by specialists and organized multidisciplinary teams at a national and/or international level who are specially trained to provide for the medical needs of children of any and all societies.

Furthermore, we hope that our voice will contribute to a solution of this worldwide problem.

San Jose, Costa Rica
04 MARCH 1998

35.3 Epidemiology

As a rule, the frequency of trauma in children corresponds with the percentage of children in the population of the particular country and also the earthquake magnitude. The percentage of children varies from 18–20 to 40–45 % in Eastern and developing countries. From our experience, there are certain factors affecting the frequency of injuries in children. Like during the Spitak earthquake (Armenia, 1988), which happened in the daytime, while all children were at school or day care facilities, the percentage of injured children was higher, compared to the earthquake in Turkey, that happened at night while most children were at home, not inside the destroyed school buildings. In the powerful Hanshin earthquake in Japan (1990), only a small number of children were injured, because the quake affected mostly wooden buildings in the city center, traditionally occupied by older people with no kids, so not too many children sustained injuries.

Similar situation was in the earthquake in North Afghanistan, even though the percentage of children in the population of that area is pretty high, but only light family residential houses were damaged then. On the contrary, very many children died or got injuries during the earthquake in Neftegorsk (Sakhalin) (1995), when brick and ferroconcrete buildings were destroyed. Generally speaking, the number and severity of injuries, like Crush syndrome, is much higher where stone or concrete buildings are affected by the quake.

Another observation is that in the private housing sector, losses are much lower than in the public housing, where, most likely, certain building requirements had been violated during construction, like in Turkey (1999). In the earthquake in Kathmandu, Nepal (1915), the number of injured children was relatively low, because the quake happened in the daytime on a weekend, when most children were outside. However, in that earthquake, many children sustained spinal injuries that required surgery.

Analysis of our own results, as well as other sources [17–30], showed that providing specialized medical assistance to children becomes one of the major problems, along with other problems associated with natural disasters.

35.4 Who Is Supposed to Provide Medical Assistance to Children in Earthquakes?

Interestingly, that even though all earthquake prone countries prepare for disaster, they experience delay in providing medical and other assistance to the victims, including children, due to the human and organizational factors when it actually happens. American people learned about the earthquake in San Francisco before the city residents. During the earthquake in Kobe (Japan), assistance was delayed, and the city administration rejected help from nearby towns, including Osaka. No doubt, mankind is learning their lessons. In Japan at this time, the level of earthquake preparation is much higher than before. However, there is a lot of room for improvement in providing specialized medical care to children. It has to be closer to the disaster area and should start as early as possible.

On numerous occasions, we showed that if specialized pediatric medical care is available nearby the disaster area, and if it is provided early, the results of treatment are much higher, while mortality and disability rates are lower (L. Roshal, 1991–2010). Child mortality in Neftegorsk, Sakhalin, for the first time ever was lower than in adults due to the participation of pediatric teams at a very early stage. In the train explosion between Ufa and Chelyabinsk (Russia), child mortality in Ufa was twice as high as in Chelyabinsk. The reason for that was that the pediatric brigade that arrived to Chelyabinsk early put all the injured children in the same hospital, while in Ufa children were dispersed between several hospitals and were treated mostly by adult surgeons.

In most countries, specialized pediatric teams just do not exist. And despite our 20-year positive experience in providing medical care to children in disasters and great reviews from all the countries we worked in, despite our numerous letters to international organizations including UN, WHO, International Red Cross, and Doctors Without Borders, no structured system of providing specialized medical care to the large number of children injured in disasters has been created.

Pediatricians mostly step in after the children have already been hospitalized. But rescuers and adult doctors who provide first aid to the victims should be thoroughly taught specifics of such assistance to children. Medical care for children with severe combination injury, multiple trauma, Crush syndrome, large wounds with bone injury especially if purulent infection is present, head and spine injuries, etc., should be provided by specially trained pediatricians. Also, it should be them to make a decision about amputation surgery. This would help to reduce mortality and disability in children [31]. Unfortunately, until now there is a shortage of skilled specialists in high-risk earthquake zones. That is why we need well-organized and efficient international support. Usually, there are many kind-hearted doctors who are willing to help, but most often, they are not specialists of the required level.

35.5 How Our Work Is Organized in Disaster Zones

Russian medical brigade includes experienced pediatric specialists including pediatric surgeons, traumatologists, neurosurgeons, anesthesiologists-resuscitators, and if needed combustiologists and pediatricians. All of them volunteer their services. Their work is facilitated by the International Charitable Foundation to Help Children in Disasters and Wars. The brigade is always ready to go. Before they take off, they research information regarding the approximate number of injured children and their geographical whereabouts to determine the number of people on the team (8–20 doctors). They cannot rely on the information obtained from journalists, because journalists tend to exaggerate the number of casualties especially in the first 24 h after the earthquake. We collect data from local doctors and hospitals. Time is taken to contact embassies of the countries we are planning to go, to get visas and air tickets.

Usually we get great help from embassies and consulates, including those of Russia. The brigade chooses the hospital where most children had been admitted. The time and scope of work is unlimited. We sent two doctors – members of the team to visit other hospitals in the region to check out situation with the injured children – to provide their recommendations and to figure out if these children can be transferred to the main selected hospital. Sometimes we have to work in several hospitals at the same time. We work in close contact with the regional health care administration and hospital head physicians. While at the hospital, we provide treatment jointly and with the consent of the hospital physicians. Also, members of the brigade exchange their professional experience with the local doctors.

Conclusion

Our long and extensive experience of providing help to children in disaster zones shows that medical assistance to children with trauma, especially with serious injuries in a hospital setting, should be provided by specially trained pediatric specialists. This will help to reduce mortality and morbidity rates in children. Besides, we believe that it is necessary to create an international structured unified system of practical coordination of international help to children in disasters, in particular in earthquakes, all over the world.

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36 Pediatric Trauma in Earthquakes: General Principles of Care in Pediatric Trauma During Earthquakes

Olga Karaseva and Leonid M. Roshal

36.1 Specifics of Treating Severe Traumatic Injuries in Children

As one of the medical science disciplines, the treatment of severe injuries has grown fast for the last 50 years. The main trigger for this discipline came from the wars, especially World War II, as well as local military conflicts of the twentieth century, the time, when the main principles of sorting and administering of the medical aid for the injured during mass destruction were established [1].

Uninterrupted technological advance, natural and man-made disasters, and terrorist attacks observed in recent years have all contributed to the increase in the amount of injured people during peacetime, including children [2, 3]. And it is the children that are protected the least during such emergency situations as earthquakes. Polytrauma is the leading type of trauma responsible for children's lethal injuries – in daily life as well as in mass disasters. It is the main cause of both children's death and disability along with all their social consequences [2, 4, 5]. The earthquakes, in this respect, are not excluded either. It is necessary to note that due to the conditions of unexpected natural disaster, the chances of survival of the severely injured decrease rapidly after an earthquake, because "the golden hour rule" is nearly impossible to fulfill. Nonetheless, it is only the fulfillment of the general principles of administering the medical aid for treating severe injuries that allow to have the child's life as well as its quality, which is important for his or her future.

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36.2 Terminology and Consistency of Notions

Clear terminology and conceptual consistency are needed in the methodology of treating children with severe injuries. Unfortunately, there is still no consistency in regard to the concepts involved.

By trauma we mean an injury to the body as a result of environmental factors' impact (mechanical, thermal, chemical, etc.). The notion of "trauma" in the modern age includes two components: (1) anatomical-morphological (injury to tissues and organs, which affects the disruption or loss of their functionality) and (2) functional (body's adaptive response that determines the state of the injured) [1]. These are the two parts

N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_36

that determine the basic concepts of treating severe injuries in children in the modern stage.

It is the correction and control of anatomical injury while sustaining, as well as by protecting the vital signs, homeostasis within accepted boundaries in order to create conditions for reconstructing the function of the damaged organ or to adapt body's vital functions under conditions of total or partial loss of the organ.

The core question is which injuries are to be considered "severe"? The question still does not have a complete, universal answer in spite of its seeming simplicity. The difficulty lies in the complexity of the individual body response to trauma depending on the localization, severity, and multiplicity of anatomical-morphological injuries [1, 6–8]. The shaping of the basic concepts is also difficult in connection to the fact that the modern trend of narrow specialization, even in general surgical specialties, justifies itself in the treatment of the certain system of the body, but in case of severe injuries, it demands that the expert in a narrow area also knows the course pattern of the traumatic disease that acts as a pathognomonic attribute of the serious injury [6].

In general, severe trauma is marked by shock; has preconditions for partial or total loss of functioning in extremity, organ, or system; and is accompanied by the disruption of vital functions or risk thereof and the development of the traumatic disease as an independent nosological entity.

36.3 Severity of Trauma and Gravity of Condition Evaluation

Rating scales for evaluating severity of trauma and gravity of the patient's condition are now widespread in trauma surgery [1, 2, 9]. These scales were needed both in military medicine and in disaster medicine for adult medical care. The ISS scale, created in 1974, became the gold standard [9]. Despite its existing flaws, this scale has a fairly good predictive value, and its intuitiveness has become the reason for the scale's practical implementation all over the world. Military field surgery scales, created in the beginning of the 1990s and based on calculus, are successfully used by military doctors, and their later modifications have good predictive value and good record in practice [1].

However, these military field surgery scales require reference tables and are deeply "Russian," which limits their use.

Despite the pediatric population being unprotected during mass disasters, the question of rating still remains a "black hole" in children's injury surgery.

Our research on predictive value of ISS scale in treating severe injuries in children in NII NDHT has shown its validity (acceptable calibration and discrimination capability) in determining trauma severity in children.

In our opinion, it is the ISS scale that ought to become the basis for determining trauma severity in mass disasters.

Since it is possible to intuitively determine trauma severity during the first stages of administering medical aid to the patient, it is also possible to determine the level of inpatient care treatment as well as the necessary amount of medical aid before a specific diagnosis in a specialized inpatient facility is given.

Main definitions of severe injuries in Russian language literature are based on separate anatomical-functional areas of the body: the head, neck, chest, abdomen, pelvis, extremities, and spinal column. Based on these parts:

Single trauma – trauma to one internal organ in one anatomical area or to one functional segment of musculoskeletal system

Multiple trauma – simultaneous injury to several internal organs in one anatomical area or to two or more functional segments of musculoskeletal system

Associated trauma – simultaneous injury to two or more anatomical areas of the body or functional segments of musculoskeletal system by one traumatizing agent

Combined trauma – injury by mechanical, thermal, and radiant energy

Polytrauma – composite notion that is mostly used in English language literature in order to determine severe injuries (multiple, associated, combined trauma) that require immediate resuscitation and surgical intervention.

Traumatic disease is a whole complex of phenomena in body's biological processes that occur with severe injuries starting with the moment of trauma and ending with the clinical outcome. Trauma disease is an inseparable attribute of severe trauma. Since genetically determined adaptation response to anatomical-morphological injury goes beyond the limits of an organ and system to the level of the whole body, it involves other organs and systems into response process with the possible disruption of their functions all the way to the failure and developing of the system reactions.

36.4 Trauma Disease

Regularity patterns of body's response to the severe trauma determine the course periods of the trauma disease and their approximate durations: (1) acute (under 3 months), (2) intermediate (under 1 year), and (3) outcome or consequences of trauma (over 1 year).

The most dynamic period is the acute one, and it can be divided into following periods: (1) shock, under 24 h.; (2) primal adaptation period, 3–5 days; (3) organ dysfunction period, under 1 month (under 2 weeks at the average); and (4) clinical stabilization period, under 3 months.

It makes sense to combine the first three periods into "acute" as the patients require life support protection for supporting their biological processes while being treated in intensive care and resuscitation unit (first stage of inpatient treatment). Clinical stabilization period is marked by patient becoming less dependent on the life support system and his growing ability to participate in active rehabilitating events that aim to continue the recovery of lost functions (including those that are a result of reconstructive surgeries) as well as to aim to help adapt the patient to the functional and anatomical deficit conditions (second part of inpatient treatment). At this stage, the patients need to be treated at the inpatient facility.

Intermediate period of trauma disease is marked by a steady stabilization of patient's biological processes within anatomical-functional deficits. Recovery processes continue but slow down significantly. The spotlight is on the patient's social adaptation in the family and community as a part of individual medical and social rehabilitation program. The patients are discharged from the inpatient facility and treated as outpatients. For palliative care, in cases of poor prognosis, patients need to be transferred to a hospice.

For each period described above, there is a list of general primary syndromes that is specific to it, the one that determines time since trauma occurred, presence of factors for secondary injury, as well as the regularity of "acute response" stage. The main attributes of the shock period are the disruption of function of an extremity, an organ, or a system as a result of the primary injury, acute blood loss, and fat embolism, which constitute, in fact, the direct reason for circulatory system failure. It is in this period when most lethal outcomes occur. If the severity of the primary injury was not lethal, the adaptational response of the body and medicinal antishock measures stabilize patient's condition, which is expressed clinically as a period of primary adaptation. It is necessary to note that myoglobinemia, being the main link in traumatic toxicosis in a crush syndrome that is leading in severe injury patterns in earthquakes, without adequate detoxication, does not allow to achieve the primary adaptation period and leads to the fast development of acute renal failure development. Later course of trauma disease is marked by the period of organ dysfunction attributed by the systemic inflammatory response syndrome while undergoing traumatic toxicosis, disruption of primarily intact uninjured organs, and systems functionality, associated infection complications as severe as sepsis, trophic disruptions, and erosive-ulcerated injuries in gastrointestinal tract. This period of trauma disease is marked by the second peak of lethal outcomes as a result of multiple organ dysfunction syndrome, sepsis, or secondary dislocation syndrome.

The period of clinical stabilization is marked first of all by a recovery of vital signs, no longer requiring medical intervention to maintain them, and by intensive repair of traumatic injuries.

36.5 Severe Injury Outcomes Scale (OISS)

It is necessary to note that the timescale of periods described is quite conditional and depends on factors mentioned above. If the healing (return to the previous level of physical, psychological, and social activity) has not occurred earlier, the outcome of severe trauma should be assessed no earlier than 1 year after the injury. Since both clinical observations and literature data support the important dynamics of the traumatic process during this period [1, 6], then later we should talk about trauma consequences. Unified assessment of severe trauma outcome is another important and unresolved question of injury surgery in children. Only objective assessment of treatment results makes it possible to choose correct decisions in forming of the modern concept of administering medical aid to the severely injured, both in regard to organizing this aid and in regard to medical-diagnostic measures. It is necessary to mention that we do not have such statistics of earthquakes either. There are well-regarded assessment scales for certain trauma types, such as Glasgow Outcome Scale (GOS) for traumatic brain injury. However, it is necessary to assess the outcome of not only single but associated traumas as well. Since severe traumatic brain injury dominates in the associated trauma pattern, with GOS as a basis, it appears sensible to use the scale of severe injury outcomes OISS developed by us.

1. No consequences (full recovery) – ability to conduct life at the same living standard with the same level of physical and psychological activity.
2. Good recovery, with trauma consequences that do not limit the level of social adaptation, that insignificantly limit the previous level of functional activity (physical and/or psychological), and that require continued rehabilitation treatment.
3. Moderate disability, with trauma consequences that do not allow to continue the same level of functional activity, with intact self-care capability. The child is not in need of special care.
4. Serious disability, with trauma consequences that significantly limit functional (motor and/or cognitive) activity. No ability of self-care; the child is in need of special care or medical support.
5. Death

36.6 Associated Trauma

The leading place (80 %) in severe injury patterns belongs to associated trauma [5, 7, 10]. Taking into consideration the power of the traumatizing agent, associated trauma rates increase during earthquake. However, medico-statistical data on trauma patterns in earthquakes is either absent or does not show the true picture. This is because a significant portion of the injured with associated trauma cannot be saved. As the experience of our mobile team indicates, severe trauma does not exceed 2–3 % among children hospitalized after earthquakes, and the majority consists of children with associated trauma injuries of moderate severity level (14.2–34.3 %). Leading injury is most often trauma to one's musculoskeletal system; traumatic brain injury occurs quite often (up to 15 %), abdomen trauma in no more than 2.5 % of cases, and spinal-cerebrospinal trauma in up to 1.5 %.

In our mind, it makes sense to separate associated trauma severity level according to ISS scale: light, moderate, and severe. It helps to accurately mark severe associated trauma (ISS >16) as a problem surgery of injuries. Usually the term "associated trauma" is used to mean severe trauma. However, it is necessary to take into consideration light and moderate associated injuries in order to form a diagnosis according to (ISD-10). Later we will talk about the severe associated trauma only.

Main symptoms of associated trauma are traumatic shock, blood loss, respiratory failure of mixed origin, vagueness of clinical pattern of organ, and system injury as a result of trauma. The pathognomonic feature of associated trauma is a reciprocal aggravation syndrome [1].

The multiplicity of afferent traumatic input, blood leakage sources, primary and secondary necrotic lesions, and disruption of coordinating function of the central nervous system lead to more severe course of each separate injury.

Therefore, the effects of primary injury in trauma of several anatomical-functional areas do not just add up to each other, but deepen and initiate the scenario of a more severe trauma disease.

Associated trauma features in children are the following: (1) traumatic brain injury is prevalent; (2) closed trauma of internal organs and abdomen; and (3) fast development of shock.

Since the relation of head mass to body mass is generally larger than in adults, the skull bones are thinner; brain is less myelinized.

Parenchymal organs, such as liver and spleen, are protected by fewer muscles; kidney are more flexible and are also less protected by muscles, and that leads to their injury more often, even without visible trauma of abdominal wall.

Due to higher elasticity of the lungs, their injuries (bruises and tears) are accompanied by rib fracture much more rarely.

Child body's hydrophilism leads to the fast hypovolemic shock, even with low blood loss on one side, but on the other side, the early diagnostics of blood loss is difficult due to compensatory reactions being more expressive compared to adults.

High level of catecholamines leads to acute vasospasm, which makes hemodynamics possible with significant blood loss (up to 50 % circulatory blood volume).

Children get hypodermic fast and that plays a significant role in pathogenesis of shock reaction.

Shock and blood loss are the most important and tightly interconnected syndromes of associated trauma. They are the main reasons for lethal outcomes in prehospital stage in daily life, as well as in earthquakes. Brain injury, which is the most common in associated trauma pattern, impacts the course of the shock. In this case, shock coincides with consciousness impairment: its growing stage becomes longer and it might be mistaken for psychomotor excitement. In severe brain injury involving diencephalic patterns, blood pressure may not only decreasing but also increasing despite present extracranial injuries. Development of dislocation syndrome is accompanied by bradycardia and fast decompensation of hemodynamics without significant bleeding. In general, unfavorable patient treatment results are related not only to the severity of primary injuries but also to the blood loss from secondary injuries (such as brain edema, sepsis, multiple organ failure syndrome) and are usually the cause for lethal outcomes at the hospital stage.

Therefore, the hospital stage plays a crucial part in administering medical aid to severely injured patients.

36.7 Prehospital Stage

The most vulnerable stage of administering medical aid to severely injured by earthquakes is the prehospital stage. Even though the main principles of medical aid in case of earthquake become very difficult to apply, successful outcome depends solely on their execution. Main principles of administering the medical aid to children at the prehospital stage are promptness, consistency, continuity, and centralization. In other words:

- A set of resuscitating and diagnostic measures for severely injured has to begin on the spot, and it has to continue during the transportation (Emergencies Ministry's doctors, emergency response workers).
- Primary hospitalization of children into the hospital that has intact infrastructure that can administer specialized surgical aid.
- The shortest possible transportation time.

The main goal in administering medical aid at the prehospital stage to the child that has associated trauma is diagnostics and control of the main injuries that lead to traumatic shock, as well as suitable protection of the vital signs along with syndrome-specific antishock therapy. In other words, it is necessary to conduct the system checkup, assess the severity of the patient's state, determine the principal and accompanying injuries considering the consciousness level, assess the shock level, and determine and fix respiratory and circulatory system failure [5, 11, 12].

The basis for diagnostics of trauma injuries at the prehospital stage is comprised of the following: knowledge of trauma mechanism and signs of local trauma and clinical signs of the function disruption of an injured organ or system. Additionally, associated trauma, including brain injury, is complicated by the absence of such important diagnostic factors as complaints and patient's adequate reaction on the pain.

Head trauma: consciousness impairment, focal neurological signs.

Chest trauma: external respiration mechanics failure, dyspnea, skin color change, subdermal emphysema, hemoptysis.

Abdomen trauma: abdomen pain, forced positioning, paleness of skin and mucosa; accelerated pulse, blood pressure decrease, muscle contractions in the from abdomen wall.

Musculoskeletal system trauma: pain, edema, deformation, abnormal mobility of extremity segment, shortage and/or disruption of extremity's function; soft tissue injury, etc.

Spinal and cerebrospinal trauma: pain and deformation in the injured spot, disruptions in motion and sensation below the injured spot.

Considering the abovementioned, the basis of anti-shock therapy at the prehospital stage in severe trauma is comprised of:

- Vital signs protection (respiratory and circulatory function protection)
- Suitable anesthesia
- Immobilization (collar, shield and/or mattress)

36.8 Hospitalization into a Specialized Inpatient Facility

Hospitalization into a specialized inpatient facility at the modern stage of healthcare is one of the necessary condition of caring for the injured with associated trauma [5, 12]. In practice, the hectic transfers of injured patients from one inpatient facility to another not uncommonly become a reason for lethal outcomes and, quite importantly, for significant disability of survived children. The earthquakes, in case of a severe injury, are not an exception. The hospitalization of the injured into a lower-level inpatient facility is acceptable only when it is necessary to perform surgical measures to save life or if the specialized hospital with intact infrastructure is out of reach.

In case of earthquakes, the main organizational goal is to set up this kind of specialized children's trauma center in the closest undestroyed hospital.

Centers like that are the basis for administering special medical aid by international teams. It is necessary to mention that the importance of a specialized trauma center does not only decrease in earthquakes but for the survived child also becomes the only chance to get professional help.

Our experience in various countries during earthquakes supports this statement. Children's hospitalization into nonspecialized inpatient facilities that lack specialists and necessary equipment more often than not lead to unfavorable outcomes of a trauma, such as a child's disability as a result of subpar-quality treatment, crush syndrome, and skeletal trauma [4, 11].

Round-the-clock availability of the following is the main requirement for the specialized inpatient facility that administers medical aid to children with associated trauma:

- Diagnostic equipment. Spiral computed tomography (CT) holds the priority, because it allows for simultaneous checkup of several body areas.

- Pediatric resuscitation-anesthesia department (intensive care unit, ICU) that is experienced in administering aid in case of severe trauma
- Personnel that is specialized in main surgery fields (pediatric surgeons, neurosurgeons, trauma surgeons) and is skilled in modern diagnostic and treatment methods (minimally invasive techniques such as laparoscopy, bronchoscopy, minimally invasive osteosynthesis)

It is necessary to mention that not just associated trauma but also single severe injuries at different stages of trauma disease require teamwork, but in case of associated trauma, coordination of the work of ICU specialists, surgeons, trauma surgeons, and neurosurgeons is a crucial part of the aid-administering concept [1, 7, 8]. The work is guided by the computed tomography specialist, who is responsible for making decisions on patient's treatment course, volume, sequence, and coordination of all specialists' work.

36.9 Diagnostics in Specialized Inpatient Facility

The set of diagnostic measures performed upon patient's arrival in the inpatient facility includes computerized tomography, with IV contrast study if necessary, ultrasound chest and abdomen study, X-ray, and endoscopic and laboratory studies. Computerized tomography needs to be made a priority, including fast performance and possibility of simultaneous study of several anatomical areas (head, chest, abdomen, pelvis, spinal column). X-ray study is the main method of studying musculoskeletal injuries (extremity bone fractures). Sonography is the screen procedure for ruling out the internal bleeding.

One of the most important components in the treatment of patients with severe associated trauma is performing antishock resuscitating measures, in order to support vital signs, simultaneously with diagnostics measures.

36.10 Surgical Treatment

Surgical treatment includes all surgical treatment on all affected body areas. Surgical treatment program depends on the stage of the trauma disease and the compensatory mechanisms; it also helps to avoid complications related to the secondary injury and supports the fastest body recovery allowed by the primary injury with minimal anatomical-functional harm.

Therefore, during the most critical stage of the shock, the surgical treatment has to lean towards antishock measures, in other words, *emergency surgeries* in order to save the life (to stop the bleeding, eliminate asphyxia and dislocation syndrome in any focalization).

In order to determine further surgical treatment tactics, in injuries of parenchymal organs with insignificant bleeding (low and moderate hematoperitoneum) and steady hemodynamics at the time of patient hospitalization, the dynamic ultrasound monitoring is indicated.

Laparoscopy is indicated in case if hematoperitoneum increases in size while blood cells signs decrease.

Only when it is impossible to perform endoscopic hemostasis related to prolonged internal abdomen bleeding, switching to laparotomy is indicated.

Extensive hemoperitoneum with unsteady hemodynamics is an indication for laparotomy.

When the patient's condition is relatively stabilized, injuries that lead to life-threatening complications need to be eliminated *urgently* (in the first 24 h) in a surgical way – surgeries of injuries in hollow organs of abdomen, surgical wound treatment, amputation, and fasciotomy.

When natural compensatory body reactions are mobilized, after getting the child out of shock at the stage of primary adaptation (under 5 days), we have an opportunity for *nonurgent* primary reconstructive invasive treatments on a full scale, which are aimed at eliminating or correcting post-trauma anatomical defect. Most of these surgeries are primary reconstructive ones, such as osteosynthesis in bone fractures, facial skeletal reconstruction, etc. [10, 11].

The period of organ dysfunction (5–14 days in average) is marked by increasing traumatic toxicosis, exhaustion of humoral adaptive systems of the body, and is very dangerous in regard to potential complications (sepsis, organ failure syndrome, intracranial hypertension syndrome) [7, 13]. Surgical treatment needs to be limited only to the emergency (acute and urgent) surgeries on any complications, as well as periodic surgical treatment of wounds, that is, a surgical sanitation of the infection focal site.

During this period, surgical reconstructive invasive treatments are not warranted, because additional surgical trauma is extremely aggressive in regard to the exhaustion of humoral adaptive systems of the body.

The period of steady clinical compensation (2 weeks–3 months) makes it possible to perform surgery again. The main direction of the surgical treatment at this stage is early surgical rehabilitation: plastic repair of wound defects, stump formation after extremity amputation, closure of posttraumatic cranial defects, posttraumatic hydropsy surgeries. Complete recovery of anatomical defects creates the conditions for the most effective recovery of disrupted body functions. This stage is also the safest for surgeries that are aimed at the optimization of vital functions in patients in vegetative state: tracheostomy and gastrostomy.

Therefore, the "injury control" tactics, initially used in abdomen surgery, nowadays are the basis of the concept or even philosophy of resuscitation treatment in associated trauma [1, 6].

Injury control and the notion of "trauma" itself are aimed at two components:

1. Anatomical-morphological: surgical aid
2. Functional: resuscitating aid

Surgical tactics is defined by the need to correct the existing injury and by the sufficiency of homeostasis for such correction, while accounting for the trauma disease stages and their corresponding syndromes.

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37 Anesthesiology and Resuscitation in Children During Earthquakes

V. Amcheslavsky, V. Bagaev, and Leonid M. Roshal

37.1 Introduction

The optimization of treatment and complex diagnostic measures, including anesthesiology aid and intensive care in children, in catastrophes and natural disasters is a high-priority problem of in the entire world [1, 2, 4, 5, 7–9, 11, 12, 17].

37.2 The Requirements for Anesthesiologist-Resuscitator that Is a Part of a Pediatric Mobile Team

There should be no less than two pediatric anesthesiologists-resuscitators with no less than 5 years of professional work experience in the specialized multidisciplinary emergency aid inpatient pediatric hospital [6].

Being skilled in all methods of inhalation and non-inhalation anesthesia, including regional anesthesia, should be a compulsory condition for accepting anesthesiologist-resuscitator into the team.

There are not usually enough physicians (anesthesiologists) and nurses (anesthetist) on site; however, when there is enough personnel, the language problem emerges.

The lack of mutual understanding among anesthesiology specialists during surgical treatment is not to be tolerated.

37.3 In Case of Mass Influx of Injured Children, Anesthesiologist's Work Has Certain Features

1. Work duration in surgery, with short breaks for meals and patient exchange, varied from 8 to 12–14 h.

   It was determined by the amount of surgeries, planned the day before (distinctive features of such planning will be discussed below), need for additional anesthesia in wound dressing of children operated earlier, and also the amount of urgent and nonurgent surgical measures for those transferred from other hospitals, or children that were newly referred in the course of daily checkups at the hospital.

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_37

The later statement is supported by our experience of almost daily discovery of children that had come in earlier, despite daily hospital checkups. This was due to their stationing at a nonspecialized department, in nontraditional places (Fig. 37.1), or saying with a relative that was also injured.

2. Significant amount of anesthesia per one specialist (increased compared to routine work in the homeland): up to 10–15 anesthesia procedures of various durations per one anesthesiologist-resuscitator daily.
3. Skills in working with various anesthesiology equipment and devices, as well as with various surgery room equipment.
4. Knowledge of international names and medical anesthetic forms, narcotic drugs, analgesics, and other medicine and solutions, which inpatient facilities were equipped with. Fast learning of their use, storage, and record.
5. Fast learning and strict completion of medical documentation that corresponds with accepted standards of filling out patient's clinical record at this facility (presurgery checkup records, course of anesthesia, postsurgery patient management in English language or in country's own language if necessary).
6. Daily (twice a day) checkups of inpatient facility's departments 1–1.5 h before surgery started, anesthesiologist-resuscitator, accompanied by the surgeon in charge and team's pediatrician along with interpreter and clinic's management representative, performed daily department checkups, evaluating the state of the children that were operated the day before and earlier, as well as those that were preparing for surgery that day.

The same checkup was performed at the end of the day after surgery.

A conference with the team's specialists, along with the surgery unit's representative, was held before the start and end of day of the surgery, where activities for the day of the surgery and the day after were discussed.

37.4 Distinctive Features of Anesthesiologist-Resuscitator's Work in the Mobile Pediatric Team

Presurgery Assessment of Anesthesiological Risk. The assessment of anesthesiological risk for planned surgical treatment was performed according to the international ASA scale [14, 16].

Almost all children checked by anesthesiologist before surgery were at high-risk level (III–IV in ASA) of developing possible anesthesiological complications during surgery.

In assessing the anesthesiological risk level, the urgency of the surgery, insufficient level of presurgery preparation (Fig. 37.2) and

Fig. 37.1 Inadequate treatment facility, often located in the basement, creates difficulty with access to the patients and compromising needed care

Fig. 37.2 Malnutrition and alimentary failure signs at the pre-surgery stage

Fig. 37.3 Example of a ‘crowded’ placement of children and their parents in hospital wards

existence of injury that limits child’s self-sufficiency as well as specific features of climate and medical and social conditions of children’s hospital stay were taken into consideration (Fig. 37.3).

When making a decision related to the possible risk of anesthesia, language barrier was considered as well relative to medical documentation examination, as well as clinical record details and specifics of the event. An important factor was that the anesthesiologist’s work had to be performed in suboptimal environment (Fig. 37.4).

Considering the hot climate (air temperature was 37–39°C, 98.6–102.2 F), lack of AC in wards (Fig. 37.5a), and patients being placed outside wards (Fig. 37.5b), all children that needed surgical treatment under general anesthesia received constant infusion therapy as a physical necessity, regardless of the extent of the surgical treatment, before and after the surgery.

Fig. 37.4 Example of simultaneous work of two surgery teams working in one Operating room (Haiti, 2010)

Fig. 37.5 (**a**) Typical ward without Air Conditioning. (**b**) Example of placing the patients in the hospital corridors (1) and underground ramps (2)

37.5 Solutions

Basic solutions used for rehydration were saline solution, Darrow's solution, and Ringer's lactate. The initial amount of liquid was injected under physician's supervision at the speed of 20 ml/kg of body weight in order to normalize hemodynamic signs. First of all, the decrease of tachycardia by 10–15 %, compared to the original level, and tissue perfusion improvement were taken into account ("pale spot" symptom, "center-periphery" temperature gradient). The fact that the majority of children were in the wards that lacked monitoring systems had to be considered as well. Veins for puncture and setting of peripheral intravenous catheter were those in the hand, brachium, and, finally, elbow, because the arm was not totally functional, and children were often without parents and had to take care of themselves alone. Only when it was impossible to puncture periphery veins, the catheterization of subclavian or jugular veins was performed. Central veins were catheterized during presurgery stage only in 10 % of children in Indonesia and 16 % in patients between 1 month and 3 years of age in Haiti. In children at bed rest, bladder was catheterized and diuresis was controlled.

As mentioned earlier, most children were observed to have purulent inflammation complications such as wound infection and septic condition (up to 70 % in Indonesia; up to 65 % in Haiti). This determined the necessity for use of broad-spectrum antibiotics as an inseparable part of preparing the children for surgical treatment. Antibiotic of choice was ceftriaxone in medicinal age-suitable doses, injected in parenteral way. It is necessary to mention that 100 % of children experienced positive improvement quickly (in 1–2 days) due to antibiotic treatment, leading to decrease in inflammations according to laboratory data (leukocytosis decrease) and clinical checkup data (fever reduction, appetite increase, and child's higher activity level).

In those children who did not have infection inflammations, antibiotic treatment (ceftriaxone in age-suitable dose) was implemented before skin incision and continued for the first 3 days after the surgery.

Alimentray failure in children was explained by significant loss of proteins related to the specific course of wound process, purulent inflammation complications, appetite decrease mostly on plant-based food, and lack of adequate control of good nutrition. As a result of high workload of personnel, meals and care were provided by children's relatives when it was possible. Nutrition control, from the time the child was taken in by pediatrician and other specialists, did not make it possible to solve the problem of recovery of adequate protein levels because there was not enough time before the surgery. As a result, parenteral feeding and 20 % albumin solution was recommended as a part of treatment aimed at preparing a child for the surgery.

Although red blood cell count decreased in almost all children (decrease of hemoglobin, red blood cell amount, and hematocrit by 15–20 % compared to normal levels), combined with moderate signs of hypovolemia, blood transfusion and other blood component delivery, including frozen plasma at 10 ml/kg of body weight in all children, was performed only in surgery, depending on duration and extensiveness of the surgery.

37.6 Children's Intake into Surgery, Premedication

There were wider indications for general anesthesia in injured children due to their psychological state, having experienced the horrors of disaster. Anesthesia was performed for the purpose of general painkilling, as well as for psychological protection of a child. According to psychologists' data, children that have experienced physical trauma always have a psychological side effect induced by an event that steps over the boundaries of regular human experience (life-threat, destruction of physical identity, loss of a home and relatives, etc.) [15].

And this is expressed as hypertrophic psychological reactions, triggered by subliminal stimuli, which the child ignores in daily life [3].

In observed cases, the lack of psychological intervention with children was substituted by volunteers, relatives, medical personnel, and religious representatives.

It is necessary to note that children had trusting and calm attitude towards medical personnel that took care of them. Children were accompanied to presurgery by relatives or people that they trusted. All children had earlier, in clinical department, intravenous catheter installed for presurgery preparation (see above). In presurgery, children were administered 0.1–0.25 mg/kg of midazolam intravenously slowly in saline solution and then, depending on the child's falling asleep, desensitizing drug and atropine sulfate in age-suitable dose.

After that, the child, breathing autonomously through own airways, was transferred into surgery where the induction of anesthesia was administered.

37.7 Anesthesia Induction and Choice of Anesthesia at the Main Stage of the Surgery

All primary surgeries and wound dressings were performed under general anesthesia. We mention just some of its specifics due to induction of anesthesia being performed according to generally accepted rules:

- Type of anesthesia and of anesthesiological aid at the main stage of the surgery was determined in the surgery right after primary assessment of the wound (injury site), after removing the dressing and inspecting the wound by the surgeons.
- It required analogue-sedation of the child by inhalation mask anesthesia while preserving child's autonomous breathing (Fig. 37.6).
- The sedative of choice for children under 5 years old was midazolam, and for children over 5 years old, propofol in 2.5–3 mg/kg dosage. For analgesia, fentanyl 0.005 % – 1–2 mcg/kg or ketamine 2 mg/kg.
- Regardless of the later course of anesthesia and its duration simultaneously at the start of induction anesthesia, infusion of 6 % hydroxyethyl starch no more than 10–15 ml/kg, in children under 10 years old, and 15–20 ml/kg in children over 10 years old.
- Upon deciding on surgical invasive treatment, muscle relaxant was additionally injected, preferable with moderate duration of action, such as rocuronium bromide (Esmeron) 0.6–1 mg/kg, performed intubation with age-suitable tube, switched to artificial respiration, and started the main stage of anesthesia (Fig. 37.7).
- In case of limiting the amount of surgical activity to just dressing the wound, they con-

Fig. 37.6 Example of induction anesthesia with inhalation mask that precedes the main stage of anesthesia and surgery

Fig. 37.7 Intubation before the main stage of anesthesia and surgery

tinued mask anesthesia with inhalation anesthetic sevoflurane in age-suitable dosage.

- With the exception of extended dressings, usually primary ones, with supposed duration of more than 20 min, preparation and intubation of trachea were performed as well. Unfortunately, at that time, our team lacked laryngeal masks in order to perform noninvasive artificial respiration.

37.8 Types of Anesthesia During the Main Stage of the Surgery

Types of anesthesia used in surgical treatment of children, injured in earthquakes in Indonesia and Haiti, are shown on the diagram (Fig. 37.8).

As seen on diagram 12, of the total of 712 anesthesia procedures in children of various age (mainly children of 1–10 years old, as shown in Fig. 37.9) performed during surgical treatment of children injured in earthquakes in Indonesia and Haiti, inhalation mask was used in most cases – 60 % and intravenous in 20 %.

The large number of inhalation mask anesthesia procedures was determined by many recurring dressings in children that were performed under general anesthesia.

It superseded the amount of primary surgeries, primary extended dressings, recurring stage surgical invasive treatments that were usually accompanied by endotracheal intubation.

Intravenous anesthesias were performed in 20 % of children, mainly of the older age group.

For this purpose, the children of older age group were given the combination of ketamine 2 mg/kg and propofol 2 mg/kg and ketamine 2 mg/kg and diazepam (Valium 0.2 mg/kg).

In this proportion of anesthesia components, there was not usually a need for another anesthesia apparatus, which was important while two surgical teams were working simultaneously in the same surgery room.

As an example of using intravenous anesthesia is in simultaneous work of two teams in the same surgery room without the need for the second anesthesia apparatus, with patient breathing autonomously while performing the stage wound dressing in Fig. 37.10.

Inhalation mask and intravenous anesthesias were used in less traumatic and shorter (up to 15–20 min) invasive treatments (mainly dressings and extended dressings).

It was due to modern inhalation and intravenous anesthesia use that made it possible to quickly

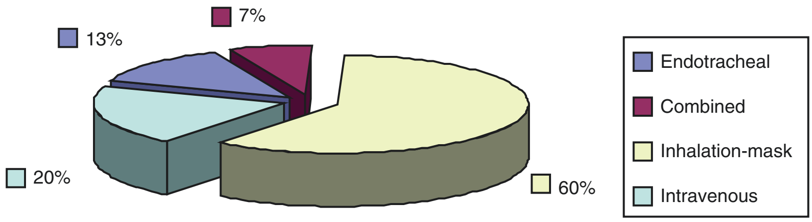

Fig. 37.8 Types of anesthesia (*N* = 712) used in children in earthquakes in Indonesia and Haiti

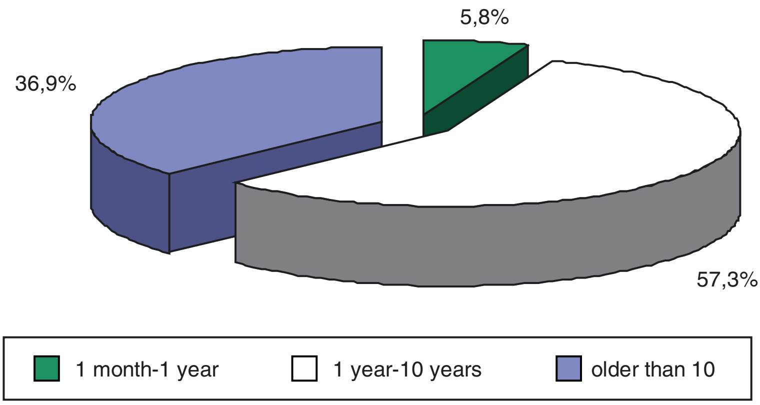

Fig. 37.9 Age distribution of wounded children required anesthesia

Fig. 37.10 Example of 2 surgical teams working in the same surgery room while performing inhalation anesthesia with artificial respiration (farther table) and intravenous anesthesia without the need for anesthesia apparatus, with patient breathing autonomously, while performing the stage wound debridement (closer table)

Fig. 37.11 General endotracheal anesthesia administered to the patient with skeletal trauma (**a**) and to the patient requiring reconstructive plastic surgery of major craniofacial injury (**b**)

perform induction anesthesia without unnecessary excitement and to support basic anesthesia.

Children woke up after anesthesia and surgery quickly and without complications.

In long and traumatic surgery treatments from 30 min to 5 h long, inhalation endotracheal anesthesia was used, 13 % of all anesthesia and 7 % of combined anesthesia.

Children with long bone fractures were treated surgically under general anesthesia, mainly while using intramedular ostheosynthesis methods.

An example of such endotracheal general anesthesia in a 12-year-old child while performing minimally invasive surgery of osteosynthesis with image output screen in femur bone fracture, is shown in Fig. 37.11a. Endotracheal general anesthesia was also necessary for children whose surgical invasive treatment was complicated and "aggressive" due to step-by-step surgeries that aimed at preparing for reconstructive plastic surgeries in order to close tissue defects. An example of that can be seen in Fig. 37.11b, in a patient with gradual reconstructive plastic closure of tissue defects in major craniofacial injury.

Patients that had combined anesthesia (general and regional anesthesia) comprised the smallest group. Limiting of the regional anesthesia methods in children after earthquake was often due to multifocality of trauma, when focal sites of trauma were in various anatomical areas. As a regional anesthesia, spinal anesthesia method was used in a total of six children (over 10 years old). This took into account the limits of possible surgery duration no longer than 2–3 h. Classic puncture method was used as cerebrospinal central canal puncture with patient lying or sitting with head up, with an age-suitable needle at the level L3–L4, and injection of 0.5 % solution of bupivacaine 2–3 ml after transparent cerebrospinal liquid. After that, the child was put up into position of 15° with the head end up. Figure 37.12 shows the stage of performing regional (spinal) anesthesia in a 16-year-old patient with further stage surgery on lower extremity. Residual painkilling effect of local anesthetic that lasted for several hours after the surgery helped to decrease need for additional postsurgery painkilling.

37.9 Anesthesiological Equipment and Consumable Supplies

Generally, the regional hospitals in team's base sites are satisfyingly equipped by anesthetic-respiratory and monitoring devices, as shown in

Fig. 37.12 Administering regional spinal anesthesia to a 16 year old patient requiring surgery of the lower extremity

Fig. 37.13 Example of supplying the surgery room of regional hospital with anesthesia-respiratory and monitoring equipment in team's base site (**a** – Indonesia, **b** – Haiti)

Fig. 37.13a, b. Timely humanitarian aid supplied a good amount of various consumable supplies, medicine, and solution.

Anesthesia apparatus were equipped with vaporizers for sevoflurane and halothane. Sevoflurane was preferred for use in younger children (up to 5 years old), while halothane was used in older children [10, 13].

While analyzing anesthesiological aid in wound treatment in children after earthquakes, we pinpointed two consecutive stages that influence the choice of anesthesia. The first stage up to 2 weeks included surgical wound debridement as primary surgery or extended dressing or secondary wound area debridement under general endotracheal anesthesia. After that, there was a series of at least 2–3 dressings under inhalation mask anesthesia combined with conservative treatment in order to prepare a child for the second stage of surgical treatment – reconstructive plastic surgery for closing of soft tissue defects. The second stage usually occurred 2–3 weeks later and was comprised of reconstructive plastic closing of tissue defects.

Since patients needed almost daily wound dressings, anesthesia count was high and duration, short. Considering high flow of patients and low traumatic dressings, anesthesia should be manageable and not deep. Sevoflurane was chosen as inhalation medicine and combination of ketamine and propofol as intravenous.

During the second stage of reconstructive plastic surgeries, when surgical invasive treatments became prolonged (up to 5 h) and traumatic (blood loss up to 30 % circulating blood volume), anesthesia of choice was endotracheal balanced anesthesia.

Conclusion

A multidisciplinary pediatric team of specialists, gathered to administer skilled and specialized emergency aid to children injured in catastrophes and disasters, has to include no less than two highly skilled professional anesthesiologists-resuscitators that handle presurgery anesthesia-resuscitation supply for children.

Condition of injured children should be anesthesiologically assessed ahead as severe, relative to a high risk of complications (III–IV by ASA scale) during the course of surgical treatment, and as a result, children need to have suitable presurgery infusion and antibacterial and nutritional preparation under team's specialists' supervision (podiatrist, anesthesiologist-resuscitator) no later than 24 h before the surgery.

The selection of the anesthesia type while administering aid to the victims of catastrophes and natural disasters is the prerogative of the anesthesiologist and depends on the severity of patient's condition, associative level, extension, localization, and severity of trauma and should not be limited by specialist's qualifications.

Optimal type of anesthesia at the preparation stage (before 2 weeks have passed), in preparation of a child for closure of tissue defects, is inhalation and intravenous anesthesia. At the second stage (after 2 weeks have passed), as well as in skeletal trauma, all types of anesthesia may be used (intravenous, inhalation, endotracheal, combined), which can supply suitable painkilling for the injured.

Creating the environment (by international and cross-sector decisions) for the fastest possible implementation of multidisciplinary pediatric team of specialist, based on multidisciplinary regional hospitals, in close proximity to the site of natural disaster or catastrophe, will help to optimize the tactics and improve the results of administering professional and specialized anesthesiological-resuscitation help to children, considering endotoxemic, purulent inflammation, and alimentary trophic complications.

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38 Medical Care for Children with Skeletal Injuries After Earthquakes

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38.1 Introduction

Diagnoses and treatment of skeletal trauma is one of the most important problems of medical assistance in earthquakes, especially in the case of mass arrival of traumatized children.

38.2 Epidemiology

Our experience encompasses medical assistance provided for more than 700 children with skeletal injury after 14 largest earthquakes in the world, in extreme conditions, in different countries over the past 27 years. Best results were obtained when care for children was provided by specially trained pediatric traumatologists, who were a part of a specialized pediatric team (Fig. 38.1). The frequency and the age of children with musculoskeletal injuries vary in different earthquakes. As a rule, those are children aged 2 months and older. The reason for that is probably that younger children are better protected by their parents. This chapter is based on cumulative statistics of skeletal injuries in children from all the countries we worked in (our own data) [1].

Speaking about the trauma problem in children, we can state that the younger the child, the greater is the share of concomitant injuries (of two or more anatomical and functional areas) (Fig. 38.2). So, in the structure of patients with concomitant trauma, 56 % were children aged 1–5 years. Half of the children in this group had a head injury of varying severity, but light injuries prevailed. The second frequent concomitant trauma (nearly 35 %) is chest injury with prevailing lung contusion.

At the same time, in 4 % of children in this group, other, more complicated types of trauma with hemopneumothorax were identified.

In every sixth child bone injury was combined with the injury of the peritoneum and retroperitoneum. We saw very few children with spinal injuries. According to our data, among all hospitalized children after the earthquake in India (2001, Gujarat), children with long bone fractures accounted for 41.7 % [2].

A similar trend can be seen in children with multiple (two or more damaged segments) skeletal trauma – more patients (35 %) aged 1–3 years. In this group of patients, we observed

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_38

mostly (70 %) bilateral and often symmetrical injuries. Usually it was the damage of the lower extremities. Second frequent of multiple skeletal trauma was seen in children aged 12–15 years. Most of them sustained unilateral injuries, predominantly in the lower extremities (thigh + lower leg, lower leg + foot bones). In the same age group, open and comminuted fractures of the long bones prevailed – almost every third child had it (Fig. 38.3, injury of the femur and lower leg in an 11-year-old child) (our own data) [1].

Fig. 38.1 Specialized team in the operating theater. Application of ilizarov external fixator

According to our cumulative statistics, in hospitalized patients we mostly see isolated injury (59 %), followed by multiple and combined trauma (19 and 17 % correspondingly), and rarely combined injuries with burns (5 %) [1].

Localization of isolated injuries is shown in Fig. 38.4. Among all injuries of the bone system, the most frequent are fractures of the lower leg then of the femur and humerus.

Most of the 3000 traumatized children (60.4 %) after the earthquake in Armenia (1988) sustained musculoskeletal injuries. Of these, closed fractures of the long bones made up almost 20 % and open fractures 8.6 %. As in other countries, most frequently were identified fractures of the lower legs, then thighs and forearms. 11.3 % of them were accompanied with Crush syndrome.

According to our data, in the earthquake in Armenia (1988), the number of open fractures of long tubular bones was about 50 % less than closed ones [1].

The most significant feature of children's trauma is the healing time of bone injuries. The younger the child, the sooner the primary bone callus is formed, followed by fracture healing. Therefore it is very important to not just early diagnose existing injuries but also perform early

Fig. 38.2 Brain CT Scan of 8-months-old child that suffered multiple trauma including head injury as a result of an earthquake

reduction of bone fragments. Bone callus develops in young children within 5–7 days, in which case, if no primary reposition has been performed or fracture healing went wrong, it may require osteoclasis followed by repositioning (Fig. 38.5, improper splicing of bone fragments) [3, 4].

Fig. 38.3 Femur and tibia/fibula fracture in 11-year-old

In the younger age group, the absolute majority of fractures of the long bones are oblique, with a relatively large surface of bone injury, which significantly aggravates the situation if fracture healing went wrong (Figs. 38.6 and 38.7, improper management of patients with a thigh injury and an X-ray of the patient). It would be impossible to perform just osteoclasis with subsequent repositioning on such patients after 14–21 days, and if it becomes necessary to eliminate a deformity, in the future the patient will have to undergo a very traumatic osteotomy [5].

In about 30 % of the children older than five, skeletal trauma is accompanied by pronounced soft tissue injuries that require special, unique for each case tactics of treatment of bone fractures. At different stages of surgical treatment and of rehabilitation of the patient, we use different methods of immobilization [6, 7] (Fig. 38.8, soft tissue damage and an open fracture of the femur).

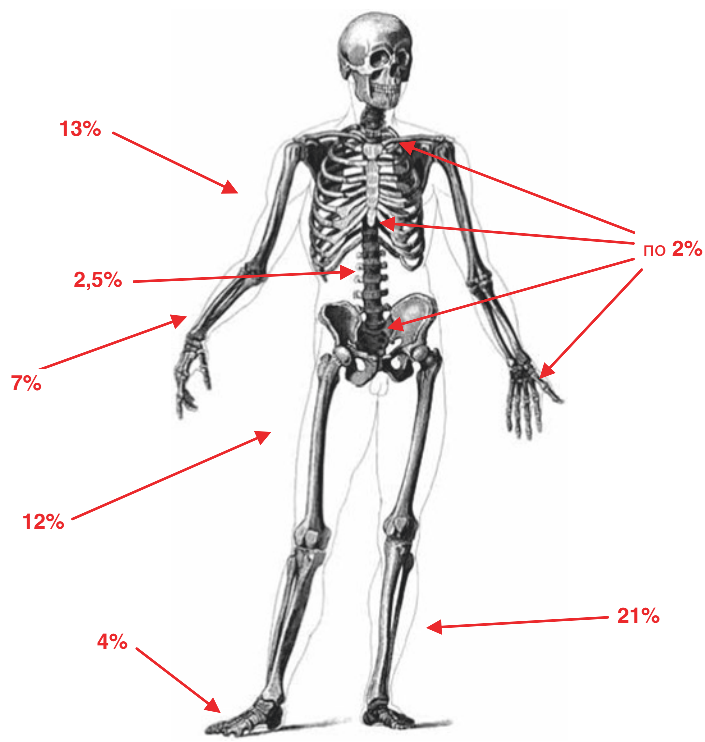

Fig. 38.4 Distribution of the skeletal trauma: Humerus: 13%, forearm: 7%, wrist and hand: 2%, clavicle: 2%, ribs: 2%, spine: 2.5%, pelvis: 2%, femur: 12 %, lower leg: 21%, foot and ankle: 4%

38.3 Equipment

Selection of tools, external fixators, and implants for children becomes a matter of particular importance. This is a significant aspect of children's traumatology. Wrong selection of external fixators and implants causes severe complications. If the variety of implants that have been selected and applied is poor, immobilization, which is vital for osteosynthesis, will not occur and that will entail at least prolongation of treatment or, what is even more unacceptable, non-union. Improper selection of implants or external fixators or wrong method of reduction (a very important point for daily practice in pediatrics and not only for work in emergencies) not only lengthens the time of fracture reduction under general anesthesia but very often causes complications like additional fragmentation of damaged bone and inefficient mobilization.

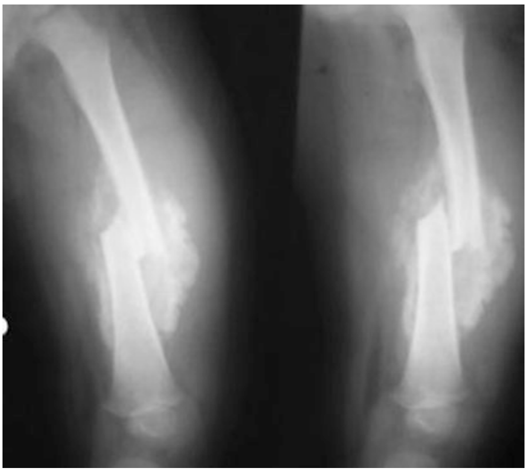

Fig. 38.5 X-rays of malunited fracuted femur on 12th day after the injury

Despite usual limitations in time and equipment, it is very important for emergency surgeon-traumatologists, who provide specialized assistance, to keep in mind when choosing the method of reduction and fixation of a fracture that for almost all the children, unlike adults, the time will come to have those implants removed. And that means that all the components that are used (different plates, intramedullary rods, external fixators, and screws) should be standard, certified, and authorized for use in order to prevent unforeseen complications when being removed.

38.4 Errors in the Treatment of Skeletal Injuries in the Disaster Zone

Providing emergency assistance to children in earthquakes typically involves dealing with massive influx of victims, shortage of specialists, and scarcity of radiological equipment, in particular,

Figs. 38.6 and 38.7 Splinting and x-rays of immobilized fractured femur

of electronic optical converters (EOC, C-arm). Based on our experience, by the time of our arrival (2–3 days after the earthquake), many children had not received any help at all.

Their limbs were fixed with available nonmedical material, and no reduction was done. In fact, we started working from scratch. In this regard, it is important for medical teams to include in the equipment they bring along a portable X-ray machine and other tools that can facilitate fracture reduction and fixation with either external fixators, elastic intramedullary nails, or plates and screws.

We have identified a number of shortcomings in the treatment of skeletal injuries in children during the first days of their stay in the hospital before the specialized pediatric team arrived. These include insufficient diagnoses of skeletal injuries. According to our estimates, about 15–20 % of fractures are not diagnosed in the first 2–4 days. Delay in the optimal timing of fracture reduction was found in almost 50–60 % of the injured. Immobilization of closed/open fractures is often performed without reduction, and solid plaster casts are applied (Pakistan, Indonesia), which almost always cause complications, including compression of the soft tissues with subsequent necrotic and persistent neurological complications (Figs. 38.9 and 38.10, circular cast and necrotic changes in the area of damage).

Often surgical treatment is avoided due to the lack of proper equipment and tools, lack of qualified specialists, and lack of appropriate training. Many times providers select wrong implants or improperly fix bone fragments which results in an unstable fixation, continuing pain, and unreduced dislocations. All these errors lead to stabilized deformation and dysfunction of the segment, as well as to development of purulent inflammatory complications (inflammation of soft tissues, osteomyelitis, etc.) [1, 2, 7].

Fig. 38.8 (Pakistan 2005)

Fig. 38.9 Circular cast applied right after acute trauma

Fig. 38.10 Same child. Neurovascular damage leading to soft tissue compromise: skin necrosis, infection

Fig. 38.11 10-year-old child. Open fracture right lower leg. Surgery: reduction and application of external fixator with primary wound closure. Wound infection on 2nd day after surgery. (Indonesia 2006)

We have seen very high rate of infection in children with open fractures who had their wound primarily closed (LM Roshal, 1998) (Fig. 38.11, wound infection on the second day after the operation).

38.5 Prehospital Stage

Providing first aid to children in emergency situations, it is important to remember that self-help here is out of the question, as well as – in many cases – mutual help, so children should be the first to receive medical help in emergencies.

Using staged approach is of primary importance in the management of patients with skeletal trauma in disasters. The following are the principles of stage approach also known as damage control:

- First, the patient should be carefully removed from the epicenter and gently evacuated.
- At the first stage of medical assistance, it is most important to provide transport immobilization and analgesia and also antishock therapy, if indicated.
- Skilled care includes choice and substantiation of the most efficient method of stable functional osteosynthesis (reposition and fixation of damaged bone segments).

First aid for fractures should aim at:

1. Relief of pain (with analgesic agents in age-appropriate dosage)
2. Quality immobilization (transport immobilization) of the affected limb
3. Stopping the bleeding and prevention of secondary wound infection (in open fractures); protruding bone fragments cannot be immersed in the wound

Immobilization of injured segment for the time of medical evacuation (transportation) of the patient to the hospital is very important, both for the survival of the victim and for the further course and outcome of the fracture. Transport immobilization is carried out with the use of special splints or those made of available materials, as well as by dressing application. Currently, vacuum mattresses and splints are considered most efficient.

Basic principles of transport immobilization:

1. The splint should block at least two joints (above and below the fracture).
2. The brace should be modeled based on the healthy limb.
3. During immobilization, the injured limb should be placed in the physiological position or, if impossible, in the least traumatizing position.
4. In open fractures bone fragments should not be reduced; aseptic bandage should be imposed and the limb fixed in the position it was at the time of injury.
5. There is no need to remove clothing from the patients with closed fractures; for those with open fractures, it is necessary to apply aseptic bandage.
6. Hard splint cannot be applied right on the body. It is necessary to put a pad underneath it (cotton, gauze, sheets, towels, etc.).

Incorrect immobilization can harm the victim. Please note that use of circular plaster bandages on children with acute injuries is inadmissible. This provision concerns primarily the victims who are subject to evacuation to the next stage of medical care and also children of younger age groups. They are most susceptible to irreversible neurocirculatory impairments in the limbs that may develop very fast (due to the compression by the plaster bandage), which leads to the occurrence of compartment syndrome. Plaster splints that are accepted in the pediatric trauma practice should cover no more than 2/3 of the circumference of the affected limb [8].

38.6 Hospital Stage

Substantiation of rational trauma care (surgical) tactics in children with skeletal trauma at the hospital stage during a massive influx of patients becomes a complex and often controversial issue. Selection and substantiation of the method of treatment of skeletal injuries are determined by several factors, including:

- The condition and equipment of the hospital in which the staged treatment of child victims is provided
- Availability of specialists (pediatric surgeons, traumatologists, pediatric anesthesiologist-resuscitators) and their qualifications and experience
- The age of the victim and severity of their general condition
- Localization of damage and the nature of the skeletal injuries

Obviously, the greatest difficulties (due to the objective difficulty of diagnosis and prognosis) are associated with arranging stage treatment for the children with polytrauma (multiple, concomitant, and combined injuries).

In providing specialized trauma assistance to patients with skeletal injuries, particularly when multiple trauma is present, we have always adhered to the principle of "damage control," which implies that surgical care to the patients of this category should be divided into two stages.

At the first stage, we perform minor and low-traumatic surgeries for life-threatening injuries and low-traumatic procedures aimed to prevent complications. At the second stage, after the general condition of the patient has been stabilized, we perform necessary recovery operations. Thus, during the first days, considering the sanitary-epidemiological situation (mass inflow of victims), preference should be given to low-time-consuming conservative (less traumatic, sparing) methods of immobilization for temporary stabilization of fractures. Once the sanitary-epidemiological situation has been normalized (when the inflow weakens or stops) and life-threatening conditions (shock, bleeding, unstable hemodynamics) in a particular patient has been eliminated, we recommend using highly effective contemporary methods of stable functional osteosynthesis for the final fixation of fractures [1].

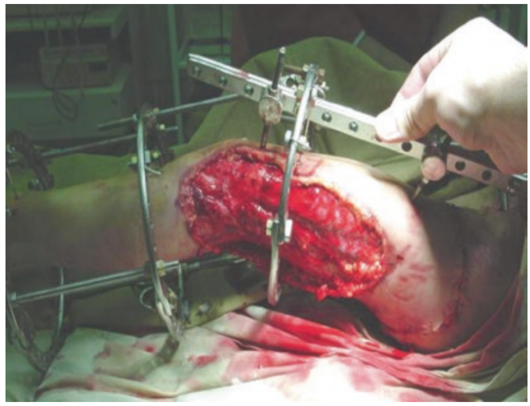

Fig. 38.12 13-year-old child with open left femur fracture with soft tissue damage extending into lower leg. Treatment: External circular/hybrid fixation

In the late 1980s and early 1990s in emergency situations (in Armenia, Georgia, Dagestan), treatment of skeletal injuries in hospitalized children was mostly conservative – fracture reduction followed by plaster immobilization or permanent skeletal traction. For open fractures it was a plaster cast immobilization with a "window" left in the projection of the wound or skeletal traction. Also for extrafocal osteosynthesis, we used devices for external fixation (Ilizarov apparatus, Volkov-Oganesyan, and others) (Fig. 38.12, an open fracture of the left femur with damage to soft tissue; installation of a combined wire rod device).

As a rule, closed reduction of fractures and dislocations or use of permanent extension

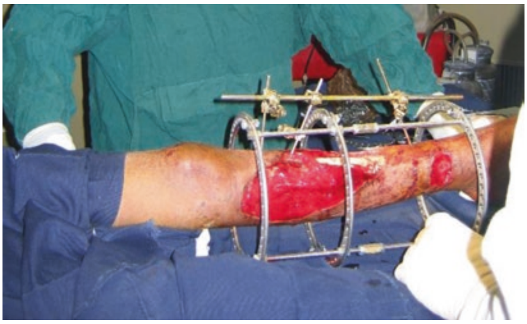

Fig. 38.13 12-year-old patient with open fracture and extensive soft tissue injury. Treatment :Ilizarov apparatus. (Earthquake Pakistan, 2005)

(skeletal or adhesive bandage traction) provides quite satisfactory anatomic and functional results in pediatric practice. At the core of this approach is a tendency to spontaneous correction of residual (permissible) displacement of bone fragments in the process of fracture healing and consolidation. At the same time, actually, "self-correction" does not work on incorrectly healed fractures of long bones with rotational and some angular deformities. It is critical that during the localization of fractures in epiphyseal zones, bone fragments should be matched very thoroughly, to prevent possible failure of bone growth [9, 10].

The widespread implementation of external fixation devices of various designs (unilateral, biplane type, etc.) in the daily clinical practice created favorable conditions for comprehensive medical support for children with injuries of the musculoskeletal system of different nature and localization. Using external fixation devices in emergency situations during mass admission of victims was very appropriate, especially in the presence of extensive wounds and soft tissue defects of the damaged segment of the limb and of a real threat of infection and development of purulent inflammatory complications (Fig. 38.13, Ilizarov apparatus) [6, 11].

Among the advantages of transosseous extrafocal osteosynthesis by external fixation devices of various designs is the possibility to achieve complete reduction of bone fragments in all cases without additional surgical treatment regardless of type, nature, severity, and location of the fracture. This method ensures reliable and stable fixation of bone fragments for the duration of healing without turning off joint function, as well as allows to maintain active functional therapy starting 2–3 days after the unit has been installed, so that the periods of full anatomical and functional recovery of the injured limb run concurrently The duration of treatment of children with skeletal trauma (such as diaphyseal fractures of the femur) aged 1–15 years, who have used external fixation device, is much shorter than in children treated conservatively – by skeletal traction followed by plaster immobilization.

The rapid development of medical science and technology in the 1990s and 2000s made it possible to develop and implement new high-tech methods of stable functional osteosynthesis in practical traumatology. It helped to prevent complications, eliminate additional external immobilization, and facilitate early rehabilitation treatment which significantly reduces time of medical and social rehabilitation [2, 3, 10, 12–14].

There is a wide range of devices that are used in everyday practice – TEN (titanium elastic nail), LCP (locking compressing plates), intramedullary nails, compression screws, various extramedullary plates, and others that allow to almost completely abandon the skeletal traction, skin traction, bulky plaster casts, diverting splints, and to exclude secondary dislocations (Fig. 38.14, TEN).

Currently, we use the following approach. For fractures of the long bones in children, as a minimally invasive method of stable functional osteosynthesis, we perform closed reduction and intramedullary fixation by flexible TEN or AO plates with angular stability and locking intramedullary nails (UFN, UTN, PFN). It should be noted that in recent years the most common practice in treating trauma has become the method of closed intramedullary nailing (Fig. 38.15, X-ray of intramedullary nailing with TEN AO).

Fig. 38.14 TEN by AO

Indications for use of flexible TEN AO:

- Diaphyseal (AO fracture classification; 3.2. A 1–3, B 1–3) fractures of the femur in young children (2–8 years).
- Fractures (4.2. A2.3 B2) of lower leg bones in children of younger and medium age group (7–12 years).
- Fractures (1.2. A1.2.3 B2) of the diaphysis of the humerus in children of medium and older age group (7–15 years).
- Proximal humerus fractures in children of medium and older age groups (7–15 years). Only in these cases, the fixators are driven through the bone sprout zone, but no negative effects have been observed.

Nailing with flexible TEN allows early ambulation of the patient; patients start on movement in bed immediately after the pain subsided. For example, children 2–4 years old with diaphyseal femur fractures start on independent, active movement of the damaged foot in 1–2 days after surgery. Limited axial load on the injured limb is allowed after 2–4 weeks.

Fig. 38.15 X-rays of femur shaft fracture treated by reduction and intramedullary fixation with TEN AO

Fig. 38.16 Locking plates

When intramedullary nailing cannot be used, it is possible to use locking plates (Fig. 38.16, plate with angular stability).

Indications for use of locking plates (plates with angular stability LCP):

- Oblique comminuted, helical (4.2.A1, B1, 4.3.A.2) lower leg fractures in children of older and medium age group, including fractures of the distal metaepiphyseal zone
- Oblique comminuted, helical (3.3.A2.3) fractures of the distal femur in children of medium and older age groups

LCP osteosynthesis allows the ambulation of the patient immediately after the pain subsided (1–2 days after surgery). Limited axial load on the injured limb can be allowed within 3–4 weeks (Fig. 38.17, lower leg X-ray with extramedullary plates).

Indications for use of locking intramedullary nails (UFN, UTN, PFN) (Fig. 38.18, locking nails):

Fig. 38.17 X-rays of tibia fracture treated by locking plate

- Transverse, oblique-transverse, and comminuted fractures of the femur and low leg fractures (3.2.A2.3, V2.3 4.2.A2.3 V2.3, C2) in children of older age group (12–17 years)

This method allows early ambulation of the patient; axial load is allowed after the pain subsides. Note that the method of UFN and PFN involves trauma of the physeal trochanteric area of the thigh, but no negative consequences have been observed.

Fig. 38.18 Intramedullary locking nails (UFN, UTN, PFN)

Also, insertion technique of nails – Expert (UFN and PFN) – for treatment of lower leg fractures requires driving them through the growth zone of the tibia. That is why for such fractures it is more reasonable to use only UTN osteosynthesis or TEN nailing for younger children (Fig. 38.19, X-ray of lower leg fracture with locking nails).

In localization of fractures in the distal femur and tibia, separate compression screws are used as fixators (Fig. 38.20, compression screws). Their use is indicated for treatment of metaepiphysiolysis of the distal tibia (4.3.A1.2) and femur (3.3. A1) in children of older age group (12–17 years). Ambulation of the patient becomes possible after the pain subsides; axial load is permitted after 3–4 weeks (Fig. 38.21, X-ray of fracture of the distal tibia with compression screws.)

Only in some cases, functionally stable osteosynthesis of comminuted fractures can be performed with the use of conventional invasive techniques with wide surgical access. Sometimes it can be combined with closed reduction and percutaneous osteosynthesis [2, 11].

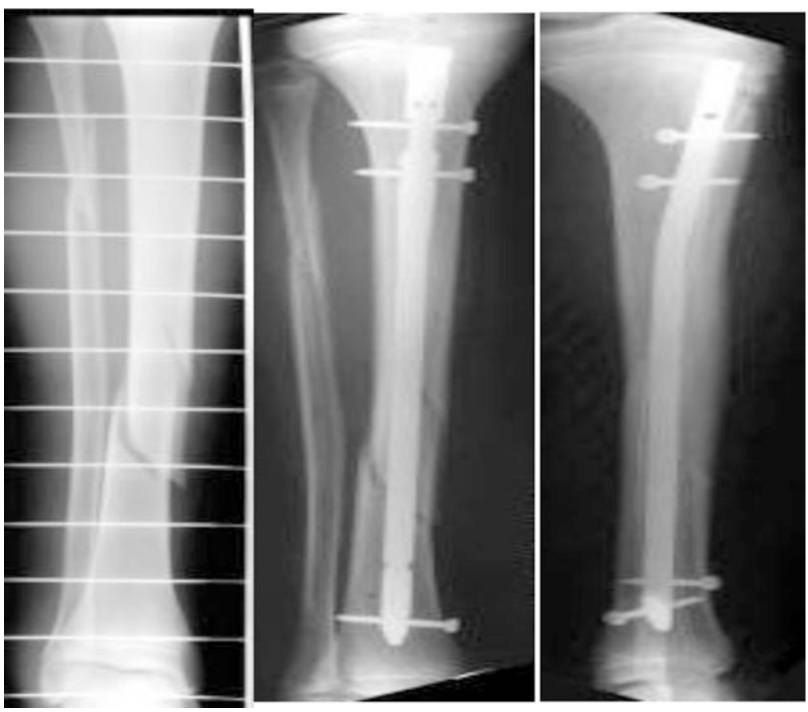

Fig. 38.19 X-rays of Tibia fracture treated with intramedullary locking nail

It should be noted that implementation of stable functional osteosynthesis does not aggravate the dynamics of prevailing injury. On the contrary, it substantially contributed to the positive dynamics, including children with multiple injuries [12].

In recent years, use of biodegradable implants as external fixators in treatment of children with near and intra-articular fractures by means of stable functional osteosynthesis was introduced into practice.

The advantage of these implants compared to other high-tech external fixators is that patients do not need to have another surgery to remove the fixator (Fig. 38.23, X-ray fracture of the distal tibia with biodegradable implant).

Treatment of affected children with open injuries of soft tissue and bones, complicated by purulent infection, was performed in accordance with the principles of active surgical treatment of wounds, which included:

Fig. 38.20 Compression (lag) screws

1. Radical debridement with removal of all devitalized tissue.
2. Local treatment of wound with multicomponent polyethylene glycol (PEG)-based ointments or iodophor solutions.
3. Primary or early immobilization of fragments of long bones with external fixation devices.
4. Primary or early wound closure and replacement of soft tissue defects only if the child was admitted to the hospital for treatment within 1 (first) day after the injury, if there are no signs of compression and crushing of soft tissue in the damaged segment. If the child comes in on a later date, or if there are signs of impairment of microcirculation in soft tissue or above complications, primary wound closure should not be performed under any circumstances, due to a high risk of subsequent infection.
5. Primary or early osteoplastic operations.
6. Rational strategy of use of anesthesia in surgical procedures and advanced dressings in multistage surgical treatment.
7. Multicomponent intensive care, including antibacterial therapy.

Despite the known disadvantages (large number of patients, "foreign" work environment, highly laborious surgical tasks, etc.) in great majority of cases that involved closure of wound surfaces and replacement of tissue defects, preference was given to methods that allowed to fully restore the skin – 77.6 % [1].

Wound coverage with local tissues was used in children with the wound surface area not

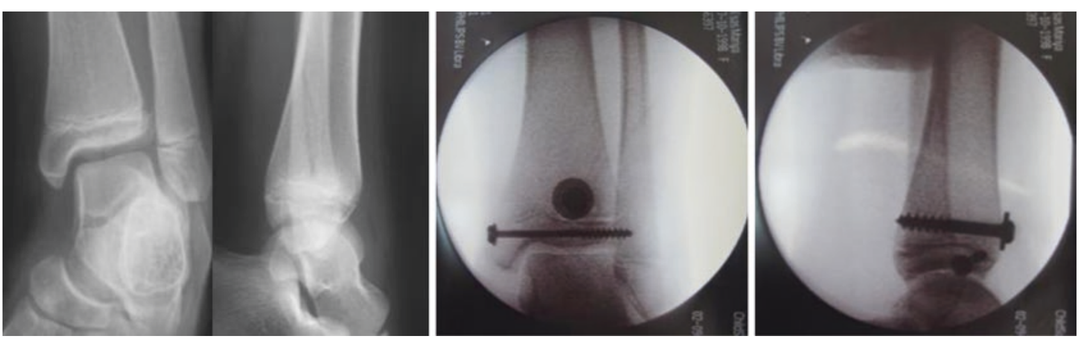

Fig. 38.21 X-rays of distal metaphyseal tibia fracture treated with compression screws

exceeding 200 cm^2 – 207 (74.7 %) cases. A prerequisite for the use of this type of plastic surgery was presence of a sufficient amount of healthy soft tissue around the wound.

Fig. 38.22 Biodegradable screws

In 41 cases (14.8 %) when the size of the skin defect did not allow immediately closing the wound surface despite the broad mobilization of the wound edges, the method of gradual tissue stretching was applied.

In cases of extensive damage and pronounced defects of the soft tissue in functionally active areas, loose displaced skin-fascial and skin-muscle flaps were used – 8 (2.9 %).

The combined use of methods of plastic surgery for closure of wounds was used in 80 (40.6 %) patients. In all cases, a satisfactory result has been achieved. Only 5 (2.5 %) patients reported minor necrosis of flap edge, which was cropped during subsequent dressings (healing by secondary stretching).

38.7 Complications

Complications of skeletal trauma can be divided into three large groups:

1. Caused by circumstances of injury. Mostly neurocirculatory disorders, occurrence of purulent-septic manifestations.

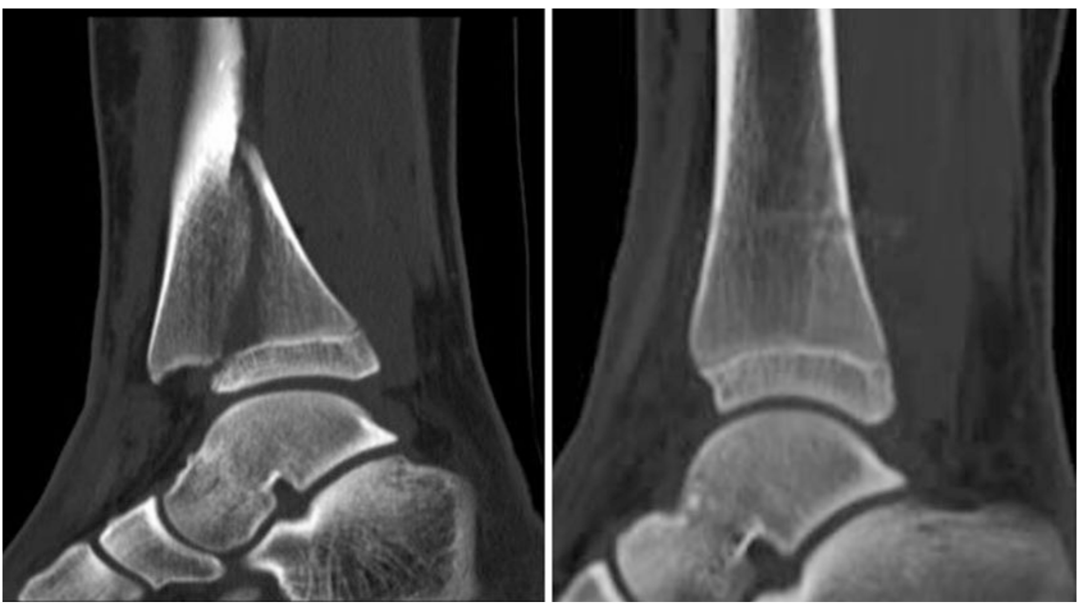

Fig. 38.23 X-rays of distal tibia fracture. Reduction and fixation with biodegradable screws

2. Resulted from underestimation of the severity of soft tissue injury in the area of the fracture, which also leads to purulent-septic complications.
3. Irrational choice of treatment of skeletal injuries, which can lead to a significant slowdown of consolidation, up to the full nonunion or improper fracture healing, which leads to long-term dysfunction of the affected limb and requires multiple reoperations with difficult recovery and high chance of disability of the patient.

Conclusion

Skeletal trauma in children during disasters is very common and associated with high risk of subsequent disability. In this regard, assistance provided to this category of patients requires high-level organizational arrangements that would determine the sequence and scope of assistance at every stage. To improve the level and quality of care and to reduce the severity of health effects, it would be more efficient to engage specialized teams of traumatologists and surgeons using the common approach to the methods of care, algorithms of actions, and surgical tactics. These specialists should be good at teamwork and have a good command of contemporary high-tech techniques of treating injuries in children. Such teams must be equipped in such a way as to have the ability to work independently, without engaging technical resources of local hospitals. It allows to expand overall capabilities of care and to increase the number of children who undergo urgent medical treatment. In our opinion, based on 27 years of experience, the team approach allows to achieve the best results in treatment and rehabilitation, to significantly reduce irretrievable losses and complications, and to provide effective assistance to local medical colleagues and the affected population.

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Crush Syndrome in Children

39

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39.1 Epidemiology

Traumatic rhabdomyolysis, or crush syndrome, is the most frequent reason for permanent disability or death as a result of earthquakes [2–4, 6–9, 12, 16, 17]. Its prevalence depends on many factors, but, first of all, it depends on the structure (stone or wooden) of the buildings, on their purpose, on the amount of children indoors, on the percentage of the country's child population, on the time of day when the earthquake occurred, etc.[12]. For instance, in northern Afghanistan (1998) or Japan (1995), the amount of those who suffered from crush syndrome during an earthquake was a few times smaller than during earthquakes in Armenia (1988) or Neftegorsk (Sakhalin, 1995) [12].

The devastation in Turkey (1999) in the private sector was less severe than in the public one, which can be explained by higher quality of the construction work [5, 15]. Crush syndrome in children in Turkey (1999) represented 52 % of all the injuries [12]. The same high percentage of children with crush syndrome was observed after the earthquake in Neftegorsk (Sakhalin), when stone buildings were destroyed during nighttime. There were fewer children with crush syndrome in Egypt (1992), Algeria (2003), Pakistan (2005), Indonesia (2006), and Haiti (2010) [10–13]. After a powerful earthquake of 6.3 in Iran (Bam, 2003), about 22 thousand people were injured [14]. Children make up 50 % of the population. However, the amount of children with crush syndrome was small, because in 90 % of cases the buildings that were destroyed were made of clay. In India (2001), the children with crush syndrome made up only 2.9 % of those transported to hospitalization from the disaster zone [12].

The prevalence of various loci of crush syndrome among children in Turkey (1999) is visualized in Fig. 39.1. The diagram shows that the most frequent injury localized on the thigh and then shoulder, foot, and toes. Children with crush syndrome were arriving at inpatient hospitals at variable times depending on the geographic factor, namely, how far was the epicenter of the earthquake from local inpatient hospitals that were intact and able to administer aid, and

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_39

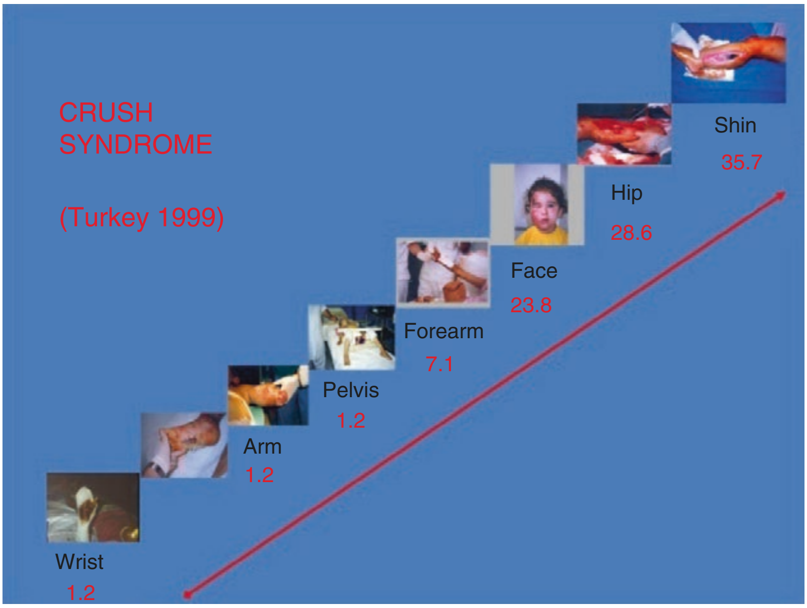

Fig. 39.1 Crush syndrome localization in children (Turkey)

also depending on the unfolding of the rescue operations and on how well the evacuation was organized [12]. In Afghanistan, for instance, travel to certain destroyed settlements took 5–6 days.

39.2 Clinical Findings

The clinical aspect of crush syndrome is known and it does not raise any questions.

In order to determine treatment strategy, it is important to determine the level of damage to the injured body part (most often, the extremity). In our practical work, we have tentatively divided crush syndrome into three stages: one, two, and three.

We classify children with little edema and soreness of an extremity or its parts, without any serious functional disruption and no signs of intoxication, as stage one. The extremity may be larger by 20–30 % as compared to the healthy one. Level two is classified by increased edema, soreness, density of the extremity, and its functional restraint. The extremity may be larger by 50 % as compared to the healthy one (Fig. 39.2).

Fig. 39.2 Photo of the child with crush syndrome of the left hip

The skin might acquire a reddish-brown color with petechiae. Thick consistency of adjacent tissues is determined by palpation. The intensity of the edematous infiltrative process of the separate muscle groups within one segment of an extremity often varies significantly. Active and passive movements in adjacent joints are restricted due to soreness. Distal from the affected spot, artery pulsation is absent. Signs of intoxication increase, and hemodynamic changes may occur, as well as the initial signs of acute kidney failure. Stage three is the most severe, with a full-scale picture of intoxication, hemodynamic disruption, and acute renal failure. The extremity may be twice as large as its healthy counterpart. This is a very broad-stroked picture where one can encounter possible transitional and mixed forms.

To determine the changes in edema levels, a simple "thread" probe (L. Roshal) is used, in which the thread is tightly tied around the thigh, shin, forearm, or upper arm, and judging by its tightening or loosening in the course of time, one determines whether there is an increase or a decrease in the edema of muscles located in the dense casing of the muscle sheaths that intensify the disruption in the blood flow. In order to detect the presence of blood flow, one can use the indicators of oxygen and carbon dioxide saturation in the blood taken from the toes on the affected side.

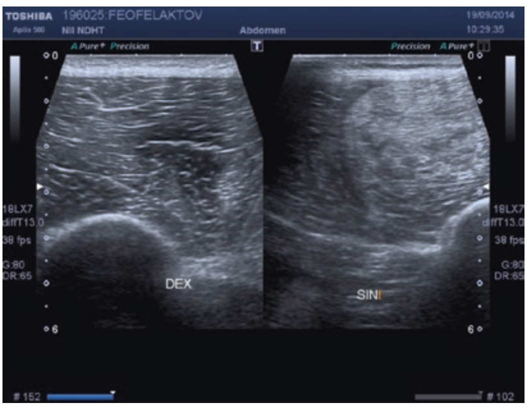

Fig. 39.3 Ultrasound image (normal and muscle contusion)

In 1995, as a result of the earthquake in the island of Sakhalin, two children most severely affected by the crush syndrome were promptly transported from Sakhalin to Khabarovsk over almost 1000 km. We used a CT scan to evaluate the afflicted muscles for the first time in clinical practice. Based on data received from CT scanner, one can evaluate the density in symmetrical muscles. In the afflicted muscle, the density decreased almost twice. Now we have modern ultrasound devices, as well as MRI, at our disposal. Ultrasound images in Figs. 39.3, 39.4, and 39.5 demonstrate thigh muscles in their normal state and in their contused state, including both the vascular mode and MRI.

In order to determine the degree of conservative treatment, it is important to repeat the tests of myoglobin levels in blood and urine, as well as all other laboratory samples that indicate renal function and risk of a fatal complication – renal failure (creatinine, urea, etc.).

In order to rule out any acute damage to long spongy bones, both frontal and lateral X-ray imaging is obligatory in crush syndrome cases. On one occasion, we used expert biopsy of the affected muscle, and based on its results, we have confirmed its demise. Myography appeared to be inefficient, and obtained data are inferior to the ultrasound and MRI tests (Fig. 39.6).

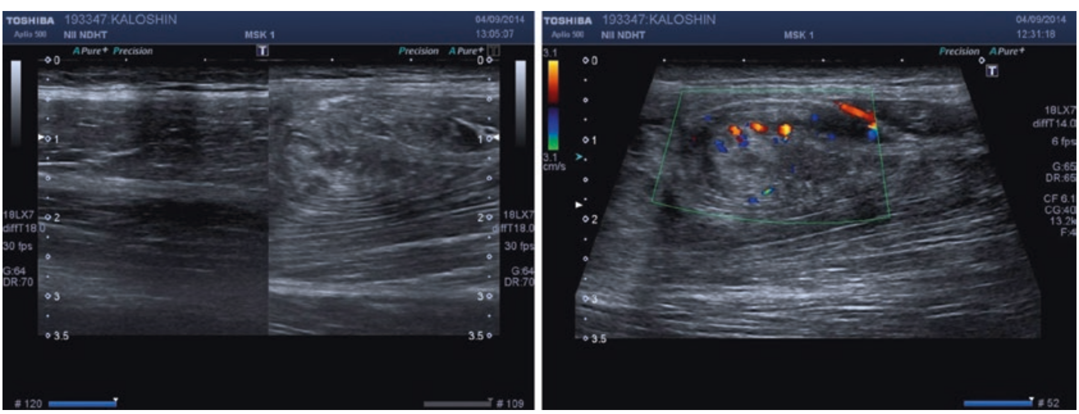

Fig. 39.4 Ultrasound image (normal and injured muscle, vascular mode)

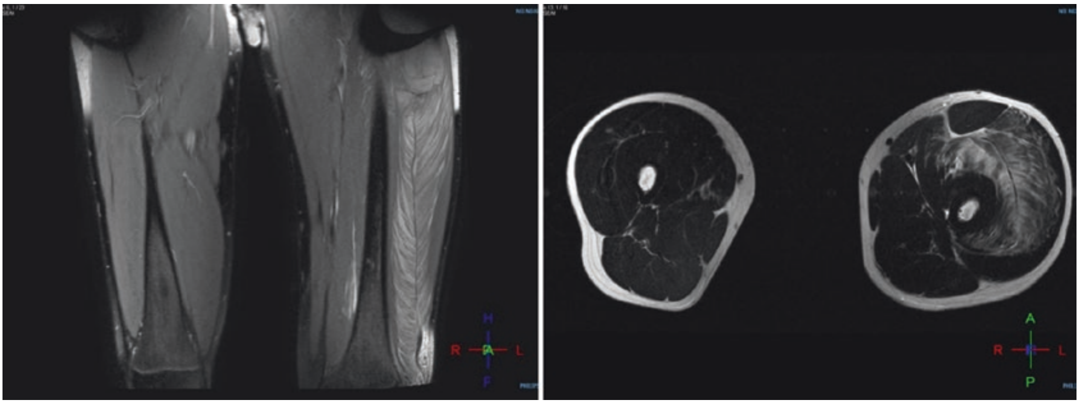

Fig. 39.5 MRI image (normal and injured muscle)

Fig. 39.6 Myography

39.3 Treatment

39.3.1 Conservative

The treatment of crush syndrome patients must begin even before extracting the body from under the wreckage, when any first intravenous access is established. The goal is to protect organism from reperfusion of the massive resorption of the muscle's breakdown products. Regardless of the crush syndrome stage, the treatment should always begin with antishock therapy, intravenous pain medication, and infusion therapy. Base dopamine injection (after alkalinization) and injection of 20 % glucose with Curantyl and Lasix in cases of inhibited excretory kidney function are an effective treatment for homeostasis correction and microcirculation recovery in the kidneys, among others [1]. These procedures are included in the first aid toolkit for the conservative treatment of crush syndrome stage 1. In stage 2 cases, in addition to the above treatment, it is recommended to add plasmapheresis (daily, in serious cases) and hemodialysis with ultrafiltration in case of intense renal failure development. Circular anesthesia and plaster splint casting are prohibited.

39.3.1.1 Approaches to Bandaging

On occasion, children are admitted to the hospital with the bandage that was applied on the spot, where the disaster occurred. There have been cases of fatalities that resulted from bandage removal without prior antishock and detoxifying treatment. If the child is admitted with a bandage applied at the time of extraction from beneath the rubble, then it is necessary to set up intensive detoxifying intravenous treatment prior to bandage removal, in order to prevent the pathological substance of the injured extremity from immediately getting into the general bloodstream and to continue the treatment after bandage removal. Our experience of administering specialized medical aid to earthquake victims testifies that even nowadays, as the first step of the so-called "pathogenic" treatment of crush syndrome, bandage is frequently applied to the extremity in order to temporarily reduce the toxin resorption from the affected segment. In these cases, instead of bandage application immediately after compression removal, it is viable to apply a light bandage to the extremity so as to prevent postischemic edema development without disrupting the blood flow in the extremity. Definite indications for bandage application are arterial hemorrhage in the affected extremity and total destruction of the constricted extremity or the development of major gangrene, in other words, unequivocal indications for amputation.

39.3.2 Surgical Treatment Methods

Surgical approach depends on effectiveness or ineffectiveness of the conservative therapy (Fig. 39.7).

In stage 2 cases, it is possible to monitor the patient while administering intensive basal care for 1–2 days. In the absence of obvious improvement, one must consider diagnostic-decompressive subdermal fasciotomy, along with maximum revision of all fascial compartments and maximum muscle release from compression within the fascial compartment (Fig. 39.8).

If necrosis of a specific muscle or group of muscles is discovered during diagnostic-decompressive

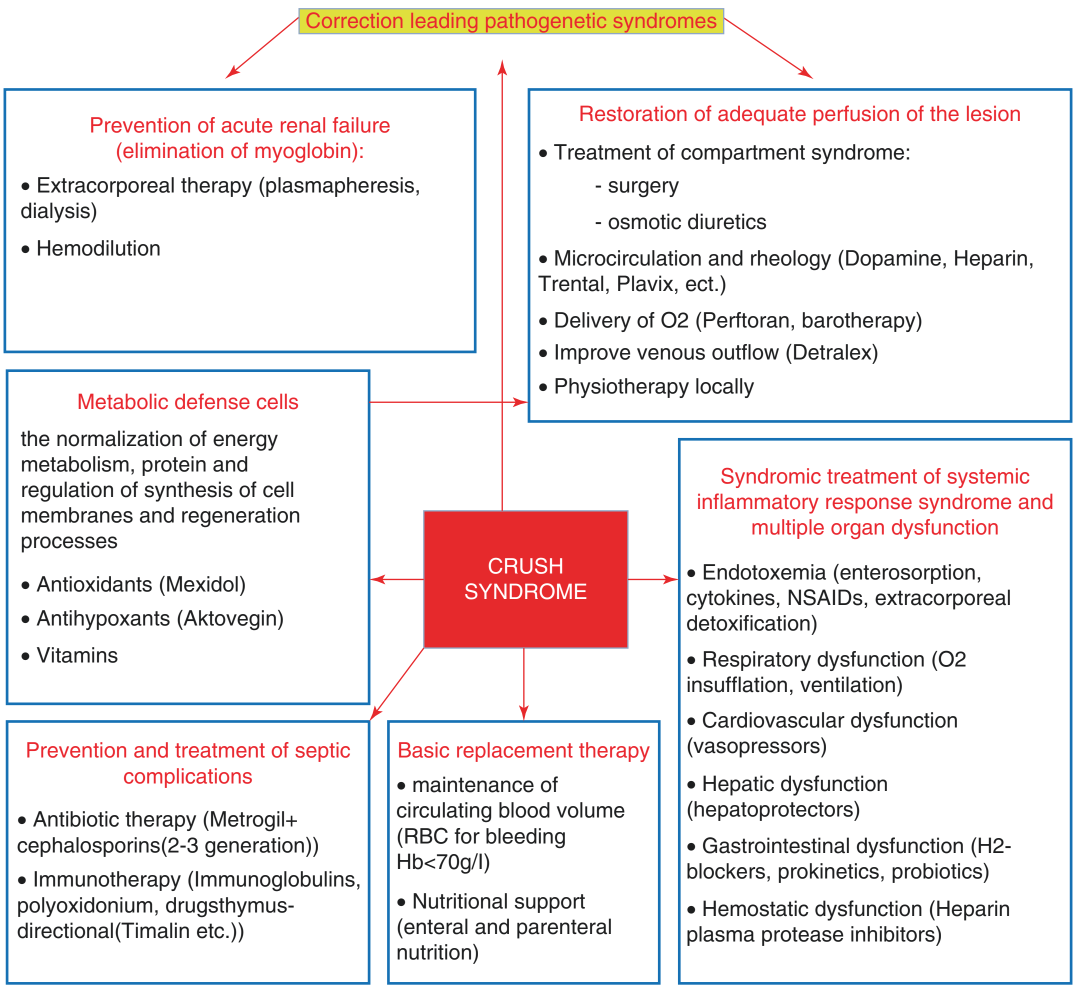

Fig. 39.7 Crush syndrome treatment

Fig. 39.8 Photo of the child with hypodermal fasciotomy

Fig. 39.9 Photo of the child with prolonged incision

Fig. 39.10 Photo of the child with local gnotobiotic camera

subdermal fasciotomy, then one moves to vertical incision with extensive excision of all observed nonviable tissues. Extensive opening of all fascial compartments in the affected area, with additional necrectomy as necessary, is considered to be one of the fundamental early detoxifying measures, since only after their execution can intensive therapy and efferent detoxifying methods result in the desired effect. This intrusion requires strong knowledge of the anatomy of the extremity and a highly qualified and skilled surgeon. It is reasonable to combine fasciotomy with division, revision, and drainage of the intermuscular spaces and muscular compartments.

Lengthy longitudinal incisions are made within the muscular mass based on the consideration of the anatomy of neuromuscular bundles at a distance from joints (Fig. 39.9).

Fascial dissection is made over the longest possible stretch, after blunt muscle detachment. Massive foci of muscular tissue necrosis discovered while performing broad fasciotomy, as well as severe purulonecrotic complications resulting from open tissue damage, are absolute indications for radical surgical treatment. Surgery is completed without sewing up the wound.

Postoperatively, as new foci of necrosis and purulent inflammation appear, recurrent surgical treatments are repeated radially, until the wound is cleared completely. Local wound treatment is performed with iodoform solutions, hydrophilic hyperosmotic ointments, gnotobiotic camera (Fig. 39.10), and, when possible, vacuum bandages.

Considering the large amount of victims with open soft-tissue and bone injuries, we prefer multicomponent polyethylene glycol-based ointments with high hyperosmotic effect and prolonged action period (18–22 h during wound inflammation phase and up to 48 h in regeneration phase).

Surgical treatment of necrotic and purulent focus in crush syndrome results not only in complete wound clearing but also extensive tissue defect and extensive wound surfaces. Comprehensive treatment helps to reduce microbial contamination of wound tissues to subcritical levels and to shift the wound process from the inflammation phase to the regeneration phase in the course of 15–24 days. During surgical treatments, the size of tissue defects and wound surfaces increases even more. In our observations, surface area of the wounds formed after appropriate surgical treatment varies from 100 to 2000 cm^2, while the length of long-bone defects varies from 4 to 12 cm. All these would require various reconstructive-restorative operations.

Due to the distinctive nature of the wound process, surgical wound closure in crush syndrome becomes possible only at a later stage, in the presence of cicatricial changes in tissues. This stage is not generally discussed in literature, because surgical approaches have not been deliberated and tend to be conservative. Wound closure is performed with delayed secondary sutures, with the aid of free dermatomal plasticity, or occurs by virtue of secondary adhesion. The development of cicatricial contractures is described as a standard consequence of surviving crush syndrome. At the same time, as our observations indicate, the earlier skin restoration is performed, the better the cosmetic and functional results are and the sooner rehabilitation treatment may begin.

Our experience allows us to reject the pessimistic approach toward reconstructive-restorative operations in crush syndrome that is complicated by purulent infection. Applying aggressive surgical strategies made it possible to revise the deep-rooted approach for treating such patients. The combination of medical measures in question has allowed to prepare wound surfaces for plastic closure by the 20th day, on average.

To fill in the acquired defects and close the wound surface, we have used various plastic surgery methods – from dermatomal autodermaplasty to complex vascularized skin flaps. The graduated tissue stretch method offered invaluable help. Its application allows for plastic wound closure to begin earlier and to gradually replace significant soft-tissue defects simultaneously with the dynamic assessment of the muscle condition underneath.

In case of simultaneous bone damage and need for fasciotomy, it is very convenient to assist the external osteosynthesis using pin and pin-rod apparatuses. In addition to highly effective temporary or permanent stabilization and bone fragment repositioning, extremity immobilization with Ilizarov apparatus also allows one to perform segmental resection of the affected long-bone area with subsequent bone defect replacement by Ilizarov's method. External fixation apparatuses are especially effective when treating open intra-articular joint fractures of the long bones that are complicated by purulent arthritis. Additionally, extremity suspension in the Ilizarov apparatus creates a favorable environment for treating extensive wounds and tissue defects and optimizes redressing and early reconstructive and plastic surgery (Fig.39.11). While applying external osteosynthesis to crush syndrome victims, we have not observed any serious complications related to it.

Long-bone defect correction and restoration of the affected extremity length were performed according to one of the forms of Ilizarov's distraction-compression osteosynthesis.

While performing reconstructive-restorative surgeries, we preferred to use a combination of skin and bone plastic methods. It should be mentioned that there is an increased risk of purulent complications after plastic surgeries in this type of injury. It is necessary to apply a stricter approach to surgery technique and to avoid excessive tissue trauma. An obligatory treatment component is antibiotic prophylaxis that takes into account responsiveness of the wound microflora.

39.4 Amputation Indications

Extremity amputation is indicated when the following are observed during diagnostic-decompressive hypodermal fasciotomy: necrosis of all of the extremity's muscle groups, complete destruction of the compressed extremity, or development of extensive gangrene, in other words, clear indications for amputation.

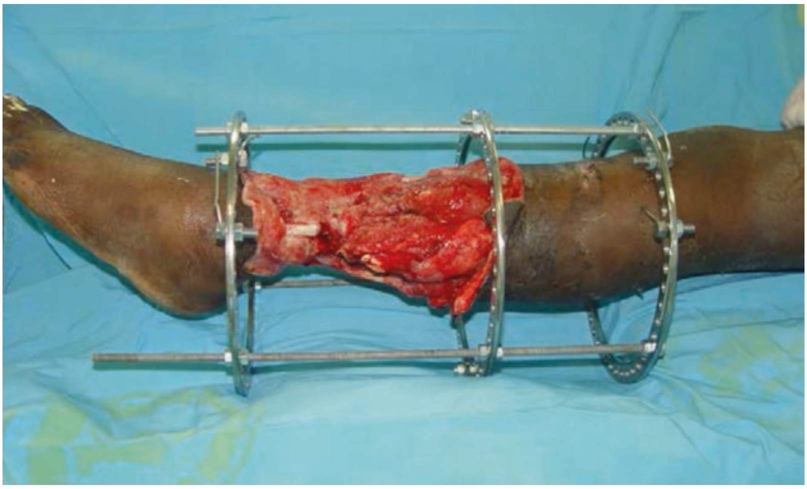

Fig. 39.11 Photo of the wound using Ilizarov's apparatus

Fig. 39.12 Long-term results (1 year) after surgical treatment of crush syndrome (right shin)

Conclusion

We advocate for aggressive surgical approach to treating crush syndrome cases complicated by purulent infection. This approach allows to eliminate the purulent focus at the early stages and to accomplish complex reconstructive-restorative surgeries with positive anatomical and functional results, which leads to earlier rehabilitation of the injured. Completing early reconstructive surgeries in crush syndrome patients has made it possible to diminish severe long-term trauma effects, to restore the anatomical integrity of the affected organ, and to increase cosmetic and functional results (Fig. 39.12).

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Amputations in Children with Severe Trauma

40

Valeriy A. Mitish, Leonid M. Roshal, and Pavel Medinskiy

40.1 Introduction

The problem behind performing amputations at all times has presented a difficult and responsible moment for correctly choosing and formulating surgical treatment for child victims [7, 8, 10–14]. N.I. Pirogov (1865) wrote "no other operation requires the same level of foresight and common sense as the development of proper amputation causes." This is especially true when the patient is a child. Amputations make children disabled from a young age; they face challenges in adapting to their new state, both from a psychological standpoint and, undoubtedly, from the perception of other children and adults. An amputation is not only a cosmetic defect; it is a psychological trauma. The decision to amputate, even to save the life of a child, is made by a group of physicians and after parenthood consent [2, 7, 8, 11, 15].

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Our experience over the last 25 years carrying out specialized surgical aid to child victims at times of catastrophic earthquakes in countries around the world, as well as following severe automobile crashes, has demonstrated the practicability of healing difficult, especially soft tissue and bone injuries, conditions created by us in the specialized children's centers for the treatment of wounds and wound infections at the bases of the region's hospitals [11–13].

40.2 Epidemiology

Severe traumatic injuries of soft tissues and bones of the extremities, resulting in children with earthquakes, are often the cause of amputations, including high ones (Figs. 40.1, 40.2, 40.3, and 40.4) [1, 3, 6, 9]. The frequency of amputations depends on many factors. If, for example, during an earthquake in Armenia (Spitatskoye 1988) they left 1.9 % among all those affected, among children with crush syndrome it was 16.7 %, and 7 of the children had to have a double amputation of the local extremities [11, 12]. During that earthquake, the damage was primarily to stone buildings. Following a major earthquake in Japan (Kobe 1995), there was not a single amputation performed, because there were very few traumatized children and the damage was primarily to old wooden buildings, most of which did not have any children at the time of the quake [11, 12].

N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_40

Fig. 40.1 Traumatic amputation of the right lower limb. Extensive necrotic wound of the right thigh limb after trying the primary closure. Anaerobic cellulitis of the right thigh and the right half of the pelvic girdle

Fig. 40.2 Open total destruction of the limb complicated by purulent necrotic changes

Fig. 40.3 Crush syndrome accompanied by the development of wet gangrene of the right foot and the lower half of the lower leg

Sometimes there are traumatic detachments of limbs, which are accompanied by the formation of extensive wounded stumps. The development of severe purulent surgical infection in the damaged limb increases the area of tissue damage and spreads it beyond the traumatic focus and thus the necessity for amputation [2–4, 6, 14].

Poorly selected strategy and errors at different stages of surgical treatment of such traumatic injuries, including crush syndrome, lead to an unjustified significant shortening of the affected limb, the development of purulent and necrotic complications in the formed stump, and, as a consequence, a deterioration of the general condition of the injured child, increasing the volume of tissue damage and the spread of necrotic changes far beyond the initial traumatic tissue damage (Fig. 40.1) [1, 3, 4, 6, 12]. Often, these changes

Fig. 40.4 Necrotic wound of the stump of right tibia after a traumatic separation of the foot

lead to the development of extremity osteomyelitis of the stump of the truncated bone. Abovementioned complications create the necessity for repeated treatments of surgical wounds, which leads to a shortening of the stump and thereby to a decrease in the possibility of proper prosthesis. Late complications of this condition include the development of defects in the form of nonhealing wounds in the stump, venous ulcers, and rough deforming scars [5, 6, 9]. It is worth remarking that phantom pain, osteophytes, and neuromas occur less often in children than in adults [5, 12].

Depending on the level of delay between injury and surgery and level of first aid provided at time of injury, including surgical, there are three basic situational variants available to victim at a specialized center:

1. Removal of victims from the rubble and evacuation to a specialized hospital immediately or within the first hours after the accident
2. Removal of victims from the rubble and evacuation to a specialized hospital after 24 h or a few days after the injury.
3. Transfer of victims to a specialized surgical hospital in connection with the development pyonecrotic complications in the stump of the extremity after amputation of the extremity at another hospital

40.3 Causes of Amputation

The causes for amputation of the limbs in children affected by disasters are the total crushing of soft tissue limb; destruction of limbs, including its skeleton; traumatic injuries, accompanied by ischemic gangrene of the limb; crush syndrome with large amount of damage to the limbs; and development of heavy surgical infection threat to a child's life.

40.4 Amputational Strategy

In the context of various disasters, formation of strategy for amputation of the affected limb (in cases of absolute indication) and the strategy of surgical treatment of necrotic wounds of the residual limb depends on the duration of the period of compression and timing of the provision of specialized surgical care to victims, the severity of the general condition of the victim, the nature and volume of traumatic tissues of the extremities, development of septic complications in damaged limbs and character of wound infection, availability and remoteness of surgical hospitals from the trauma site, and surgical treatment at the early stages of treatment and the nature of developed postoperative complications.

Each of the three situational variants above corresponds to an embodiment of the characteristic clinical picture of significant damage to soft tissues and bones of the extremities and their complications, an absolute indication for amputation of the latter.

Among patients taken in as a result of the first situational variant, one of the following major tissue damages without the development of surgical infection were observed: open total destruction of limb, subtotal destruction of soft tissue damage to major vessels, crush syndrome with open tissue damage to limbs, and traumatic separation of the distal part of the limb.

In the second situation variant, virtually among all affected, the traumatic complications from surgical infection and the clinical picture correspond to the following local change: total destruction of limbs complicated by purulent necrotic changes (Fig. 40.2), open total destruction of the limb accompanied by the development of wet gangrene of the limb (Fig. 40.8), open total destruction of the limb accompanied by the development of anaerobic non-clostridial cellulitis in the limbs, dry gangrene of the damaged limb, crush syndrome and the development of wet gangrene (Fig. 40.3), and the necrotic wound to the stump of the limb (Fig. 40.4).

The third situational variant of the clinical picture can be represented by various changes in the postoperative residual limb: soft tissue necrosis and abscess of the residual limb (Fig. 40.5), necrotic wound to the operated residual limb (Fig. 40.6), extensive purulent or granulating wounds to the residual limb (Fig. 40.7), and shorter residual limb with extensive wounds (Fig. 40.8).

The strategy of surgical treatment of child victims with absolute indications for amputation of the affected limb should be developed, taking into account the severity of the general condition of the child and the severity of lesions in the injured limb. Extensive amount of tissue damage of the limb (mostly characterized by crushed tissue without clear boundaries), severe general condition caused by failure of internal organs and systems, as well as a large number of incoming victims dictate sometimes the need for a multistage surgical treatment aimed at saving the patient's life and the preservation of greater length and better function of the affected limb.

It must be taken under consideration that unlike their adult counterparts, children are affected by the continuing growth of the limbs. Bone growth is outpacing the growth of soft tissue. Peroneal and radial bone can grow faster and cause deformities. The general rule is the maximum preservation of the bone and soft tissue. Particular attention is paid to saving children's growth areas of the limbs. Paired bones are resected on different levels – fibula

Fig. 40.5 Necrosis of soft tissues of the stump of the left shin

Fig. 40.6 Necrotic limb after amputation of the left thigh with the primary formation of the stump over crush tissue of the lower limb

Fig. 40.7 Extensive granulating wound of the limb of right shoulder after disarticulation of the forearm

Fig. 40.8 A short stump of the lower leg with extensive trauma and deficit of covering tissue

1–3 cm, depending on the age, higher than the tibia. The same applies to the radius, which is growing faster than the elbow. Surgical amputation in children should emphasize maximum preservation (M.V. Volkov, 1955, E. Lyandris, 1961, S.I. Doletskiy and U.F. Isakov, 1970, and others). To accomplish these goals, a subperiosteal method of processing the periosteum will be used, when it is cut below the expected level of sawing bones at some distance of from the bone is peeled in a proximal direction and then sutured over the sawed area (Volter 1910).

40.5 Methods for Amputation for Children

Performing amputation of limbs and stump wound debridment a surgeon must follow principles of maximal sparing of viable tissues in the injured limb and maximally possible preservation of the length of the extremity. A surgeon must use all possibilities to preserve a knee joint and to preserve a maximally possible length of the thigh stump. It should be remembered that children with amputation, as a rule, should not adhere to the generally accepted level of truncation of the limb. This is due to continued growth in this segment and the possible delay in the growth of the upper limb. Particular attention in children should be paid to the preservation of germ zones. It is important, for example, to carry out resection of the ankles below the germ zones.

The amputation strategy of the affected limb and surgical treatment of necrotic wounds of the stump is based on the principles of active surgical treatment of purulent wounds of various etiologies. The basic principles of the method are radical debridement and pyonecrotic hearth to remove all devitalized tissue and tissue of doubtful viability, impregnated saturated pus, local treatment of wounds by various methods, repeated surgical treatment of wounds of the residual limb, and the plastical formation of the stump in a planned manner.

40.6 Stages of Surgical Treatment

Surgical amputations in children are performed under general anesthesia. During the first stage of surgical treatment of the affected limb, amputations are performed in the volume of surgical treatment with radical position with respect to the soft tissues. Devitalized limbs are removed at the distal part of the cutoff level of long bone fractures or disarticulation at the level of the proximal joint of the affected segment. On the surviving limb segment, all nonviable tissue and tissue of questionable viability and those that are saturated with pus are removed, a revision of muscle sheaths is performed, and subcutaneous and intermuscular pus swells and pockets are disclosed. NVB is treated in the classical way.

A particular feature of the surgical treatment of necrotic wounds of the limb (especially in children) is to preserve for future use different parts of the cover and deep soft tissue, which has preserved viability, in the form of nonstandard perfused grafts to form the optimal stump length.

In our opinion, at this stage of surgical treatment of the bone, resection length above the line of fracture (in the absence of purulent focus in the medullary canal), as well as the intersection of intact long bones and proximal border of viable soft tissue, is inadvisable. Preservation of a greater length of the bone facilitates dressing the wound and at a stage of reconstruction allows one to select the optimal level of bone resection and form a prosthesis ready stump (Figs. 40.9 and 40.10).

The result of amputation and debridement is the formation of the stump wound defect with a high surface area – 25–340 cm^2. Given the impossibility of determining the precise boundaries of traumatic tissue damage and the presence of local and often generalized surgical infection at this stage of treatment, the use of any method of closing the wound surface is inadvisable. The stump wound remains open. Postoperatively, topical treatment is carried out by one of the methods depending on the nature and stage of healing.

In cases of extremely dire conditions of the victim, accompanied by multi-organ failure, inefficient methods of extracorporeal detoxification,

Fig. 40.9 Complete destruction of the upper left limb accompanied by the development of wet gangrene

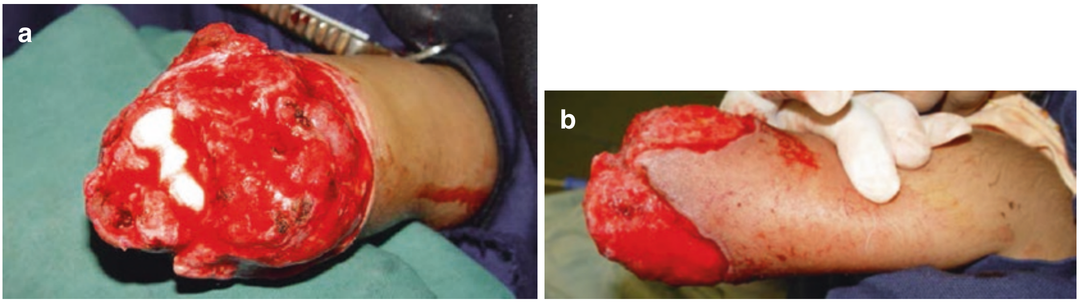

Fig. 40.10 (**a**, **b**) Left shoulder stump after disarticulation of the left forearm and forearm debridement

and sepsis, we are convinced, based on practical experience, that a guillotine method of amputation and disarticulation of the distal part of the limb as an intermediate step in the complex surgical treatment should play a major role (Fig. 40.10). These methods allow for prompt truncation of limbs in the first phase of treatment and without loss of blood to remove necrotic focus (cause of severe general condition) and to create conditions for effective intensive care. Subsequently, after the stabilization of the general condition of the patient, the reconstructive phase of treatment is routinely carried out. At this stage, there is a potential for the formation of the residual limb prosthesis at an optimally low level while preserving the large joints (particularly of the knee).

In cases of large-scale destruction of tissue, soft tissue crush, crush syndrome, and a complication of traumatic injuries of anaerobic nonclostridial infection, achieving radical surgical treatment in the first stage is extremely difficult because of the extensive damage and challenges associated with determining the true volume of tissue damage.

In this situation, as the new foci of necrosis of tissue occur, additional surgical treatment of wounds of the residual limb until their full cleansing is carried out. We are committed to the principle that in the primary amputation in cases of crush syndrome produced in the acute phase, tight closure of the stump is not advisable. If possible, a flap is cut for extra overlay, without imposing tension from secondary deferred seams.

40.7 Postsurgical Treatment

The primary goal of postsurgery treatment is to eliminate postoperative inflammation, further cleansing wounds of necrotic tissue, and ensuring adequate drainage of wound and the transition of the wound healing process from the first phase (inflammation) into the second phase (regeneration). The best methods of local treatment of residual limb wounds in terms of accidents are dressings with iodophor solutions and dressing with multicomponent ointments on the basis of polyethylene glycol. One can use a variety of sorbent dressings, topical treatment of wounds of negative pressure, and methods for local gnotobiological isolation.

During the first 2–3 days, we dress the wounds with iodophor solutions. Thereafter, we made the transition to Russia-made ointment based on polyethylene oxide – 5 % dioxidin and “Levomekol”, which has pronounced osmotic and anti-inflammatory properties, as well as a wide spectrum of antimicrobial merits.

Local treatment of the wound by means of negative pressure is a highly effective method that allows to quickly achieve positive dynamics of healing the wound. This leads to a reduction in the number of painful dressings, as well as the number of required general anesthesia. However, in cases of a simultaneously large number of victims, this method may not necessarily be available to all patients in need.

The abovementioned principles of surgical and postoperative local and general treatment dramatically reduce bacterial contamination of the wound, promote its rapid purification, reliably notify the development of in-hospital infections, and allow for the stabilization of the general condition of the injured child.

This facilitates optimal conditions for the formation of high-quality residual limb or for the carrying out of reamputations of limbs on functionally favorable level.

40.8 Reamptutation of Residual Limbs

The final stage of complex surgical treatment of patients with wound defects of the residual limb is reamputation of the residual limb after amputation conducted with a guillotine or disarticulation of a limb segment and reconstruction and formation of the residual limb with extensive wound defects.

Reamputations of the residual limb after amputation carried out via guillotine or disarticulation of the limb segment follow conventional principles, similar to the formation of primary amputation stump. It can be carried out via the flap surgery way of amputation (fasciotomy or myotomy), transperiostal osteotomy of the long bone at the appropriate level, transection of the nerve trunks 4–6 cm above the level of amputation following local anesthesia, and separate stitching and dressing of the main arteries and veins just above the level of amputation.

Surgical reconstruction of the residual limb with the closure of large wounds presents complex challenges, especially in situations with short stumps accompanied by a substantial deficit and coverage tissue. This is vital due to the fact that the primary emphasis is on preserving the large joints, even with the smallest possible length of the stump of the damaged limb segment in the child. In order to achieve this task, one must utilize different methods and techniques of plastic surgery: dissection and mobilization of individual muscles or certain muscle groups with the aim of concealing sawed long bones of the stump and creating a muscle socket, the formation of nonstandard perfused tissue grafts from viable tissue, the reduction of excess volume of the stump and the reduction of the wounded surface area by excision or extirpation of nonfunctional muscle, and use of various methods of plastic surgical closure of the wound.

In cases of a large number of victims, we also used various well-established methods of plastic closure of wounds: plastics of wounds with local tissues; plastics of wounds with local tissues by dosaged stretching; plastics of wounds with flaps (both classical and non-standard); closure of wound surface with skin grafts; and in some cases a combination of all mentioned techniques above.

Closure of the wound with local tissues by means of dosed stretching is the most preferred method, because viable skin cover is generated on the support surface of the stump by means of neighboring tissue, meanwhile saving blood supply and innervation.

The method of dosed tissue stretching throughout the process of wound surface closure allows for monitoring and control of the healing process. This process does not require additional draining of cavity wounds and replaces defective skin stump with viable tissue. This method eliminates the need for using other complex methods of plastic surgery.

Limited sources of covering tissue surrounding the wound are indications for the use of perfused skin flaps. Either classic posteriorly rotated flap on a permanent or temporary feeding legs or nontraditional, formed from tissues of the distal part of the limb to preserve its viability, is utilized. The method for autologous transplantation of free perfused full-flapped grafts with microsurgical technique is of limited use in terms of mass-scale disasters.

We carry out the reconstruction of the stump of the thigh following surgery for necrotic complications of severe trauma of the limbs utilizing the flap method, using the following surgical techniques:

1. Formation of the classical flap
2. Mobilization and formation of muscle flaps in the stump of the thigh
3. Transperiostal end resection of limb bone of the femur
4. The formation of muscle coupling of the bone above the sawing by stitching the muscle antagonists
5. Suction drainage of spaces underneath flaps by using perforated tubes
6. Closing the wound or skin-fascial musculocutaneous flap (Figs. 40.11, 40.12, 40.13, 40.14, 40.15, 40.16, 40.17, and 40.18)

We carry out reconstruction of the short stump of the lower leg with extensive surface wound

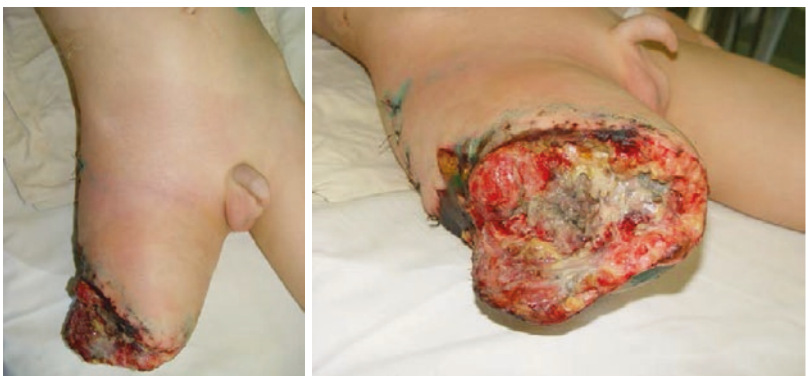

Fig. 40.11 Traumatic amputation of the right lower limb. Extensive necrotic wound of the right thigh stump after attempting the primary formation. Anaerobic phlegmon of the right thigh and the right half of the pelvic girdle

Fig. 40.12 Radical debridement of necrotic wounds of the stump

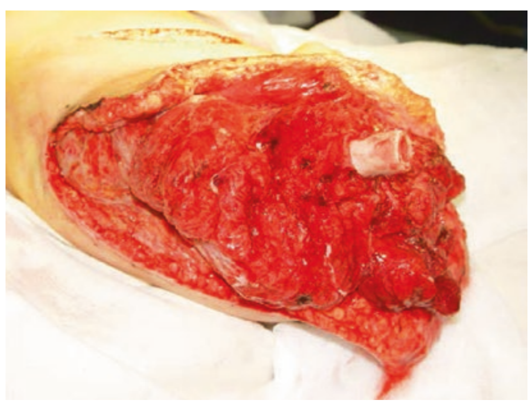

Fig. 40.13 The result of a radical debridment and phlegmon lancing of the anterior abdominal wall. The femur residual limb is not resected in order to prevent the development of osteitis in the area of osteotomy

Fig. 40.14 The view of the wound 2.5 weeks after surgery. Local treatment is carried out with multicomponent ointment on the basis of polyethylene oxide. The type of the wound cytogram is regenerative, indicating the second phase of wound healing and the possibility for reconstructive surgery

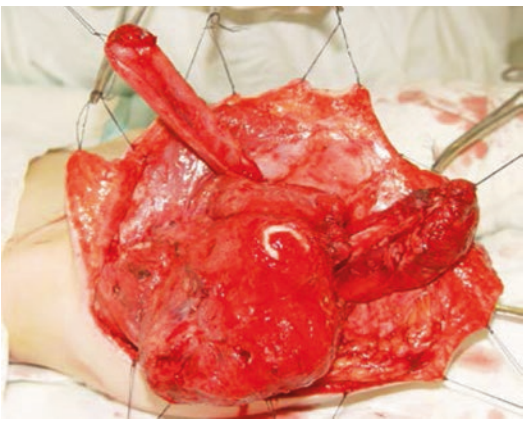

Fig. 40.15 Wound surface after debridment. Resection of a bare end of the stump of the femur is produced. Muscle flaps are isolated and formed. The edges of the wound are mobilized in the form of fascial and muscle structures

accompanied by a defect/deficiency of the skin, by means of the flap manner, using the following surgical techniques:

1. Reduction in the volume and surface area of the stump by means of extirpation of the no longer functioning soleus muscle
2. Formation of rear sural musculocutaneous and front skin-fascial flaps
3. Transperiostenial processing end of the stump of the tibia with oblique resection of its crest

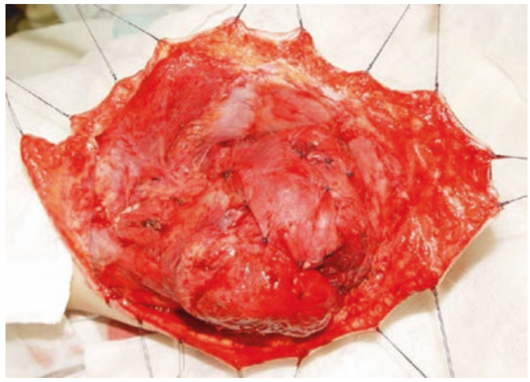

Fig. 40.16 Antagonist muscles are sewn together, thereby forming a muscle mass over the sawed bone of the femur

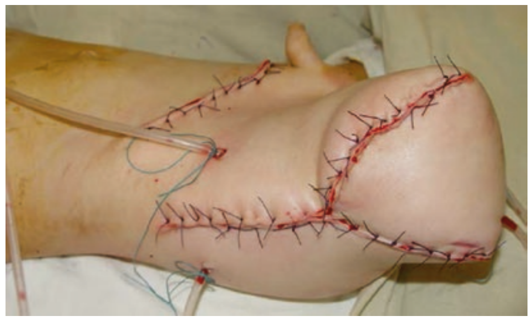

Fig. 40.17 Formation of a stump of the right thigh with the closure of the wound created with nontraditional medial skin and fascial flap

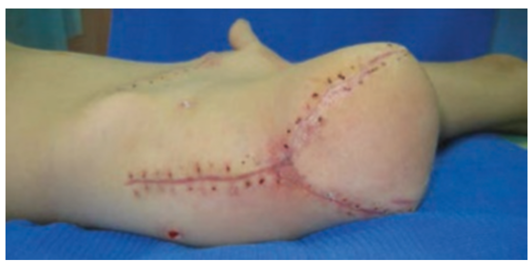

Fig. 40.18 View of the stump of the right thigh following the removal of the sutures

4. Suction drainage of spaces underneath flaps by means of perforated tubes
5. Formation of the lower leg stump supplying the perfused flaps if necessary, using dosed stretch tissues (Figs. 40.19, 40.20, 40.21, 40.22, 40.23, and 40.24)

The advantage of the proposed method is the formation of the lower leg stump by means of local tissue surrounding the wound surface. In addition, during the surgery it is possible to conduct a thorough audit of the tibia tissue stump, ligate the vascular bundle at the appropriate level, and mobilize and transect the nerve trunks at the most available proximal level without causing tension. Removal of the soleus muscle reduces the surface area of the wound of the stump and creates the possibility for formation of a cylindrical shape of the stump and, in the late postoperative period, reduces the degree of atrophy and reduction of stump.

The reconstruction of the stump of the shoulder and forearm after surgery for necrotic complications of severe upper limb injuries are carried out with flap surgery, applying the above-described surgical techniques. Of particular importance in these situations is the principle of saving every centimeter of viable tissue.

During the postoperative stage, immobilization for the formed stump is inadvisable. The extremities provide functional status for implementation of stump movement to a moderate extent.

> It's worth remembering that in children, with their reparative abilities, oftentimes vicious scars with reasonable exertion in the sleeve of the prosthesis may reset, and become viable for almost total exertion. This can reduce the amount of previously anticipated intervention. (B.G. Spivak 1998)

Fig. 40.19 Short stump of the tibia with extensive wound and lack of cover tissue

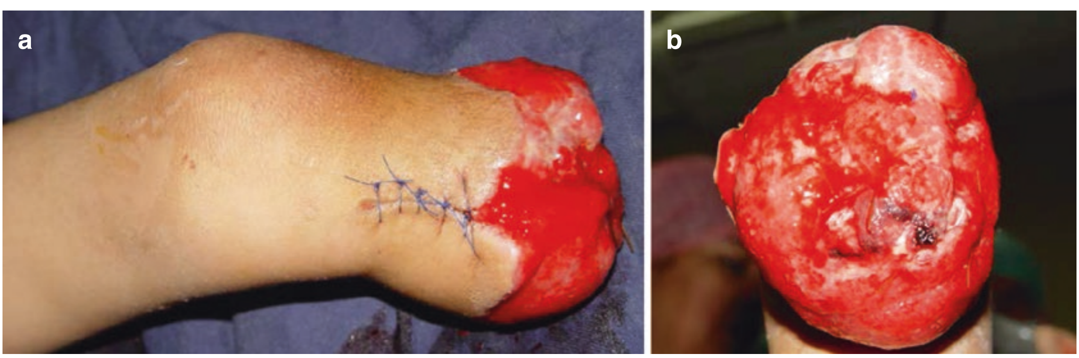

Fig. 40.20 (**a**, **b**) View of the tibia stump after 2 weeks of surgical treatment and local treatment by means of multicomponent ointment based on polyethylene oxide

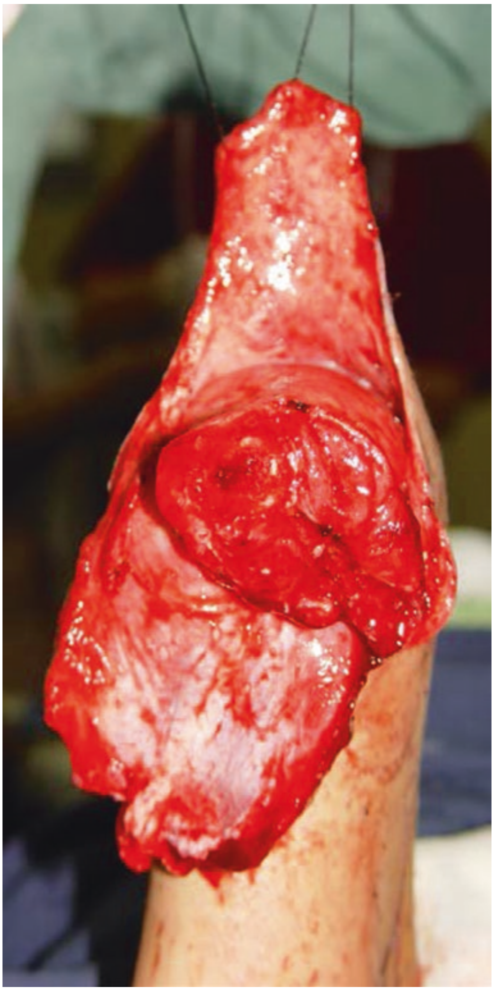

Fig. 40.21 Extirpation of the soleus muscle is carried out, forming the rear sural musculocutaneous and front skin-fascial flaps

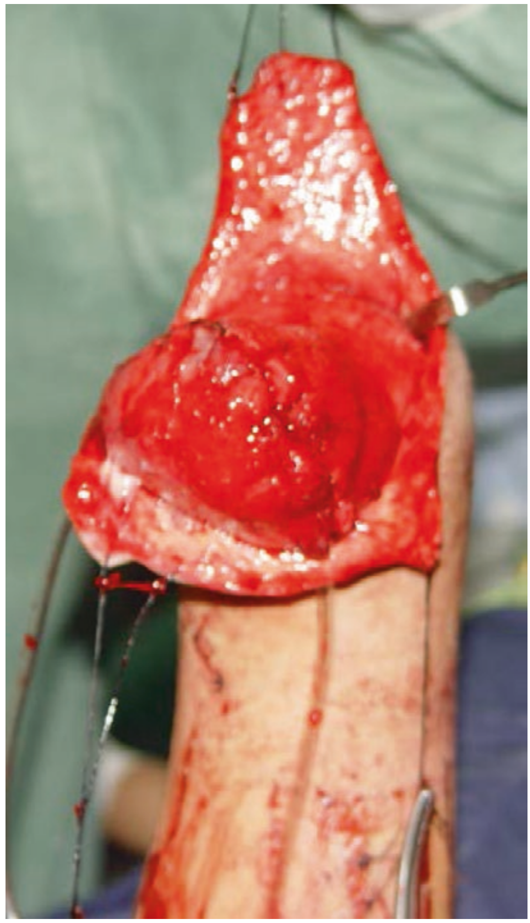

Fig. 40.22 Muscle mass is formed at the tip of the stump of the tibia and antagonist muscles are stitched together

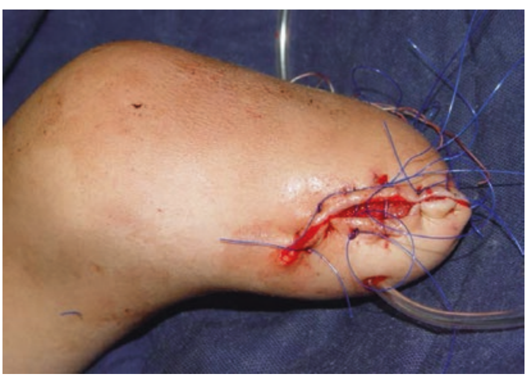

Fig. 40.23 The first stage in reconstructive surgery of local tissues by dosed stretching of tissue

Fig. 40.24 The final stage of reconstructive surgery on local tissues by dosed stretching. A complete tibia stump is thereby formed

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Spine Trauma in Children in Earthquakes

41

O. Iskhakov, S. Mescheryakov, and Leonid M. Roshal

41.1 Introduction

Spine trauma in children after earthquakes is less frequent than limb fractures and head injuries but is considered the most severe type of trauma. Often times, spine trauma is accompanied by a shock and impairment of movement. Pretty often, it causes disability. According to Rathore M.F. et al. [20], out of 187 hospitalized patients who were admitted to spinal injury units after the earthquake in Pakistan in 2005, 89 % were paraplegic. There are very few publications regarding spinal trauma in children and even in adults, sustained during earthquakes. Compared to adults, a child's spine is more elastic and flexible. It is more resistant to fractures, but its excessive bending and unbending may cause overstretching of the spinal cord and, consequently, impairment of circulation in the spine, with no radiographic signs of damage of bone structures [11, 12, 20, 26].

Mortality rate in children after a spinal injury is higher than in adults – 25–30 % [6, 12]. The key factor in providing adequate medical help to children in emergency situations is development of a comprehensive treatment plan [1]. In order to reduce the number of victims and to increase the survivors' number, it is important to refer such patients to the hospitals where pediatric intensive and specialized care are available.

According to various data, among all the injured in an earthquake, children account for 30–53 % depending on the percentage of child population in the affected region and its timing [7, 22, 24].

The mortality rate is highest among the elderly and children [4, 14]. About 30–35 % of all injuries sustained by earthquake victims are head trauma [16]. According to S. Keshkar et al. [15], spinal cord trauma is found in 12 % of the injured. Damage of peripheral nerves accounts for 0.5 % of injuries [2]. Considering the importance of providing treatment to patients with trauma of central and peripheral nervous systems close to the epicenter of earthquake, we included a neurosurgeon in the mobile pediatric team.

41.2 Epidemiology

From our experience, the majority of spine fractures occur when heavy fragments of collapsing buildings and roofs are falling on the people or people are falling from a height. This opinion is supported by other authors [6, 10, 23]. Frequently, it happens when people are jumping from the windows and/or balconies of residential homes. In such cases, the basic mechanism of fractures is bending mechanism. The thoracolumbar area is

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_41

affected most frequently, especially the thoraco-lumbar junction. These injuries are often combined with head injuries, internal injuries, and fractures in the pelvis and limbs. Spine and spinal cord trauma, both light and severe, is found in children less frequently than in adults, making up 1–10 % of total spinal trauma [11, 13].

In 25–50 % of children, spine and spinal cord trauma is combined with head injury [11, 24]. The comparison of 223 patients, who sustained spinal trauma in the Sichuan earthquake of 2008, and 223 patients with the same kind of injuries not associated with earthquake showed that in the first group injuries in the lumbar area clearly prevailed (55.3 %) [27]. The actual number of cervical spine injuries, compared to the control group, was lower. Similar data was obtained by Ghabili K. et al. after an earthquake in northwest Iran [9]. Among 38 victims, there were 14 minor children (36.9 %). Based on the analysis of injuries sustained by children in the earthquake in Bat, Iran, in 2005, among the 119 children admitted to the hospital of third level most patients, 83, had limb injuries and 17 thoracic and abdominal injuries, and 36 sustained spine and spinal cord injuries (30.2 %) [22]. In the 2005 earthquake in Kashmir, spine and spinal cord injuries made up 12.3 % [15].

The analysis of the CT data on thoracic injuries (223 victims) sustained in the Sichuan earthquake in 2008 showed that 21 % had a fracture in at least one vertebra; 72 % had fractures in at least one rib; 55 % had lung contusion; and 68 % had pleura injury [7, 17].

41.3 Classification, Basic Mechanisms, and Pathogenesis of Spine and Spinal Cord Trauma in Children in Earthquakes

According to the AO/ASIF classification based on the mechanism of injury of 3-column model of the spine [5], we identify bending fractures, extension fractures, rotational fractures, axial compression injuries, and cutting injuries. Besides, there are 3 types of vertebrae fractures. Type A is a vertebral compression injury: AI, impact fracture; AII, injuries causing breakage of vertebrae; and AIII, bursting fracture. Type B includes damage of the front and rear muscular-skeletal system: B1, damage of the rear muscular-ligament apparatus; BII, damage of bone structures of the rear complex; and BIII, damage of the front complex with the involvement of an intraspinal disk. Type C is damage of the front and rear complex with rotation: CI, compression of vertebral body; CII, stretching of vertebral columns; and CIII, rotational dislocation combined with horizontal shift of fragments [3].

Below is the classification of severity of spine trauma quoted by the American Spinal Injury Association (ASIA) [3]:

- A – Complete: no motor or sensory function is preserved in the sacral segments S4-S5
- B – Incomplete: Sensory but not motor function is preserved below the neurological level including sacral segments S4-S5
- C – Incomplete: Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3
- D – Incomplete: Motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade 3 or more
- E – normal: moving and sensory functions are intact

Spine injuries include concussions, contusions of various severity, crush of the spinal cord, and injury of the cauda equina and of spinal roots. Less frequently we see spinal injuries of SCIWORA (spinal cord injury without radiographic abnormality) type, which is the injury of the spine without radiographic changes with hematomyelia. Such injury can be seen in children due to high elasticity and flexibility of vertebral segments [25]. Excessive bending and extension of the spine does not cause bone injuries but sometimes leads to overstretching of the spine cord, its roots, and blood vessels and, as a result, to impairment of spinal circulation and hematomyelia [26].

Generally, cervical spine injuries occur in children more frequently than in adults [21]. It happens because of different proportions between their head and body. Due to their relatively big head size, children experience higher load on their cervical area. Thus, head injury in children is often accompanied by cervical trauma.

41.4 Primary Evaluation of Patients' Condition, Triage, and Providing Help for Spinal Trauma on Different Stages of Evacuation

Treatment plan for spinal injuries in children is determined primarily by the type, severity, and level of trauma, as well as by the child's age. Timely and appropriate prehospital care; medication treatment and adequate surgical assistance, including use of contemporary implants and fixation devices for spinal fractures; and also use of early movement rehabilitation approach substantially improve treatment results for the children with spinal trauma [8, 18, 19, 26].

Beside the pain and impaired movement, clinical picture of a spine fracture depends on the severity of the spine trauma (from concussion to fracture, to complete tear). That is why it is so important to watch out for any function impairment of vital organs. Trauma of upper cervical vertebrae can be very dangerous, because a part of the medulla which contains respiratory and blood circulation centers is located there. Also, in the treatment of spinal fracture, more than of other injuries, it is particularly important to place the patient in a functional position. For this purpose it is absolutely necessary to use a flat solid surface (board, hard stretchers, or soft stretchers with a board or plywood on top of it, or a door removed from the hinges) in order to prevent the patient from bending, sidewise or rotational movement. When placing the patient, caregiver should take into consideration the proportions of a minor child that are different from the adults'. Thus, in order to preserve normal spinal axis in the cervical spine, it is recommended to put a small bolster under the child's upper back. It is important to make sure that there is no bending in the neck or in other areas of the spine if the child is suspected to have a spine trauma or his consciousness is deeply impaired.

First aid for spinal fractures includes control of bleeding, use of common pain killers, application of aseptic dressing to the wound, placing the patient on the back with a bolster under their lower back, or placing them on their stomach and gentle transporting to a medical facility. Arterial hypotension below 85–90 should be avoided. It is recommended to use neuroprotective and vascular therapy.

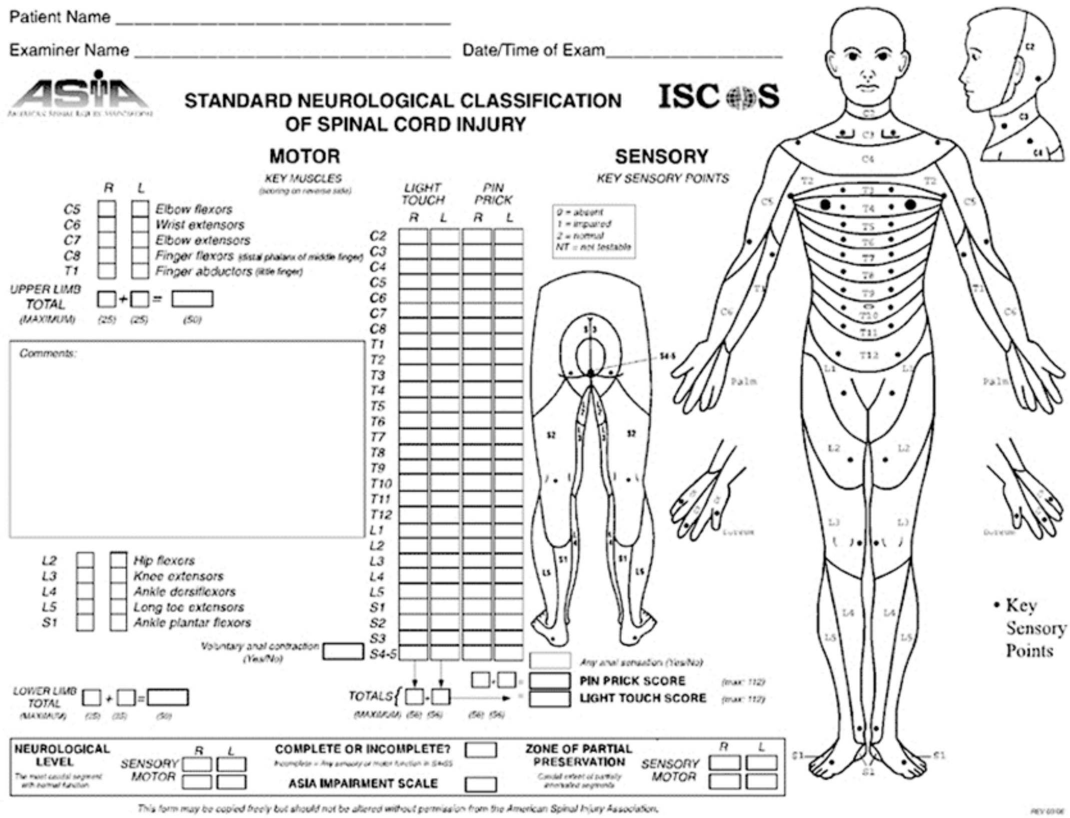
In our practice, we treat acute spinal trauma based on the following principles:

- Complete evaluation and identification of the severity of spinal trauma.
- Immobilization of the patient until the severity of injury, type of fractures, and scope of spine ligament damage is determined.
- Correction of the spinal axis and restoration of the normal anatomical state.
- Protection of the spinal cord from compression. Early decompression of the spinal cord and nerve structures.
- Providing necessary fixation of the spine with the use of methods of internal fixation, if necessary.

Diagnostic possibilities in a disaster zone, with massive influx of earthquake victims, are pretty limited. Most often we have to come up with a diagnosis based on questioning, physical exam, and radiographic data. However, a timely and appropriate diagnosis allows to substantially improve the results of treatment. At the exam it is important to evaluate the overall severity of injuries, thoroughly research the injured area, and identify deformities and wounds. In order to make conclusions regarding the level and severity of trauma more objectively, it is recommended to test them using a special testing scale that has been developed by ASIA (Fig. 41.1).

Testing of motor and sensory response is an important stage of neurological examination. It becomes a basis for topical diagnosis (Fig. 41.1).

It is important to correctly immobilize, transport, and move the patients with spinal trauma,



MUSCLE GRADING

0 total paralysis

1 palpable or visible contraction

2 active movement, full range of motion, gravity eliminated

3 active movement, full range of motion, against gravity

4 active movement, full range of motion, against gravity and provides some resistance

5 active movement, full range of motion, against gravity and provides normal resistance

5* muscle able to exert, in examiner's judgement, sufficient resistance to be considered normal if identifiable inhibiting factors were not present

NT not testable. Patient unable to reliably exert effort or muscle unavailable for testing due to factors such as immobilization, pain on effort or contracture.

ASIA IMPAIRMENT SCALE

☐ **A = Complete**: No motor or sensory function is preserved in the sacral segments S4-S5.

☐ **B = Incomplete:** Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5.

☐ **C = Incomplete:** Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3.

☐ **D = Incomplete:** Motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade of 3 or more.

☐ **E = Normal:** Motor and sensory function are normal.

CLINICAL SYNDROMES (OPTIONAL)

☐ Central Cord
☐ Brown-Sequard
☐ Anterior Cord
☐ Conus Medullaris
☐ Cauda Equina

STEPS IN CLASSIFICATION

The following order is recommended in determining the classification of individuals with SCI.

1. Determine sensory levels for right and left sides.
2. Determine motor levels for right and left sides.
   Note: in regions where there is no myotome to test, the motor level is presumed to be the same as the sensory level.
3. Determine the single neurological level.
   This is the lowest segment where motor and sensory function is normal on both sides, and is the most cephalad of the sensory and motor levels determined in steps 1 and 2.
4. Determine whether the injury is Complete or Incomplete (sacral sparing).
   If voluntary anal contraction = **No** *AND all S4-5 sensory scores =* **0** *AND any anal sensation =* **No**, *then injury is COMPLETE. Otherwise injury is incomplete.*
5. Determine ASIA Impairment Scale (AIS) Grade:

Is injury Complete? If **YES**, AIS=A Record ZPP (For ZPP record lowest dermatome or myotome on each side with some (non-zero score) preservation)

NO ↓

Is injury motor incomplete? If **NO**, AIS=B (Yes=voluntary anal contraction OR motor function more than three levels below the motor level on a given side.)

YES ↓

Are at least half of the key muscles below the (single) neurological level graded 3 or better?

NO ↓ AIS=C YES ↓ AIS=D

If sensation and motor function is normal in all segments, AIS=E
Note: AIS E is used in follow up testing when an individual with a documented SCI has recovered normal function. If at initial testing no deficits are found, the individual is neurologically intact; the ASIA Impairment Scale does not apply.

Fig. 41.1 ASIA scale for the evaluation of sensory and motor impairments because incorrect handling may cause shifting of vertebral fragments and damage to the spine and spinal roots. One of the best ways of moving and transporting such patients is to use X-ray negative sheet stretchers (Fig. 41.2) that allow more than just transport the patient but also to do X-ray testing on them, as well as to turn them while placing the patient onto the surgical table, thus minimizing chances of spinal shift in unstable injuries.

Possibilities of surgical treatment of spine injuries in disaster zone may be narrow as well. Doctors may experience lack of special implants and tools for spine-stabilizing surgeries. In this case we need to use available materials that we have to adjust to our purposes.

41.5 Our Observations

We examined 587 children with neurotrauma – victims of the earthquakes in Algeria (2003), Pakistan (2005), Indonesia (2006), and Nepal (2015) who were hospitalized within 3–20 days after the earthquake. All of them were admitted to the hospitals closest to the epicenter, in the disaster zone. Their age varied from 1 month to 17 years. 205 of them had combination and isolated head and spine injuries. Spinal trauma was found in 67 (11 %) patients. Surgical treatment for spinal injuries was provided to 32 patients (younger than 18), 81 % of those were older children aged 12 and above. There was no possibility to do CT or MRI testing of all the victims with spine injuries, so there is a great chance that some non-aggravated spine injuries remained unidentified. Among the operated children with spine injuries, there were 21 children with thoracic and lumbar area trauma. Six patients (18 %) were operated for trauma in the cervical spine and spinal cord.

Surgical treatment of the injured was reserved for unstable spine fractures and compressions of spinal cord and its roots.

Most patients with spinal injuries were operated on the 5th day after the earthquake or later. Such delay was caused by organizational problems. In the first days there were no specialist-neurosurgeons or traumatologist-vertebrologists available. Also, there was a shortage of surgical room due to the overwhelming volume of surgeries.

Due to the poor material and technical supply in disaster zones and to the lack of specialized original implants for fixation of the spine, many times local surgeons used low-quality nonspecific implants and devices. Thus, for fixation of spine fractures in patients in Algeria (2003) and Indonesia (2006), they used available materials such as wire and plates intended for limb fractures. Operations on the spine were mostly limited to laminectomy and rear spondylodesis.

Along with the use of standard methods of treatment of unstable fractures, on 16 out of 24 operated patients whom we followed up in 2003, 2005, and 2007, local doctors had used inadequate implants. In the surgeries on the thoracolumbar area, they always used rear access. In case of compression of the spinal cord, they performed

Fig. 41.2 Transporting and moving patients using X-ray negative sheet stretchers

laminectomy, while posterior spondylodesis was done with the use of titanium wire and/or plates intended for metal osteosynthesis of the femur or lower leg (Fig. 41.3).

While we were working in Nepal after the 2015 earthquake, we observed great improvement in specialized care provided to children and adults with spinal trauma. Necessary tools and implants for spinal surgeries, as well as CT and MRI machines to be used for pre-op testing and C-arm for surgeries, were available. It allowed to substantially increase the efficiency of surgical treatment and to improve the quality of fixation of spinal fractures. Here are some of our own observations of surgical treatment of children and adults in Katmandu, where we performed 15 surgeries on patients with spinal injuries.

Due to the shortage of neurosurgeons, sometimes we had to operate on adults. Here is the observation of two patients with thoracolumbar and spinal cord injuries. On (Fig. 41.4) one can see surgical treatment of a 13-year old girl with closed complex atlantoaxial injury.

Figure 41.5 and 41.5a demonstrate a 40-year old patients with the diagnosis: Closed unstable complex spine trauma ASIA-C. Bursting fracture in L1. On the 4th day after the injury, the patient was operated: rear spondylodesis, transpedicular 4-screw fixation of L1 fracture at the Th12–L2 level. The control CT identified remaining compression and instability caused by the bursting fracture of L1 body. On the second week after trauma, we performed the 2nd stage of surgery: thoracoabdominal access, partial corpectomy in L1, and discectomy of Th12–L1 disk with the decompression of the spinal cord. Considering that no full-fledged expandable or mesh cage was available and the L1–L2 and lower part of L1

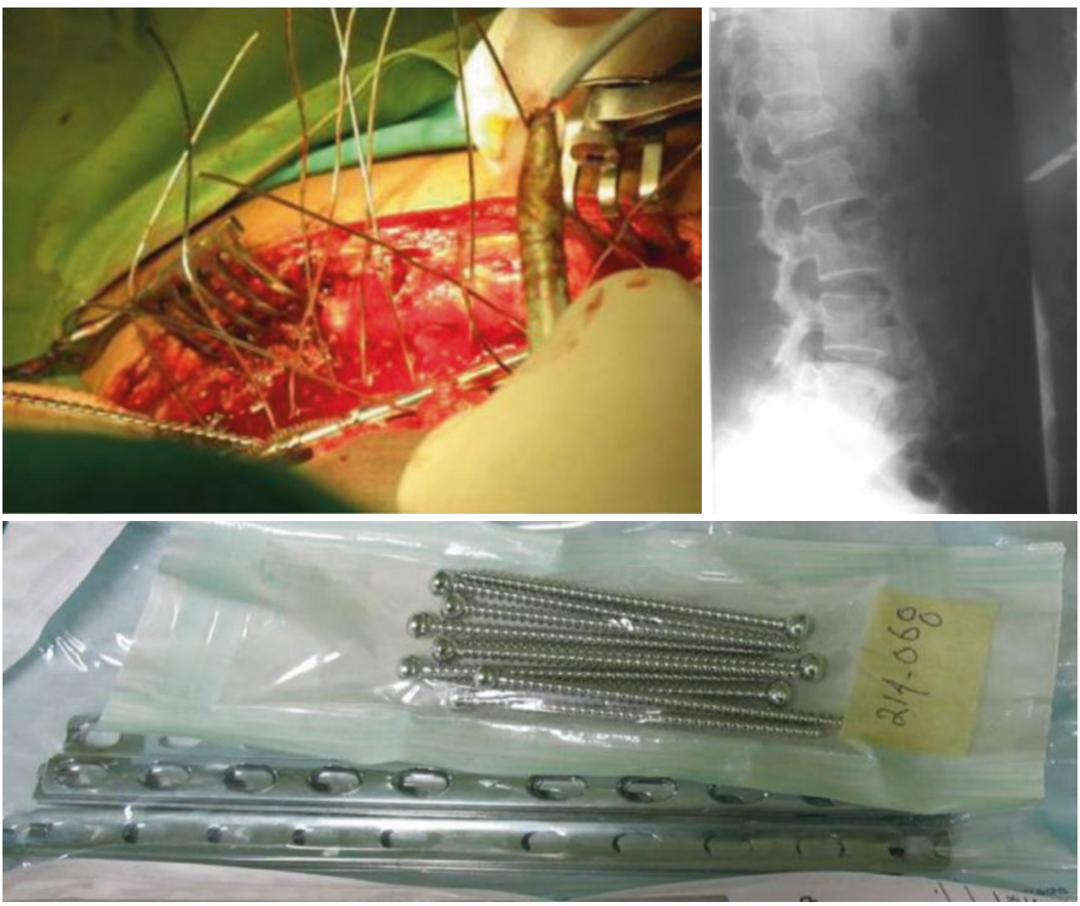


Fig. 41.3 Titanium wires and metal plates used for rear spondylodesis (our own observation)

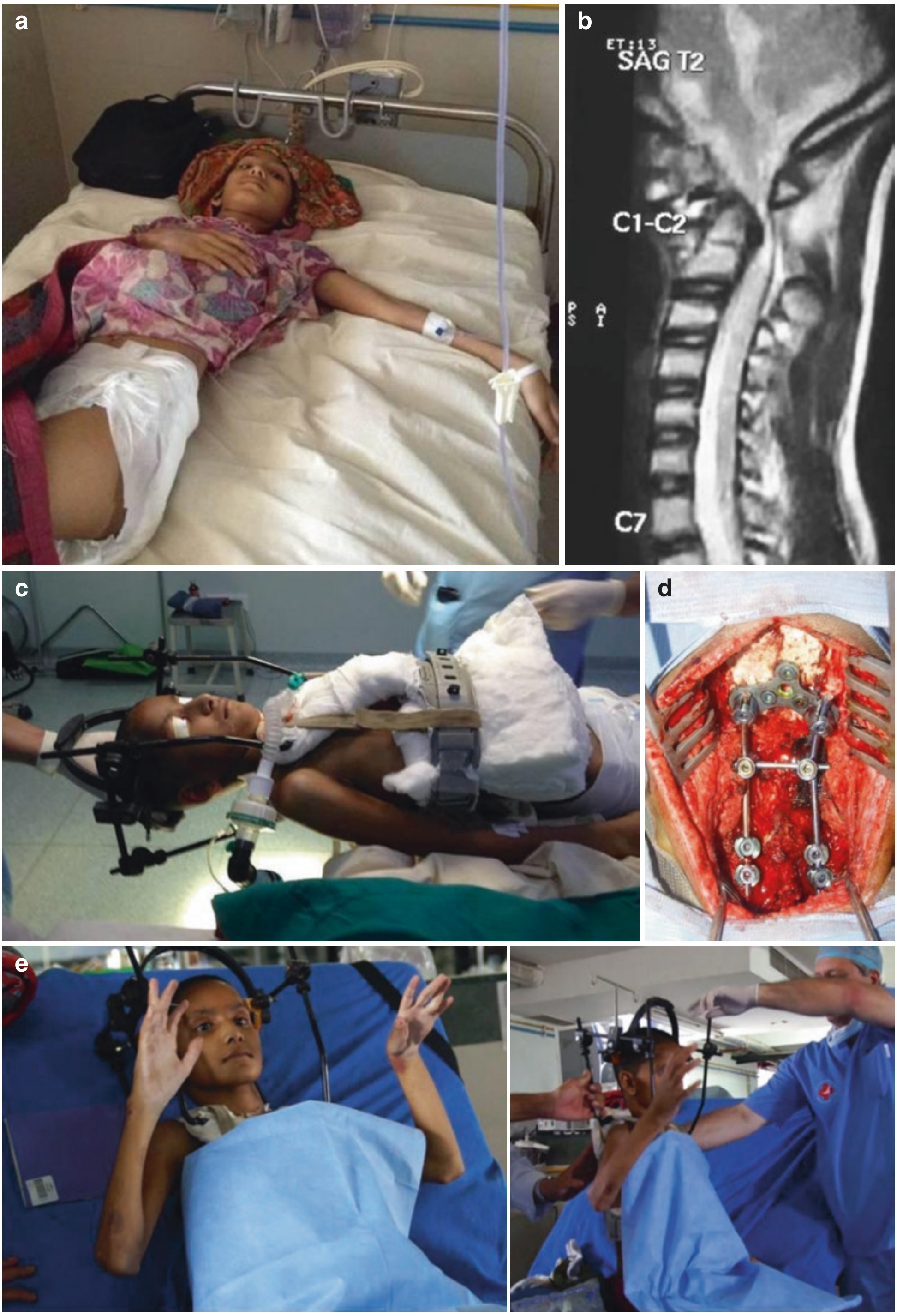


Fig. 41.4 Observation of patient K, 13 years old. The diagnosis: a closed complex atlantoaxial injury. Fracture-dislocation of dens C2 (type 3) with dysfunction of spinal cord (ASIA - B) tetraplegia; On the third day after admission a bitemporal skeletal extension clamp was applied (**a**). CT of cervical spine showed fracture-dislocation (transluxation) in C2 (**b**). After 2 weeks from the injury we performed (consecutively) the following surgeries - tracheostomy, installation of a gala- apparatus, atlantooccipital correction of the spinal axis, and occipitospondylodesis with rear decompression of the spinal cord (resection of the arc of the atlas) and transpedicular 4-screw fixation at C5 and C4 level (c.d.). During the first 2 days after the surgery we observed weak movement in the hands and feet, and substantial increase of strength and movement on the 3rd and 4th week from the injury (**e**), up to 4 points on the ASIA scale

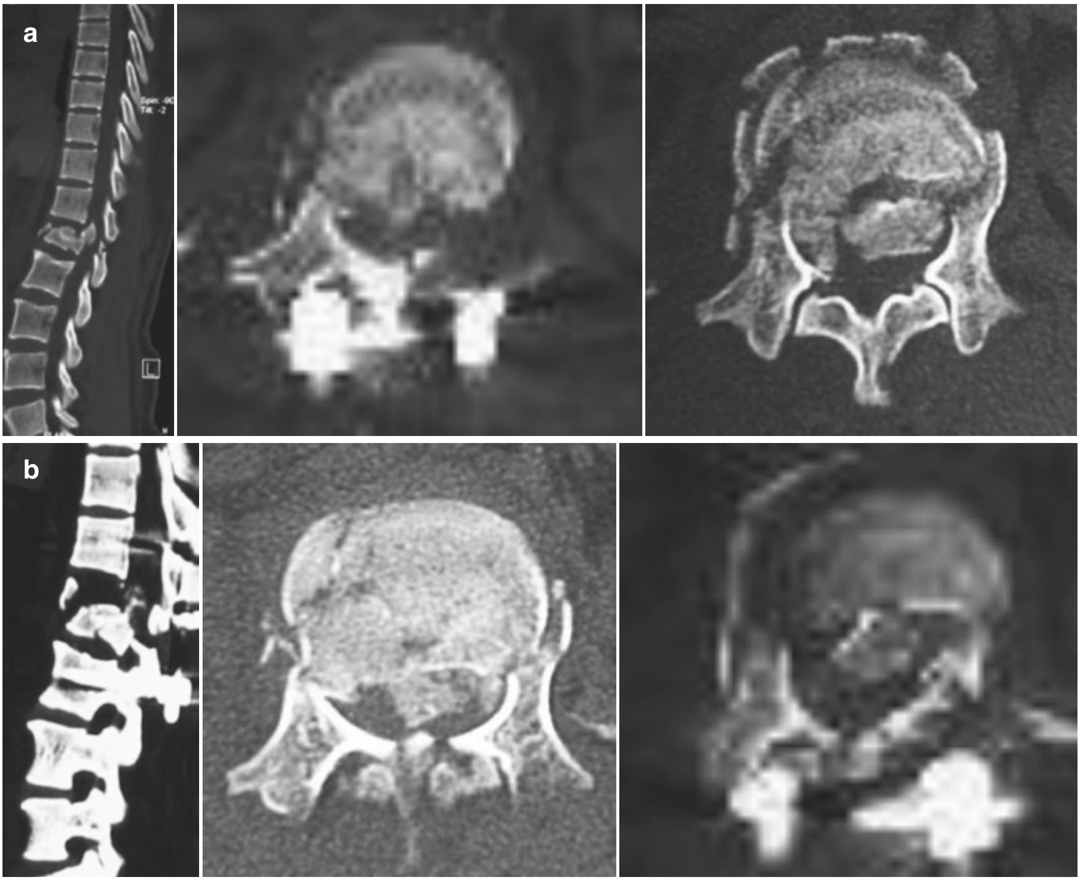


Fig. 41.5 (**a**) 40-year old patient . CT control after the first stage of surgical treatment: spondylodesis, transpedicular 4-screw fixation of L1 fracture at the Th12–L2 level. (**b**) The same patient. The second stage of surgical treatment. in 10 days and CT control

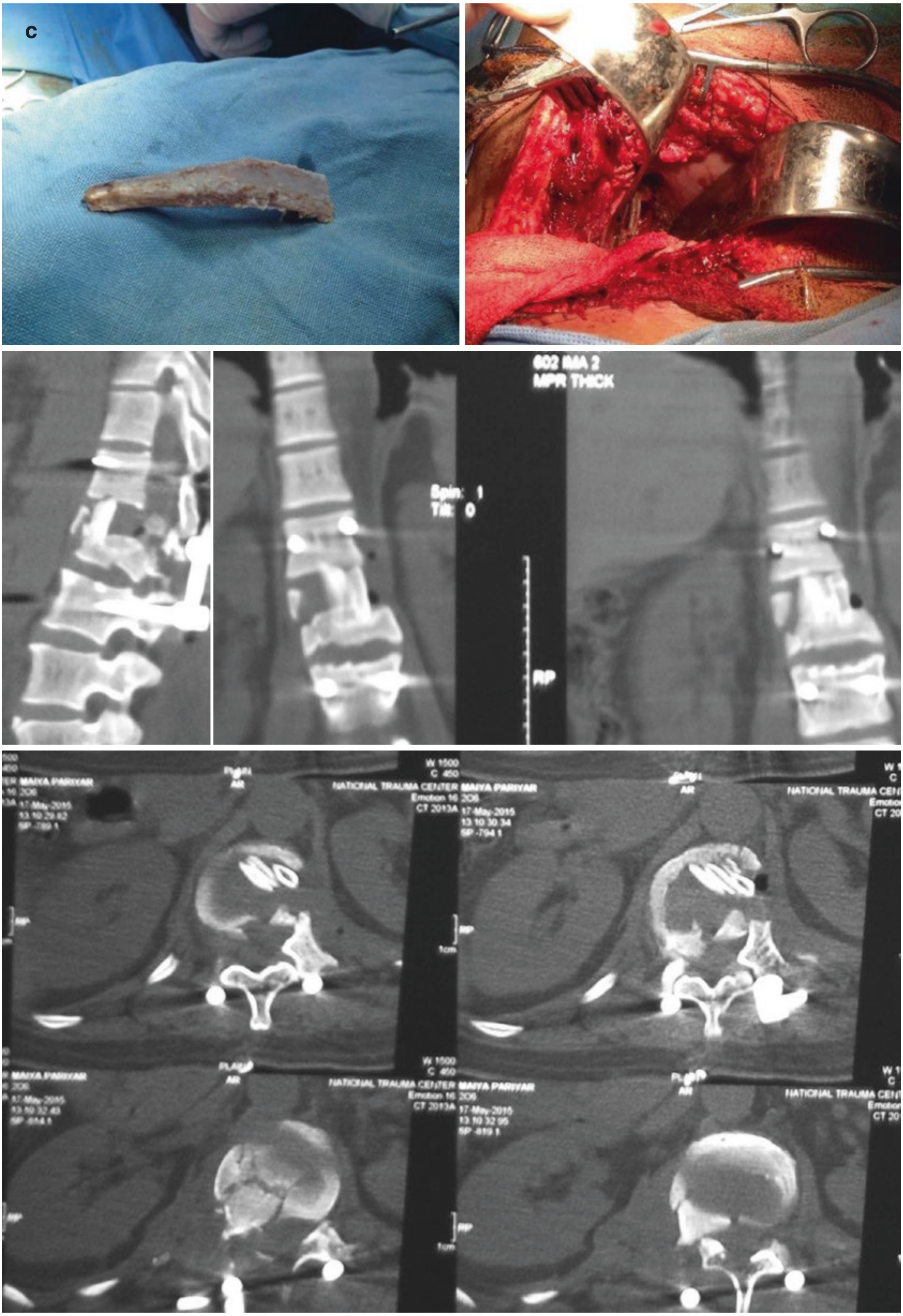


Fig. 41.5 (continued) (**c**) Transtoracic stabilization. A partial corpectomy of L1 and discectomy of Th12–L1, decompression of the spinal cord, spondylodesis of L1 body by autograft bone (three rib fragments). The control CT showed that the compression of the spinal cord was eliminated and the injured segment of the spine was stabilized

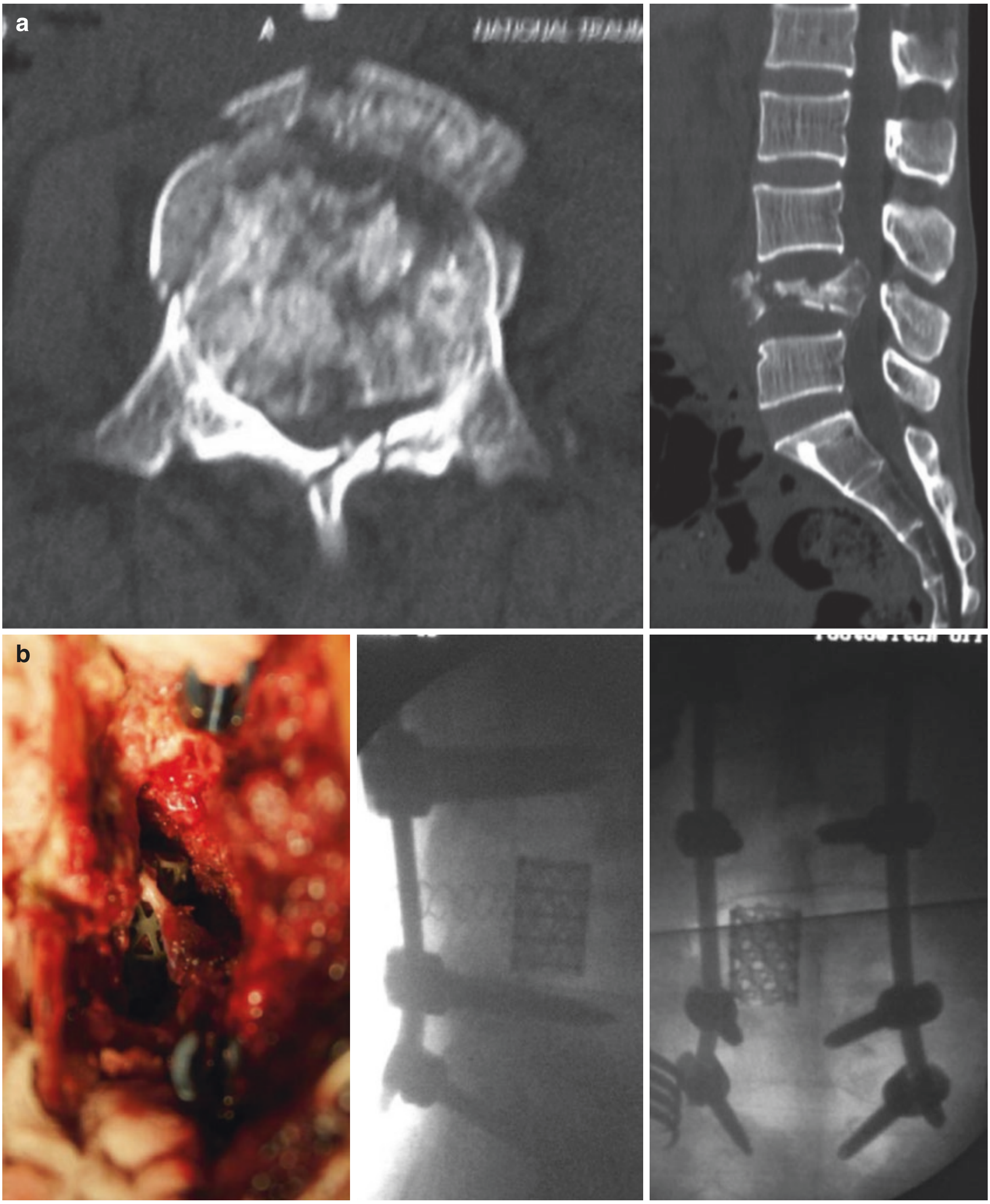


Fig. 41.6 Patient J, 55 years. Closed unstable complex spine and spinal cord injury ASIA – C. Bursting fracture in L4 with 3/4 compression of the spinal canal; (**a**) CT before surgery; (**b**) rear spondylodesis with installation of transpedicular system with 8 screws L2, L3, L5, and S1, corpectomy on L4 with installation of titanium mesh replacement endoprosthesis from rear access. CT control

body being intact, we performed a partial corpectomy of L1 and discectomy of Th12–L1 with decompression of the spinal cord, frontal spondylodesis, and prosthetic replacement of L1 body by a rib autotransplant (three rib fragments). The control CT showed that the compression of the spinal cord was eliminated and the injured segment of the spine stabilized.

Figure 41.6 demonstrates of a 55-year old patient with a closed unstable complex spine/

Fig. 41.7 Patient A., 17 years. Diagnosis: complex spine and spinal cord trauma. Contusion of the spinal cord and hematomyelia on the Th12–L1 level SCIWORA. ASIA – A

spinal cord injury ASIA-C. Bursting fracture L4 with 3/4 compression of the spinal canal. The patient was delivered to the hospital on the 7th day after the trauma. Neurological status: lower paraparesis, reduced sensory response, and dysfunction of pelvic organs. On the 10th day we performed a surgery: rear spondylodesis with installation of a transpedicular system with 8 screws L2, L3, L5, and S1 and corpectomy L4 with installation of titanium mesh endoprosthesis from rear access.

The control CT showed that the implants' position and correction of axis are satisfactory, with enough stabilization. No new neurological symptoms are present.

On Fig. 41.7 there is a 17-year old girl with a complex spine and spinal cord trauma sustained in an earthquake. Contusion of the spinal cord and acute impairment of circulation in the spine at the Th 12-L1 level. SCIWORA .ASIA-A.

Due to the lack of radiographic symptoms of spine injury, or instability of the patient, and also presence of lower flaccid paraplegia that developed right after the injury, we prescribed conservative treatment, vascular therapy, and physical therapy.

Conclusion

Treatment of children with spinal trauma is largely determined by the timely and adequate evaluation of their condition, appropriate first aid and transportation to a specialized medical facility, availability of state-of-the-art equipment and implants, and participation of specialists for diagnostics and surgical treatment of such patients.

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42 Severe Fractures and Pediatric Orthopedic Trauma in Disasters and Mass Casualties

Keith D. Baldwin and John P. Dormans

42.1 General Concepts in Pediatric Orthopedic Trauma and Polytrauma

Trauma is the most common cause of death in pediatric patients greater than 1 year of age [1]. Mortality rates of up to 20 % can be expected in polytraumatized patients. The greatest share of morbidity and mortality is due to injuries to the brain and musculoskeletal system [1]. The assumption should be made at the outset that the child will make a full recovery, and medical and surgical treatment decisions made with future rehabilitation in mind.

42.1.1 Medical Concepts

Children require immediate assessment of primary and secondary surveys similar to adult patients. Airway, breathing, and circulation should be assessed in all patients [2, 3]. Pediatric patients stay hemodynamically stable longer than adult patients if they have experienced significant hemorrhage. Large-bore access should be obtained promptly, and if unavailable or unobtainable, intraosseous infusion is recommended [4–6]. Late hypovolemic shock may result if fluid resuscitation is inadequate. The patient should be kept warm and have adequate resuscitation.

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42.1.2 Head and Neck Injuries

Children's heads are large relative to their body size; this large head size requires transport boards with occipital cutouts to prevent excessive neck flexion during transportation. In resource-limited settings, the back may be elevated with towels on a normal spine board with the goal of maintaining a straight spine [2]. This is necessary to prevent iatrogenic exacerbation of preexisting neck injuries. The pediatric Glasgow Coma Scale within 72 h of injury and the presenting oxygen saturation are predictive of mortality [5]. As such these factors should be closely monitored. Intracranial pressure should be controlled by elevating the head of the bed, controlled hyperventilation, adequate analgesia, and maintaining urinary flow through IV fluids and diuretics if necessary. Invasive monitoring can be considered with the presence of appropriate surgical expertise.

N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_42

Children have greater ability to recover from brain injuries than adults, and as such the remainder of their care should be undertaken under the assumption that a full recovery will be made.

Spasticity develops rapidly following brain injury, and as such splinting in functional positions may help diminish long-term disability or need for further surgery. Heterotopic ossification (HO) may form particularly in the hips and elbows [7], with early signs being warmth, pain, and decreasing range of motion. Nonsteroidal anti-inflammatory drugs (NSAIDs) are generally prescribed, but their utility is unclear in preventing or minimizing the clinical effects of the HO [7]. Early mobilization is desirable but passive range of motion should be gentle to avoid exacerbating soft tissue injury.

42.1.3 Visceral Injuries

42.1.3.1 Intra-abdominal Injuries

Intra-abdominal injuries are somewhat unusual in pediatric blunt trauma. Although uncommon, these injuries result in a great deal of mortality [2, 6]. They are the third leading cause of death after head injury and thoracic injury. Abdominal bruising or swelling or a "seat belt sign" (bruise of the lap belt across the belly) in an older child may suggest hollow viscus injury such as a colonic rupture [8]. These signs often coexist with lumbar spine burst fractures. A diagnostic peritoneal lavage (DPL) or a focused abdominal sonogram for trauma (FAST) will help to assess for free fluid within the abdomen. CT scans if available will provide greater detail of the abdominal viscera from which medical and surgical decisions can be made. These CT scans can also be reconstructed to examine spine injuries the child may have. Children are vulnerable to splenic and liver injury. Liver injury is the most common reason for lethal hemorrhage in pediatrics. Also consider duodenal hematomas, traumatic pancreatitis, and avulsion injuries of the bowels as they are more common in pediatrics due to less developed abdominal musculature [2, 6].

42.1.3.2 Thoracic Injuries

Thoracic injuries can either be picked up during primary or secondary surveys, or a more subtle injury may be picked up during further radiologic workup. The workup and treatment of these injuries are similar to adults; however, pediatric-size uncuffed endotracheal tubes and cuffs should be available [9]. Rib fractures are less common than in adults because of the greater elasticity of the bones. If sternal fractures exist, a high index of suspicion for myocardial contusion should be present. Scapular fractures can also be a marker for thoracic trauma [10]. Pulmonary contusions are the most common pediatric thoracic injury in blunt trauma. Injuries to the vessels and heart are less common in children and adults [2, 6]. Multiple long-bone fractures may cause fat embolism syndrome; when lung injury exists care must be taken before intramedullary fixation of long bones. Recent studies have shown that the acute lung injury associated with nailing long bones is not as severe in children as in adults [11]. The chest should be observed for penetrating trauma, JVD, and accessory muscle use. It should be auscultated for breath and heart sounds and palpated for tenderness, crepitation, or subcutaneous emphysema [2].

42.1.3.3 Genitourinary Injuries

In the setting of blunt trauma, genitourinary injuries are relatively rare. They can be suggested by blood in the urine (in the Foley bag), difficulty passing the Foley, or in the case of a male a high-riding prostate on rectal exam. A genitourinary injury should be suspected if there is a pelvic fracture or if the mechanism of injury was a fall with the patient straddling an object [5]. The examiner should look for urethral bleeding and bone fragments on vaginal or rectal exam if indicated by the injury.

42.1.4 Musculoskeletal Injuries

42.1.4.1 Musculoskeletal General Considerations in Pediatrics

Pediatric bone is more flexible than adult bone, as such incomplete fracture patterns such as greenstick fractures and buckle fractures are possible [5]. Children have a thick, active periosteum, which is generally intact on the side that the fragment is displaced toward. This fact makes pediatric fractures more amenable to closed treatment with immobilization than adult fractures [5]. Additionally children have the ability to remodel deformity that exists as the result of fracture malunion. As such, a greater degree of deformity is acceptable in children compared to adults. Generally in younger children, fractures closer to the physis (growth plate) and less displaced fractures heal and remodel better than fractures with the opposite characteristics. The reverse side of that benefit is that children's growth can be disturbed by fractures. As such, in cases when the growth plate is affected, long-term follow-up is necessary to identify and treat limb length and angular deformities promptly [5]. All joints should be taken through a range of motion and observed for lacerations, contusions, and deformities. The pelvis should be examined in compression to assess for stability. Pulses and distal neuro examinations should be completed [2, 6].

42.1.4.2 Compartment Syndrome

Compartment syndrome is most common in the leg (tibia region) and forearm region. It may result from either initial injury or vascular embarrassment and reperfusion. Children with high-risk injuries (high-energy tibia fractures, supracondylar fractures with ipsilateral distal radius fractures) should be monitored for swelling. High-risk obtunded patients should be examined with serial compartment checks in the setting of a high-risk injury [12]. The first sign of compartment syndrome in a child is typically increasing narcotic requirement [13]. Pain with passive stretch and increasing pain may be difficult to assess in an injured child. A high index of suspicion must be maintained for obtunded children with high-risk injuries and tense compartments. Clinicians should have a low threshold for invasive testing and fasciotomy in these cases because the risk of intervention is far less than the risk of nonintervention. Crush injuries are uncommon but can portend massive soft tissue injury and are more common in an earthquake setting than in the general trauma population [14, 15]. This topic is covered in more detail in Chap. 41.

42.1.4.3 Open Fractures

Open fractures continue to be a source of debate among orthopedists. The standard of care remains urgent treatment with antibiotics and surgical debridement of the fracture site, along with the stabilization of the surgeon's choosing. Clinical data shows no difference between delay and emergent treatment of open fractures [16]. In children the risk of infection has been shown to be [17] linked to the severity of the fracture by the classification of Gustilo-Anderson [18]. The goal should be to treat these fractures in as an expeditious fashion as practical given the situation. In a disaster situation, life-threatening injuries in other patients may delay surgical treatment of these fractures. In these cases data suggest that surgical debridement can be safely delayed [16] but that antibiotics should be administered as quickly as possible and surgical debridement should take place at the earliest possible time. Currently intravenous first-generation cephalosporins are administered for type 1 fractures, gentamicin is added for types 2 and 3 fractures, and penicillin is added for farm injuries or injuries in which a vascular repair has been performed. Clindamycin can be substituted for first-generation cephalosporins in cases of penicillin allergy [18].

42.1.4.4 Peripheral Nerve Injuries

Peripheral nerve injuries are not uncommon in cases of trauma. High-energy or penetrating trauma cases are particularly predisposed to nerve injuries. Penetrating trauma or trauma associated with open fractures generally warrants nerve exploration. Most blunt traumatic nerve injuries may be safely observed. The exception to this rule is when a nerve is functioning pre-interventionally and not functioning post-interventionally. Most surgeons will explore the nerve in these cases except for select situations.

42.2 Issues Specific to Disaster Pediatric Orthopedic Trauma

42.2.1 General Issues

Disasters and mass casualty events (MCEs) can be the result of natural disasters (e.g., the Haiti earthquake of 2010, Hurricane Katrina in 2005, or the Japanese tsunami of 2011) or man-made disasters (the terrorist attacks of 2001, or the Oklahoma City bombing of 1995, or civilian casualties of conflicts) or can be a combination of the two (the Fukushima Daiichi nuclear disaster which followed the Japanese tsunami). Smaller scale mass casualty events are possible in situations such as airplane crashes, shootings, or multivehicle accidents.

Children are involved to varying extents in these disasters. Though, in broad terms, the percentage of children under 18 is generally reflective of the population at large, it will vary depending on the type of MCE. Natural disasters that are unpredictable and effect a broad swath of geography are likely to affect children to the extent that children are present in that population. Targeted attacks will affect children more or less depending on the nature and location of the attack. Children are often survivors of these MCEs [19–21].

42.2.2 Initial Response

Initial response, similar to adult MCE, is going to take place in the field. Figure 42.1 highlights the flow of patients from the disaster scene to definitive medical care. Similar to adult disaster care, patients are triaged by the urgency of their injuries. Patients with airway problems or active bleeding are quickly stabilized and brought to the nearest facility in which advanced airway control or hemodynamic control is reasonably available. Pediatric care is similar. Ideally, a level I pediatric hospital or its equivalent will be ready to receive the patients injured in the disaster. In some cases however a pediatric trauma center may not be readily available. In these cases, the nearest facility that has the ability to provide the child with lifesaving therapy or the ability to stabilize the child's physiology is acceptable. The patient can be transferred to a more specialized hospital with pediatric orthopedic care when they are medically stable [9]. Various algorithms are available which aid in decision-making regarding triage to higher

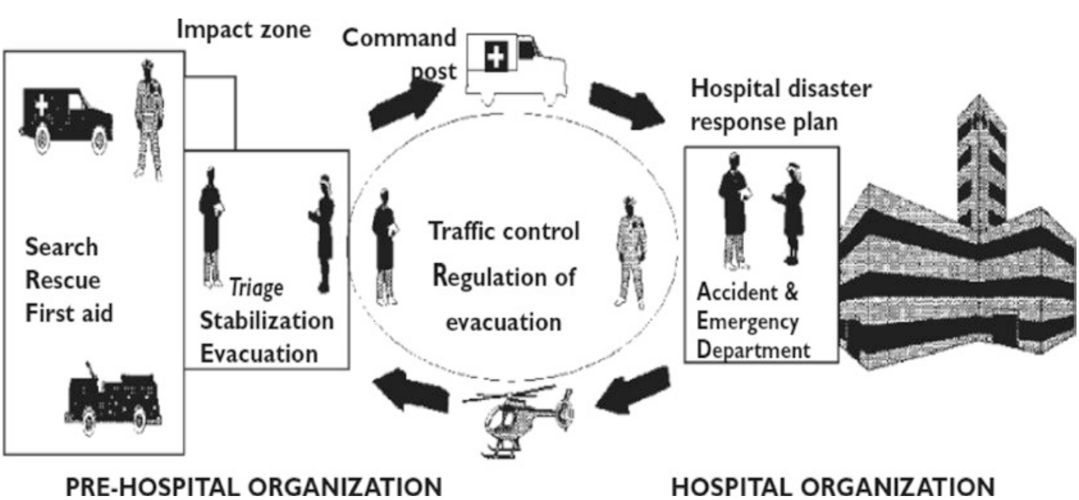

Fig. 42.1 Flow of patients from disaster scene to definitive management; (Permission from Establishing a Mass Casualty Management System, Washington D.C., 1996)

level facilities based on urgency and expected survivability of injuries.

42.2.3 Recommended Trauma Equipment for Pediatrics

The American Academy of Pediatrics publishes a list of recommended equipment (Table 42.1) [9]. These are primarily tools used to manage airway, breathing, and circulation. Primary among these are endotracheal tubes that are of appropriate size and pediatric-sized defibrillator paddles. Pediatric spine boards are particularly important to prevent excess disability resultant from spine injuries. These specialized boards have cutouts for the head to accommodate the relatively large size of the head to prevent excessive neck flexion.

42.2.4 Injuries Specific to Disasters

Though almost any injury may be seen in the setting of a disaster, some injuries are more common in disasters and MCEs than they are in a community injury scenario. Injuries such as burns, smoke inhalation, electrical injury, and blast injuries are relatively uncommon in a general trauma population that may be seen at a children's hospital.

Table 42.1 Recommended equipment for pediatric disaster management

Airway management
Oxygen source with flow meter
Simple face masks – infant, child, adult
Pediatric and adult masks for assisted ventilation
Self-inflating bag with 250, 500, and 1000 cc reservoir
Wall suctioning device or suctioning machine
Suction catheters – Yankauer, 8, 10, 14F
Oropharyngeal airway tubing (infant and adult sizes)
Nasal tubing – infant, child, and adult sizes 1–3
Optional for intubation
Laryngoscope handle with batteries
Miller blades – 0, 1, 2, 3
Endotracheal tubes, uncuffed – 3.0, 3.5, 4.0, 4.5, 5.0, 6.0, cuffed – 7.0, 8.0
Intubation guides – small, large
Adhesive tape to secure endotracheal tube
Intravascular access or fluid management
IV catheters – 18-, 20-, 22-, 24-gauge
Butterfly needles – 23-gauge
Intraosseous needles – 15- or 18-gauge
Boards, tape, tourniquet IV
Pediatric drip chambers and tubing
5 % dextrose in normal saline and half normal saline
Isotonic fluids (normal saline or lactated Ringer's solution)
Miscellaneous
Blood pressure cuffs – premature, infant, child, adult
Nasogastric tubes – 8, 10, 14F
Sphygmomanometer
Splints and gauze padding
Rolling carts with supplies such as abundant blankets
Warm water source and portable showers for decontamination
Thermal control (radiant cradle, lamps)
Geiger counter (if suspicion of radioactive contamination)
Personal protective equipment (PPE)

(continued)

Table 42.1 (continued)

Monitoring equipment
Portable monitor/defibrillator (with settings <10)
Pediatric defibrillation paddles
Pediatric ECG skin electrode contacts (peel and stick)
Pulse oxymeter with reusable (older children) and non-reusable (small children) sensors
Device to check serum glucose and strips to check urine for glucose, blood, etc.
Among the recommended equipment, elements for proper airway management in children are crucial. A major challenge of any disaster response is gathering, organizing, and moving supplies to the affected area
Resource management within the hospital and other facilities or agencies may prove to be a decisive factor in whether a mass casualty event can be handled or not

Taken from http://www.aap.org/en-us/advocacy-and-policy/aap-health-initiatives/Children-and-Disasters/Documents/MANUAL-04-internacional-2011.pdf#page=5

42.2.4.1 Burns and Smoke Inhalation

Burns in pediatric patients are devastating injuries. They are more common in disaster scenarios. Orthopedic or plastic surgeons may become involved later in the patient's care for escharotomy or contracture release. The initial management of the pediatric burn patient is critical [9]. Survival and disability are related to total body surface area (TBSA) burned and initial care. Patients should be aggressively volume resuscitated; early rapid sequence intubation is indicated in cases where smoke inhalation is present. Dry dressings should be placed, and patients transferred to a burn center. Escharotomy should be performed early to prevent posttraumatic compartment syndrome. Burn patients are at risk of contracture formation and heterotopic bone formation. As such these patients require ongoing splinting and reassessment by orthopedic specialists.

42.2.4.2 Electrical Injury

Electrical injuries may be less innocuous than they look. There can be small entry and exit wounds with a large amount of damage in between. Late neurologic and ocular complications may occur. Serial debridements may be necessary, and contracture release may be necessary dependent on the amount of tissue destruction and necrosis present.

42.2.4.3 Blast Injuries

Blast injuries generally result in primary, secondary, tertiary, and quaternary injuries. Primary injuries are the result of the initial blast and the effects on fluid-filled cavities and can include air embolus, abdominal injury, spinal cord injury, and lung injury. Secondary injuries are blunt or penetrating injuries as a result of debris or collapsing infrastructure. Fractures are common from secondary injury. Tertiary injuries occur when the body is displaced by the blast (thrown) and lands some distance away. The energy absorbed by the body can cause fractures, traumatic amputations, or head injuries. Quaternary injuries are injuries which evolve over time such as burns or inhalational injuries. Orthopedic surgeons are key to managing many of the injuries resultant from blasts [9].

42.3 Specific Pediatric Orthopedic Injuries

42.3.1 General Concepts in Pediatric Polytrauma Orthopedic Treatment

Pediatric patients with multiple traumatic injuries may be treated surgically in a more aggressive fashion than general pediatric orthopedic trauma care. Pediatric patients with multiple traumatic injuries should be treated with their future rehabilitation in mind. If fractures can be treated reasonably in a physis-respecting fashion so that a patient may be weight bearing as tolerated on at least one limb, it will assist with transfers and

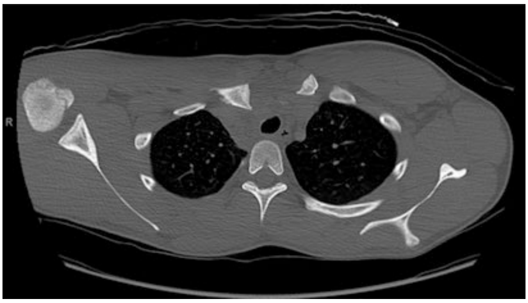

Fig. 42.2 16 yo male with medial clavicle SH II fracture with posterior dislocation and impression on the great vessels

Fig. 42.3 A severely displaced proximal humerus fracture in a 13 year old that failed closed reduction

mobility and decrease morbidity associated with immobilization.

42.3.2 Shoulder and Clavicle Injuries

42.3.2.1 Medial Clavicle Physeal Separation

Anterior medial clavicle physeal separations and sternoclavicular dislocations can be treated conservatively in a sling. Posterior dislocations and fractures can impinge on the great vessels or the trachea (Fig. 42.2) and can cause neurovascular injury or respiratory compromise. These injuries should be closed or open reduced in the operating room preferably with cardiac surgical backup during the reduction. The usage of metal implants is frowned upon due to the potential for migration. Heavy suture fixation is preferred.

42.3.2.2 Clavicle Shaft Fractures

The majority of pediatric clavicle fractures are treated non-operatively. Shoulder immobilizers or slings are used per surgeon preference. These fractures heal quickly with few sequelae. In older children and adolescents, a malunion may lead to an unsightly bump [22]. The adult literature suggests that shoulder abduction strength is decreased with excessive shortening (<1 cm) [23]. As such older children and adolescents with shortened fractures may be offered surgery though this is controversial. Adolescent patients in which the fixation of a clavicle fracture may alter the weight-bearing status may benefit from open reduction internal fixation. Open fractures, or fractures which tent the skin, should be open reduced and fixed.

42.3.2.3 Proximal Humerus Fractures and Dislocations

Proximal humerus fractures in children are mostly treated non-operatively. Over 80 % of the longitudinal growth of the humerus comes from the proximal humeral physes. As such, these fractures are very forgiving [24]. Axillary nerve palsies are not uncommon with proximal humerus fractures and dislocations. The vast majority of these are neurapraxias which resolve uneventfully. Surgical fixation can be considered in proximal humerus fractures in patients approaching skeletal maturity with displaced fractures (Fig. 42.3) that cannot be maintained by closed means. Dislocations should be promptly reduced and examined with AP lateral and axillary x-ray views.

42.3.2.4 Humeral Shaft Fractures

Humeral shaft fractures are generally treated non-operatively; shaft fractures are initially treated with coaptation splinting followed by a fracture brace when seen in follow-up. Distal 1/3 humerus fractures can be particularly problematic, as they tend to displace into varus alignment. These fractures have a high incidence of radial nerve palsy

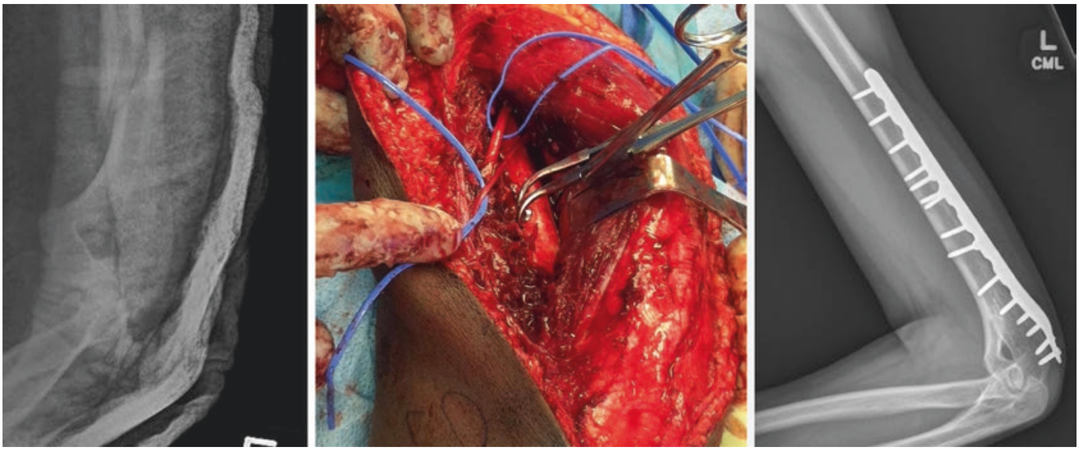

Fig. 42.4 Distal 1/3 extra articular humerus fracture with radial nerve palsy in a 15 year old (*left*) The nerve was entrapped in the fracture site, but was extricated, and transposed (*center*) 4 months later the fracture is healed and the radial nerve recovered (*right*)

(Fig. 42.4). These palsies are generally neurapraxias and will generally resolve independent of treatment. If a new nerve palsy occurs following a reduction maneuver, exploration should be considered. Fixation of humeral shaft fractures depends on the patient's other injuries and the effect that fixation would have on the patient's overall rehabilitation.

42.3.2.5 Fractures About the Elbow

Supracondylar humerus fractures are the most common surgically treated children's elbow fracture. There is a strong association with neurovascular injury with this fracture; as such a careful neurovascular exam should be conducted [25]. Pulseless fractures should be taken urgently to the operating room for closed versus open management (Fig. 42.5). Older children and adolescents may get transcondylar fractures which may require more aggressive open management to restore the joint surface. Lateral condyle humerus fractures are a problematic children's fracture because of the intra-articular nature of it. Most are managed operatively with closed or open reduction followed by smooth pin placement. They are vulnerable to redisplacement, nonunion, and lateral condylar overgrowth. Medial epicondyle fractures are usually avulsion-type injuries of the flexor-pronator mass, and they are associated with elbow dislocation. Elbow dislocation post-reduction films in children should be carefully scrutinized to assure that the reduction is concentric and no incarcerated fragment exists [26]. Monteggia fracture-dislocations are also far more common in children than they are in adults. As such the radiocapitellar relationship should be carefully scrutinized [27].

42.3.2.6 Forearm and Distal Radius Fractures

Ninety percent of forearm fractures and an even greater percent of distal radius fractures in children and adolescents can be treated nonoperatively [28]. The most common reasons for surgical treatment are failure to maintain acceptable alignment in a cast and an open fracture at presentation [29] (Fig. 42.6). Both plate fixation and flexible nails have been used with a large degree of success. Surgical management may be considered more optimal in cases when rehabilitation depends on upper extremity usage or weight bearing.

42.3.2.7 Fractures of the Hand and Carpus

These fractures are relatively common in polytraumatized patients. Surgical fixation will rarely result in additional ability to mobilize based on

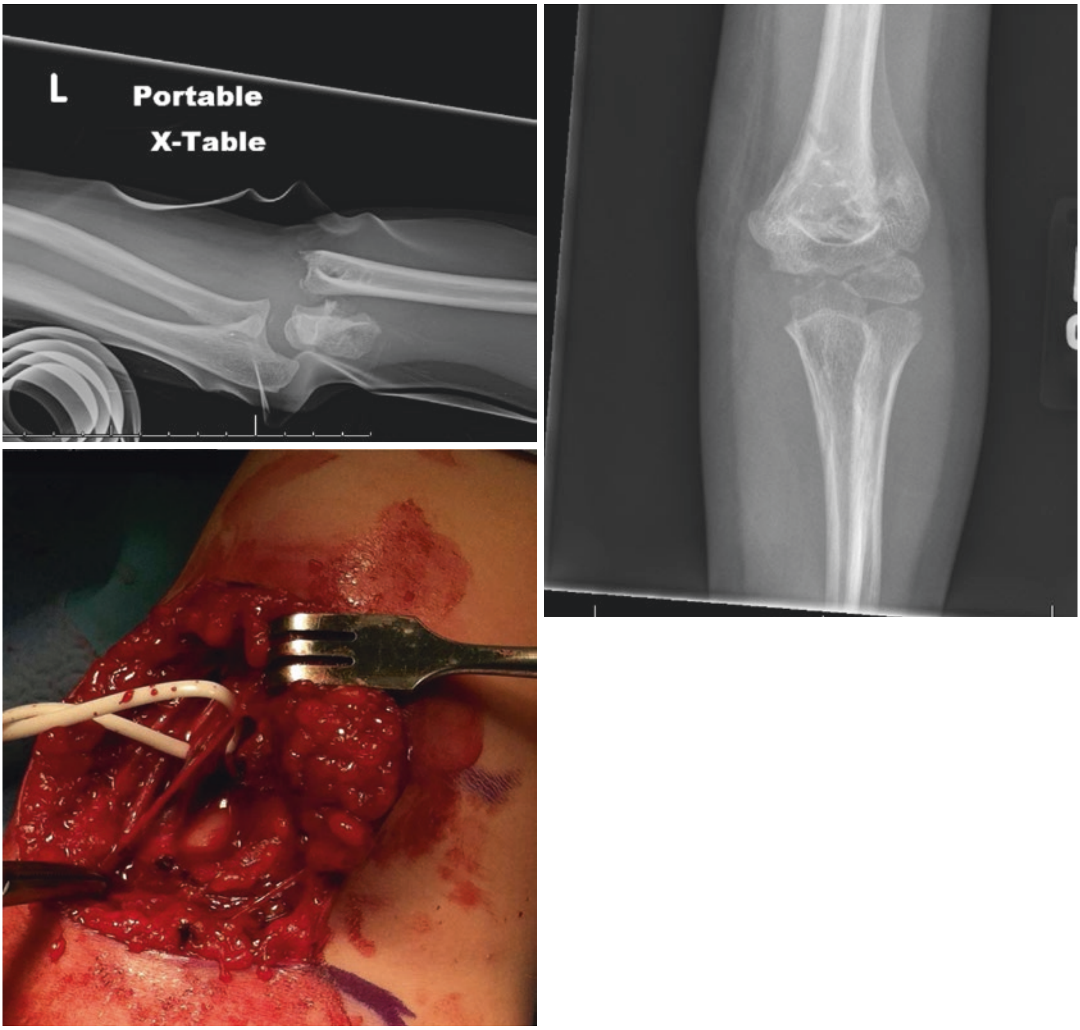

Fig. 42.5 This severe type 3 supracondylar fracture in a 7 year old was pulseless with an anterior interosseus nerve palsy at the time of injury (*left*) At the time of surgery the the fracture was irreducible, and the hand became white with reduction maneuvers, an exploration was performed and the brachial artery (vessel loop) was found in the fracture site (*center*). Following surgery the fracture was healing well at 6 weeks with a resolving nerve palsy, pulses were intact (*right*)

the fixation provided. As such aside from soft tissue concerns, management of these fractures is dictated mainly by the injury pattern and surgeon preference.

42.3.2.8 Spine Fractures

Spinal cord injury is relatively rare in pediatric trauma (1–2 % of spine injuries) [30]. Children can suffer SCIWORA (spinal cord injury without radiographic abnormality). This entity is most common in children under the age of 8 years old. The cervical spine should be immobilized if there is suspicion of a spine injury or if there is a distracting injury (such as a femur fracture) in which the patient could not adequately express pain in their spine.

42.3.2.9 Fractures of the Pelvis and Acetabulum

Fractures of the pelvis and acetabulum in children with open triradiate cartilage represent different injuries compared to fractures of the

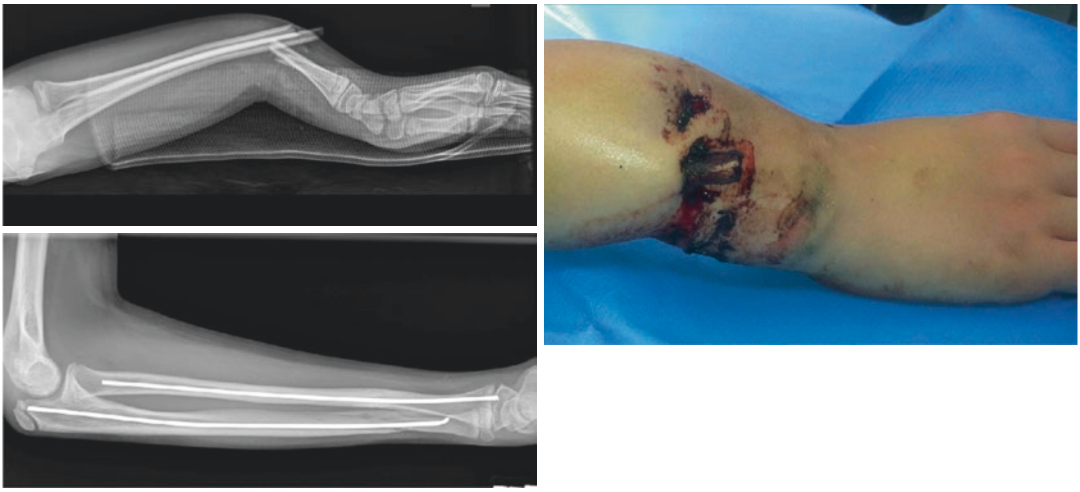

Fig. 42.6 This open both bone forearm fracture in a 13 year old (*top*) was grossly contaminated at presentation (*center*) It was immediately debrided in the operating room and flexible nails were placed. At 4 months follow up the fracture is anatomically healed, the patient has full motion and strength and no infection (*bottom*)

pelvis and acetabulum in more skeletally mature patients [31]. In skeletally immature patients many pelvis injuries are stable and may be treated with immobilization or weight-bearing limitation. As patients reach skeletal maturity, the likelihood of an unstable pelvic fracture increases. Pelvis fractures in children are highly associated with head injuries, as such careful neurovascular exam should be undertaken. Additionally, unstable pelvis fractures can lead to bleeding from the venous plexus present in the deep pelvis. As such volume-reducing strategies such as a pelvic binder or bedsheet wrapped around the patient can assist in controlling blood loss. Occasionally, these injuries will result in an arterial bleed, in which case embolization in interventional radiology is warranted. In situations where this is not practical, emergency external fixation and/or surgical exploration may be necessary. Additionally, careful attention to the patient's volume status is necessary. Pelvic fractures may require fixation if they are unstable.

42.3.2.10 Femur Fractures

Femoral neck fractures in children and adolescents require urgent/emergent treatment with decompression and internal fixation to minimize the risk of avascular necrosis [32] (Fig. 42.7). Femoral shaft fractures in children are generally treated in an age-appropriate fashion. Infants can be placed in a Pavlik harness or webril splint. Toddlers and young children may be placed in a spica cast immediately or traction followed by spica casting [33]. School-aged children may be treated by submuscular plating, flexible intramedullary nailing [34, 35], or external fixation as the situation calls for (Fig. 42.8). Older children and adolescents can receive reamed locked intramedullary nails as soon as the medical situation allows (Fig. 42.9). Management of these fractures may be tailored to surgeon comfort and the resources available in a given situation, with principles of limb alignment, length, and rotational profile preserved as carefully as possible. More rigid fixation allows for earlier

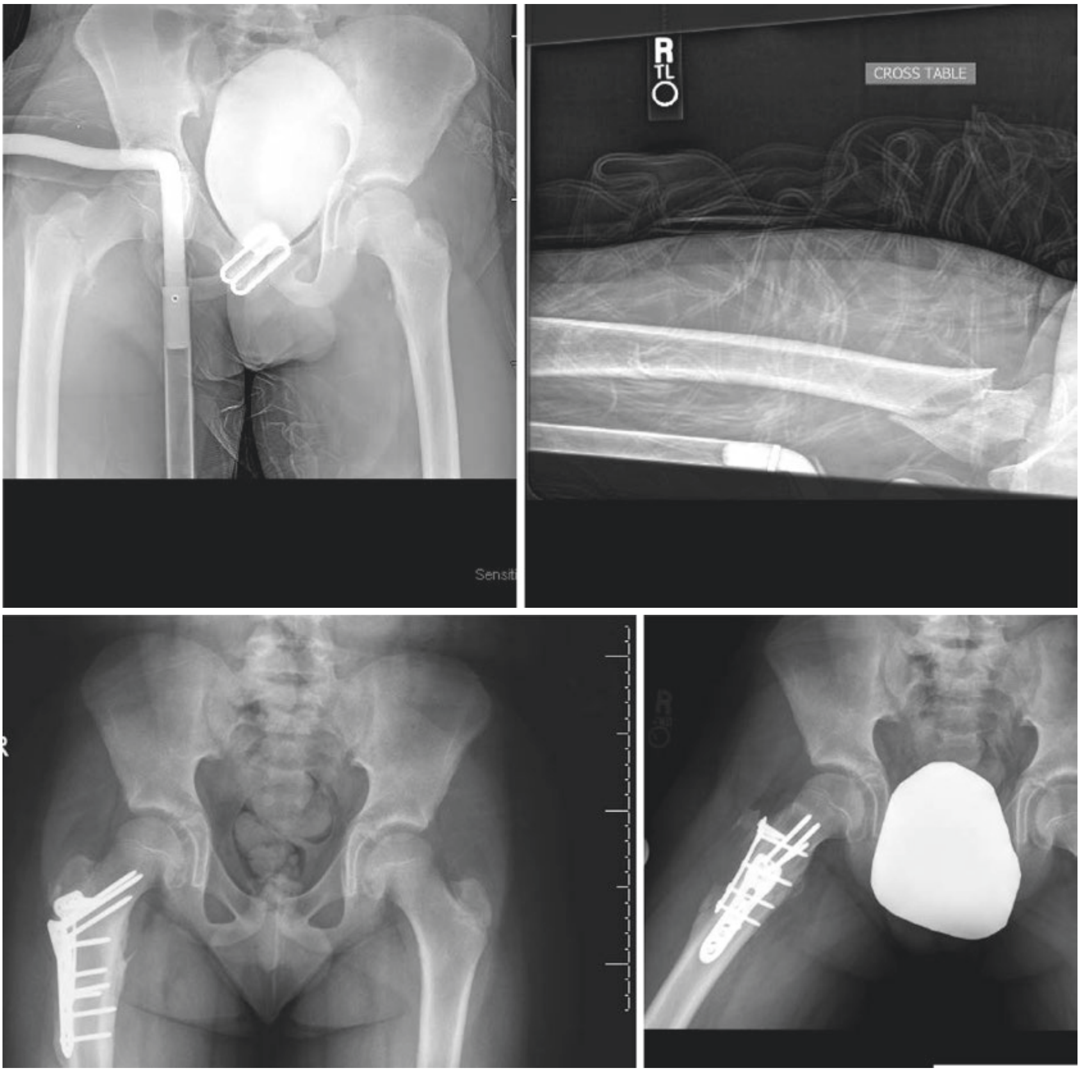

Fig. 42.7 This high energy proximal femur fracture in a 10 year old male was highly unstable (*left*) After locked plate fixation there was still sagittal plane instability, so a distal radius plate was placed anteriorly to buttress the sagittal plane instability. He is healed now and full weight bearing with no pain and full range of motion (*right*)

mobilization. Distal femoral physeal fractures present a unique challenge in that they should be closed reduced and pinned or fixed with screws depending on the pattern. These fractures carry a high incidence of growth arrest and should be followed for at least a year after injury and longer if a growth arrest is suspected or detected.

42.3.2.11 Proximal Tibia Fractures

Proximal tibial tubercle fractures are associated with potential for anterior compartment syndrome due to disruption of the anterior tibial artery by the fracture [36]. Displaced fractures should be fixed to prevent compromise of the extensor mechanism. Fractures of the tibial tubercle with the shaft involved proximally carry

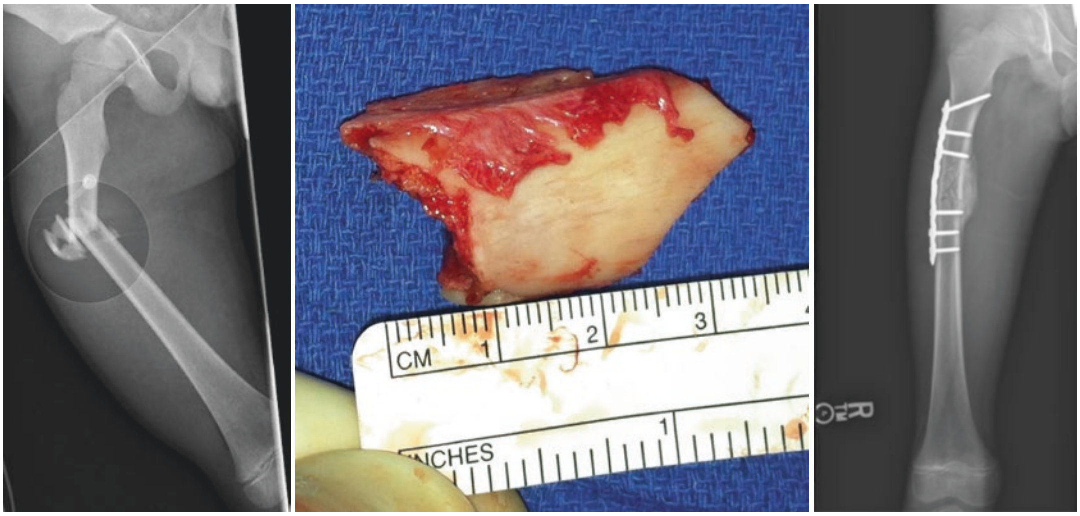

Fig. 42.8 This 7 yo patient had a high energy open femur fracture (*left*). There was a 3 cm intercalary piece (*center*) which was opened washed and replaced to maintain length and alignment. He then had compression plating performed. Though at 3 months the graft is resorbing, callus is abundant (*right*)

the risk of neurovascular injury similar to a knee dislocation in an adult due to the intimate relationship of the vessels with the back of the tibia (Fig. 42.10). Proximal tibia metaphyseal fractures (the so-called "Cozen" fracture) may develop a valgus deformity that develops over time and remodels over the course of a year or two, but parents should be counseled regarding this possibility.

42.3.2.12 Tibial Shaft Fractures

Tibial shaft fractures in the setting of disaster and polytrauma should be assessed constantly for compartment syndrome (Fig. 42.11). Options of fixation range from casting to reamed intramedullary nailing. In the setting of polytrauma, surgical fixation is often favored. Patients with closed growth plates are treated with reamed locked nails. Younger patients may be treated with flexible intramedullary nails versus plating. Isolated injuries or younger children may be treated with cast fixation.

42.3.2.13 Ankle Fractures

Ankle fractures in children with open growth plates can often be treated with closed reduction and cast fixation. Exceptions include older children with triplane or Tillaux fractures in which the joint is disrupted by greater than 2 mm. Older children and adolescents with closed growth plates often experience fracture patterns similar to adult patterns. Weight-bearing status is often not effected by surgical intervention. As such surgical decision-making is dependent on injury pattern.

42.3.2.14 Foot Fractures

Similar to ankle fractures, the majority can be treated non-operatively. Crush injuries should be monitored carefully for compartment syndrome. Multiple metatarsal fractures which are displaced in older children may be fixed at a surgeon's discretion. Surgery will likely not effect weight-bearing status.

42.3.2.15 Traumatic Amputations

Though covered in more detail in Chaps. 33 and 40, it bears mention that children have a high rate of limb loss as the result of disaster trauma. Multilevel fractures with open contaminated wounds and neurovascular injury may preclude limb salvage (Fig. 42.12).

Fig. 42.9 This 12 year old female suffered bilateral femur fractures, a tibia fracture an ulna fracture and spinal fractures (*left*). She was treated with internal fixation with rehabilitation in mind using locked nails in her femurs and plate fixation for her ulna. Her tibia had flexible nails because of her age. The extent of her injury caused her to form extra ectopic bone (*right*)

42.4 Recent Experience in Pediatric Trauma in Disasters and MCE

42.4.1 2011 Japanese Tsunami [37]

The earthquake and subsequent tsunami and nuclear disaster in Japan was one of the worst natural disasters in recent history. Nearly 1500 children lost one or both parents in the disaster. The majority of fatalities were due to drowning in this case as opposed to the crush injuries more typically seen in earthquake scenarios. There continue to be questions regarding the long-term effects of the nuclear disaster that followed the earthquake and tsunami.

42.4.2 2010 Haiti Earthquake

The 2010 earthquake in Haiti was a major disaster and MCE. Over 200,000 were killed and over

Fig. 42.10 This 14 yo female had a proximal tibia fracture resultant from a gunshot wound. Her popliteal artery required acute repair and she had a nerve deficit though the nerve was in continuity

300,000 more were injured; 37–53 % [38, 39] of those injured were children. Of these children nearly 50 % have fractures or orthopedic injury [38]. One-third of those with fractures had open fractures, and nearly ¾ had lower limb fractures. Open surgery was sparing because of the risk of infection. External fixation was used but with nonstandard hardware because of the limited availability of equipment. Most compartment syndromes were encountered late and so were treated non-operatively [38]. Amputations were used sparingly for uncontrollable infection or nonviable limbs due to the poor rehabilitation resources in Haiti.

42.4.3 Other Recent Disasters

There is little data on some recent disasters such as Hurricane Katrina in which a majority of the maladies were not trauma related, but due to displacement and infrastructure disruption that occurred as a result of the disaster. Additionally there is little information on the terror attacks of 2001 in New York and Washington. These were atypical in terms of pediatric trauma in the sense that mostly places of business were targeted, and as such the percentage of pediatric injuries were relatively low. We know from experiences in Israel that terror-related injuries generally require a longer hospitalization and greater rehabilitation resources than those not terror related [40].

Conclusions

Pediatric orthopedic trauma in a disaster or mass casualty setting can be difficult. Psychosocial issues surrounding loss of life of parents and social issues can dominate the later picture. In a smaller scale disaster, often typical treatments can be used. In cases of large-scale natural or man-made disasters, basic concepts of pediatric orthopedic trauma should be kept in mind, but often practicality and local resource availability will dictate what treatments are available. In cases where open treatment is dangerous, closed management or external fixation may be accepted in lieu of open treatment. Overall, each disaster has its own characteristics, and optimum management principles must be kept in mind with care directed toward resource availability and eventual rehabilitation. In the developing world, resources are scarce, and interventions must be performed with the setting in mind to avoid unnecessary complications [41].

Fig. 42.11 17 yo male with a transverse tibial fracture from high energy (*top left*), with a posterior tibial artery injury and compartment syndrome with a white pulseless leg on presentation (*top right*) treated with temporary spanning external fixation, fasciotomies and serial debridements (*bottom left*) followed by definitive intramedullary nail fixation (*bottom right*)

Fig. 42.12 This four year old child had severe injuries including a grossly contaminated upper extremity amputation with joint damage and multilevel fractures (*upper left and lower left*) She also had a grossly contaminated degloved foot with multiple tendon joint and bony injuries. (*upper right*) she was ultimately treated with a completion ampuation of the upper extremity and a syme amputation of the lower extremity (*lower right*)

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Part VI

Treatment of Orthopaedic Injuries: Continuation of Care

Prosthetic Rehabilitation in Disaster Areas

43

Israel Dudkiewicz, Nimrod Rozen, and Michael Heim

43.1 Prosthetic Rehabilitation in Disaster Areas

Rehabilitation after mass casualty incidents; natural disasters such as earthquakes, tsunamis, and fires; or man-made incidents such as terror events or war is very problematic due to increasing needs and decreased resources. Prosthetic rehabilitation presents specific problems in these situations that require special consideration.

In essence the specific conditions that dictate the procedures, the prosthetic types, and the end results of rehabilitation procedure are:

- Number of amputees and amputations
- Amputation levels
- Stump shapes
- Local prosthetic technological knowledge
- Follow-up capabilities
- Population profiles
- National financial resources
- Local priorities
- Upper limb vs. lower limb

43.2 Number of Amputees and Amputations

The number of amputees and amputations is of primary concern. High numbers of amputees/amputations limit the ability to give an efficient response within a reasonable time frame. Furthermore, the higher the ratio between the number of amputations and amputees (these vary as some patients lose more than one extremity), the more complicated the rehabilitation. The rehabilitation of patients who lost both legs is much more difficult and takes longer, due to greater stamina requirements. Also when there are two or even three amputations, there is the added difficulty of balance and stability [1, 2]. Even a combination of lower and upper limb amputation inhibits rehabilitation mainly due to balance and stability problems and the ability to regain normal gait. Additional asymmetry is caused by the use of only one side support, such as a cane or a crutch, and due to difficulty in using a walker or parallel bars.

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_43

43.3 Amputation Levels

The amputation level is of great significance – transfemoral as compared to transtibial amputation or transhumeral vs. transradial amputation. Higher level amputation that requires the supplementation of an extra joint such as the knee or elbow, which necessitates greater technical skill, is more complicated and demanding of the patients and significantly more costly.

High-level amputation also affects the delicate equilibrium between safety (stability), performance (freedom levels), and cost. High-performance, safe knee joints, such as the new generation of computerized knees (the Ottobock Genium or C-Leg knees, the Ossur Rheo Knee, the Endolite Adaptive knee, or others), are available. However, they demand sophisticated technology facilities, long-term follow-up, and maintenance, and they are also very expensive (some may cost in the region of 100,000 USA$ for a knee prosthesis).

43.4 Stump Shapes

One complication of mass casualty is that many amputations are not performed using classical techniques, with the amputation being undertaken at the time of the disaster or being carried out in less than ideal conditions. There are also many medical complications that may result, including crush injuries, open fractures, or delayed procedures. The damaged limb may need ablation at an unusual level and soft tissue closure may require unconventional skin and muscle flaps. These could result in irregular stump shapes or problematic scarring. The adverse effect of complicated stump shapes may cause difficulty in socket adaptation and may limit available prosthetic component types (stumps which are too long or too short), possibly leading to either a large number of surgical revisions or special socket usage. Once again, costs are therefore increased, leading to higher need for specialist professional knowledge.

Limb stumps change shape with time, and prosthetic sockets need to be remolded or completely restructured. An ill-fitting prosthetic socket may cause open wounds on the amputation stump. This is particularly true where skin grafts have been used and in the event of numb areas on the stump (Fig. 43.1).

43.5 Local Prosthetic Technological Knowledge

The local prosthetic technological possibilities have, of course, a major effect on prosthetic rehabilitation. Even in the "normal" world, the accessibility of medical services in general and prosthetic services in particular in low-income countries is much lower than in high-income countries. Although low-income countries account for 84 % of the world's population and 90 % of the total disease burden [3], less than 3 % of persons with disabilities in these countries have access to rehabilitation services [4]. On the other hand the need for prostheses is continuously on the increase, with a rough estimation of the WHO (World Health Organization) that the need for prostheses among disabled people living in low-income countries was over 30 million in 2011 [5].

43.6 Follow-Up Capabilities

Another point to be considered is that the demographics of low-income countries are totally different from most high-income countries. The population in low-income countries is mainly rural (over 90 % in Africa) [6], making access for routine follow-up and maintenance problematic. Generally, in many countries, patients are sent to Europe or America for treatment [7].

43.7 Special Populations

In all societies there are individuals with special needs. Some of these people live with their families residing in normative residential areas. Others are institutionalized, their well-being dependent upon caregivers. During times of crisis

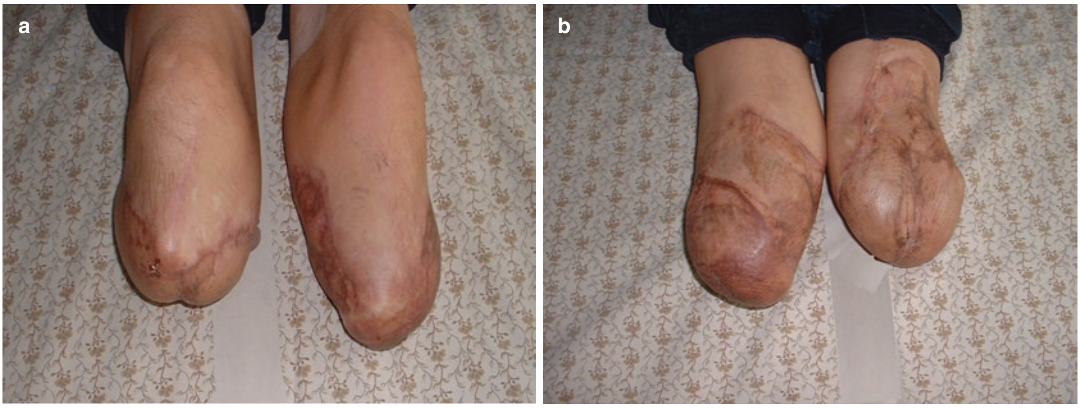

Fig. 43.1 Traumatic bilateral BKA with flaps and skin grafts (**a**, front; **b**, back)

these caregivers may not be accessible to provide services. Centralized administrative units should be made available so that, in time of a disruption in the reactive personnel placements, provisions are immediately available to provide continuity in care and safe transition in services. This provision is of high priority for these residents who urgently require assistance in every aspect of their lives – feeding, personal hygiene, etc.

43.7.1 Children

The pediatric population is usually much larger in low-income countries than in high-income countries. Consequently, more children require prostheses in low-income countries than in high-income countries. This large pediatric population increases the prosthetic demand more than the equivalent adult population, due to the frequency of prosthetic replacement required as a result of children's hyperactivity and natural growth.

Furthermore, children are often severely affected by disturbances in their environment where they previously felt confident and safe. The family unit may be affected, the house may be destroyed, and certainly devastating conditions exist. The therapeutic aim should be to try to normalize the conditions of their very existence. This is actually impossible on an individual basis due to the lack of housing and psychological support. Education should be provided on a regular basis so that a life regime is created. To diffuse the tension of the situation, an environment similar to a pre-disaster scene can be created wherein the children are grouped according to age and function. In each age group the participants are divided into teams which compete against each other. These internal divisions built new comradeship corporation and provide a social stability within the "external chaos." Collectively, like in a "summer camp" environment, all aspects of a "community" are established and both medical and other problems addressed (Fig. 43.2).

43.8 National Financial Resources

The precise number is still unknown, but probably over than 100,000 people were killed, and 200,000 lost at least one limb, in the Haiti earthquake of 2010. These numbers occurring after a mega-disaster require special arrangements. Even in a high-income country, there would be a negative impact when dealing with such a mega-disaster.

All the more so, in a low-income country, where even the most basic rehabilitation needs (such as wheelchairs) (Fig. 43.3) cannot be met, a far more demanding prosthetic rehabilitation might not/most likely would not be feasible.

Financial aid is initially donated to the country from other nations, the United Nations, and private contributions. At first, the sustenance of life

Fig. 43.2 Child with Syme amputation

Fig. 43.3 Improvised wheelchair

is the initial driving force and only thereafter the rehabilitation of the severely injured. As discussed earlier, artificial limb rehabilitation demands special skilled technicians, physiotherapists, and a complete medical team. Probably, the best solution in these situations would be to evacuate groups of amputees to an established center, rather than to try and create such a center within a chaotic environment. Many companies will donate components to such a center and the United Nations will foot the bill. International media exposure will often result in additional funds, especially when children are involved [8].

43.9 Local Priorities

Even in normal day-to-day situations, without any additional crises such as earthquakes in low-income countries, rehabilitation services are less prioritized [8, 9] in comparison to primary health care. When there is good primary care, the gap between the needs and resources of rehabilitation services increases over time, as more disabled people survive infancy [10]. In the event of a disaster, and even more so a mega-disaster, financial priorities may change due to the diversion of resources and efforts to restore basic survival needs such as food, water, accommodation, and acute medical care. Prosthetic rehabilitation in these situations is usually pushed back and remains an afterthought.

One example demonstrating the par between a mega-disaster in high- and low-income countries is by comparing the largest single terror event – the collapse of the World Trade Center (the "Twin towers") on September 11 – to the Haiti earthquake of 2010. Following the Trade Center attack, Western medical resources, supported by the American economic capabilities, easily dealt with the needs of the injured, including prosthetic rehabilitation. However, in Haiti, or in other countries such as Turkey and India, where medicine is relatively less developed, with poor resources (low-income countries), the acute phase of disasters is hardly manageable, making prosthetic rehabilitation problematic, if at all possible. Even in continuing war situations like in Syria, Iraq, or other places, due to decreased resources affecting medical staff, technicians, and workshops and reduced income, the increased number of amputees is very challenging to prosthetic rehabilitation. High amputation numbers are very commonly the result of a mega-disaster, secondary to limb sacrificing for lifesaving purposes, especially in rural or developing countries, and due to multiple land mine injuries which are very common in “chronic” battle areas.

43.10 Upper Limb vs. Lower Limb

Are upper limb amputees or lower limb amputees more difficultly placed? Who should be treated first? What are the priorities? Both have lost physical abilities and independence. Both groups need appropriate prostheses to fully recover and regain their previous physical, social, psychological, and even occupational status. Both groups need wound healing, stump care, and prosthetic provision. The provision of an artificial limb is, in itself, insufficient. The amputee needs to be instructed how to function with the provided prosthesis. Obviously, this entire process is, and should be, delayed. This cannot be regarded as a lifesaving service. Initially, efforts need to be focused upon lifesaving and only thereafter to quality of life. Under normal circumstances these procedures are undertaken in specialized centers, and it is probably better to transport the needy to such a center, and yet, in a world of limited resources, if prioritization is required, lower limb amputees are, relatively, in a worse position in an “after disaster situation.” Lower limb amputees, even in normal circumstances, have severely decreased mobility. Without an artificial limb and appropriate rehabilitation procedures, lower limb amputees will be, at least partially, wheelchair bound or, if young and healthy, walking with crutches for short distances. In contrary, relatively large numbers of upper limb amputees abandon their prosthesis for many reasons and do quite well without them [11–13].

Even normal accessibility for limited populations (wheelchairs or crutches users) is far from ideal, especially in developing and low-income countries. After disasters and especially mega-disasters, accessibility to many places is damaged, jeopardizing the chance of lower limb amputees to reach salvage centers and, consequently, preventing them from receiving the basics – food, water, shelter, and medication. In these situations, their lives are at risk, and therefore they should be the first patients to receive artificial limbs.

43.11 What Kind of Artificial Limb Should Be Provided in These Situations?

There are some basic principles that should be followed. The prosthesis should be cheap and technically simple to produce, to maintain, and to master. The prosthesis should have a long life span and should be resistant to tough conditions such as humidity, water, dust, trauma, and high forces of action and in a way less sensitive to inappropriate or not-recommended usage. Another important requirement is the ability to work without the need for regular maintenance. The prostheses should be safe to use, modern, and as flexible as possible within the range of limitations.

These requirements reduce options, excluding all modern computerized knees, ankles, and myoelectric hands. These are too complicated to produce and maintain and difficult to master. Furthermore they are very fragile and vulnerable to inappropriate environmental conditions (dust, humidity, etc.); they need regular maintenance and a reliable power source (electricity, which is not available all the time in disaster areas) so they can be recharged on a regular basis. For the same reasons, most of silicone liners, used with and without shuttle lock, are inappropriate in these situations. They are delicate and have a relatively short life span.

Based on these considerations, the recommendations for prosthetic provisions in disaster areas are:

- Modular prosthetic construction.
- For lower limb amputation patellar tendon-bearing socket for transtibial amputations and quadrilateral ischium-bearing sockets for transfemoral amputations. Sockets should be made from simple, cheap, and resistant commonly used plastic material.

Fig. 43.4 Result of low-cost prosthetic rehabilitation (SACH foot)

- Prescribe an SACH foot in the first place – it is cheap, resistant to poor conditions, and easily replaceable, if necessary. It is very simple to use and it provides a good solution to most walking situations [14] (Fig. 43.4). In the second stage after the general rehabilitation system is established, it can be changed to a singe axis or flexible foot if required and available.
- For transfemoral or trans-knee amputations, the mechanical knee will probably provide the best option due to its flexibility, simplicity, and relative safety. It is cheap, easily produced, and available. It is easy to learn how to use, is simple to repair, has a long life span, and does not require regular maintenance. Hydraulic or pneumatic artificial knees should be provided only as a second stage. Although they have better biomechanical properties, they are more expensive and more sensitive to environmental conditions and require regular maintenance. They are complicated to repair and to master.
- For upper limb amputations there are basically two options. The PVC (polyvinyl chloride) passive/cosmetic hand is a good option. It is simple and cheap to produce and long lasting and requires no regular maintenance. The disadvantage is the lack of motion of the device with reduced function. If an active end device is needed, a body power cable hook should be provided. It is cheap and simple to produce, simple to learn how to use, and resistant to difficult conditions and provides excellent function. The main disadvantage is the short life span of the rubber bands that should routinely be replaced [11–13, 15].
- In bilateral upper limb amputation, body power cables and hooks should be provided for at least one side to ensure personal independence.
- Other special conditions such as short stumps in high-level amputations, trans-knee amputations, very high-level amputations such as hemipelvectomy, or forequarter amputations need special consideration and should be rehabilitated only in experienced prosthetic rehabilitation centers, to avoid wasting resources because the rate of success in these very problematic injuries is limited in the first place.

43.12 Conclusions and Recommendations

- Identify the amputee and amputation numbers and types.
- Define the needs: stump care, prosthetic types and amounts, special rehabilitation teams (doctors, nurses, prosthetic technicians, physiotherapists, occupational therapists, etc.), workshops, etc.
- Assess costs vs. needs.
- Import medical specialists who have experience with amputations and are able to establish and care for the amputees and their requirements.
- Attempt to secure financial backing to transfer the amputees to large experienced rehabilitation centers where the amputees will receive more professional care, thereby reducing costs.
- Start to provide prostheses as recommended.
- Improve the service by increasing the number of distribution centers including the periphery.
- Upgrade prosthetic type provision, taking into consideration the professional and economical limitations.

Acknowledgement Pictures were donate / given by Dr. Alexander Daich, Department of Orthopedic Rehabilitation, Sheba Medical Center, Tel Hashomer, Ramat Gan, Israel, Email: zivalex2@gmail.com.

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44 Education and Training in War Surgery and Disaster Management

Seema Biswas, Molly Sonenkler, Nathan Douthit, Sakal Kiv, and Nikolaj Wolfson

44.1 Introduction

War surgery has existed for perhaps as long as war itself. From the Greek myths in which the sons of Asclepius, the God of Medicine, tended the wounded in the battle for Troy [1] to the Romans who evacuated their fallen soldiers [2] and Shalya Tantra, war surgery in ancient India [3], caring for the injured and dying, has been as important on the battlefield as winning the battle; the responsibility for the care of the wounded has weighed heavily on military personnel.

As the centuries have passed, both conflict and medicine have gained in complexity. Training in both has become professionalized, and in this chapter, we describe how one trains to become a war surgeon and to be an expert in disaster management.

Education and training in war surgery and disaster medicine mirror the formative principles of modern-day surgery: the study of anatomy and basic science (especially physiology); techniques in hemostasis; the prevention and treatment of sepsis; wound care and debridement; and, of course, safe anesthesia with pain control. One might argue that although surgery has been practiced since ancient times, only in the last two centuries has surgery evolved into the professional clinical practice we recognize today. It is no irony that many of the advances in surgery have been as a result of advances in technologies used in war, or, indeed, as necessities to deal with the casualties of war, with injuries that are more penetrating, more destructive, and, now, sadly, widespread among noncombatants and civilians. It is here that modern military and civilian surgical practice have come to overlap. In this chapter, we shall discover how the same core surgical decision making and practical and management skills are equally applicable in the theater of war, post-conflict (especially in dealing with landmine injuries), in the aftermath of terrorist attacks, in response to disaster (natural or man-made), and in dealing with civilian injury and trauma (the principles of management of which, as we shall discuss later, have been hugely impacted by what we have learned in the arena of conflict).

Today, surgeons from both civilian and military backgrounds have come together to learn from past experience and devise, with their non-surgical colleagues, plans to manage mass casualties and triage, operate in the midst of fighting, and evacuate safely to distant centers for definitive treatment. Also thrown together, in the massive expansion of the humanitarian sector, are practitioners from the developed and developing

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_44

worlds; and, while much focus on this chapter is on how to train to then "go out and practice," in truth, we know that there is no surer way to train in surgery than by simply looking after patients and performing surgery. This is exactly what surgeons who find themselves precipitously in the midst of conflict have done, often without adequate resources, rest, or relief, whether in Bosnia or Angola in the 1990s or in Somalia today. Their contribution to what we know about operating in under-resourced environments, overwhelmed with work and facing the same threats as the injured around them, is immense, and we honor them in this chapter, knowing that much of the world's conflict and disaster is focused in the poorest areas and that, were the efforts in fueling and sustaining conflict to match the efforts in development, healthcare, and disaster preparedness, the focus of training and education for surgeons might be considerably altered.

44.2 The Evolution of War Surgery and Training

Figure 44.1 summarizes some of the developments in war surgery. A detailed discussion of the history of war surgery is beyond the scope of this chapter but what is clear is that, worldwide, priority for dealing with the slain and wounded shifted away from the soldiers themselves to the barber surgeons who performed amputations and then toward the development of an army corps dedicated to tending the wounded. Much of the evolution of care is because of the change in injury patterns: from penetrating trauma associated with swords and arrows to gunpowder and cannon blasts. Bullet wounds became cavitating injuries as weapons became automatic and energy transfer became lethal. Improvised explosive devices (IEDs) are the latest challenge, where limb loss secondary to explosives is compounded by fragment injuries from nails or stones. According to the Pentagon's Joint IED Defeat Organization, the proportion of US casualties from IEDs in Iraq and Afghanistan in 2011 was 63 % [4].

Other landmarks that have shaped war surgery are Baron Dominique-Jean Larrey's system of triage and evacuation during the Napoleonic wars [5], the understanding that immediate amputation, performed rapidly and with arterial ligation, was superior to delayed surgery with the expectation that soldiers would improve in the interval without intervention and that fractured limbs did not routinely require amputation, Nikolay Pirogov's refinement of plaster casts for the treatment of fractures [6], the commitment to the care of combatants by Henri Dunant and the development of the Red Cross [7], and revolutions in field hospital care led by Florence Nightingale [8] and Yelena Pavlovna [9]. With these landmarks has come progress in antisepsis, anesthesia and analgesia, ambulance transfer to field hospitals, and the development of forward surgical units closer still to fallen soldiers.

The expectations of a modern-day war surgeon and the training required are illustrated in the careers of two of the fathers of war surgery:

By the time of Dominique-Larrey (1766–1842), surgery had become an established discipline within the medical profession. Larrey, raised by his uncle, the chief surgeon in Toulouse, trained first in medicine and then in surgery. He then served a 6-year apprenticeship to the chief surgeon in Paris, Desault. He served in the French navy as chief surgeon on a frigate and in wars across Europe and the Mediterranean. His pioneering work was in taking medical care to the battlefield and evacuating the wounded using ambulances. Napoleon is said to have viewed Larrey's responsibility toward the lives of his men as greater than his generals; and he described him as the best man he had ever known. Some of the characteristics Napoleon so admired would seem ideal qualities in a war surgeon: "judicious but bold and rapid; calm and self-possessed in every emergency; but full of feeling and tenderness." [10]

At around the same time, Nikolay Pirogov (1810–1881) trained in Russia and then in Germany, under Langenbeck, as a surgeon. His study of anatomy and research on the ligation of the abdominal aorta was a firm foundation for his surgical career. He introduced ether anesthesia

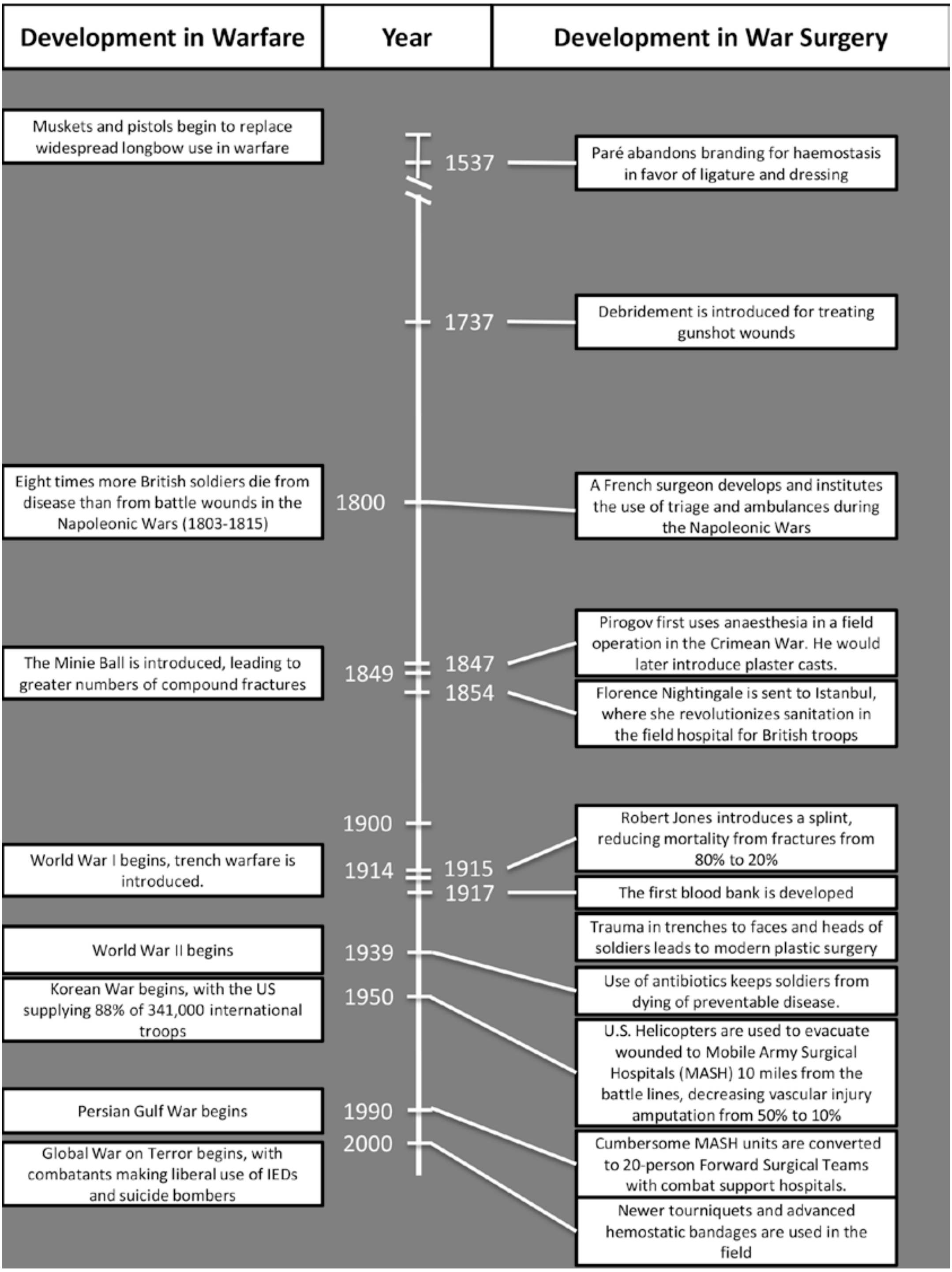

Fig. 44.1 A brief history of the developments in warfare and the corresponding development in surgery

for the wounded on the battlefield and worked with Yelena Pavlovna to improve battlefield medicine. Among his contributions to war surgery were the control of major hemorrhage and the development of forward medical units in the theater of conflict with early analgesia, anesthesia, wound care, and limb salvage. His legacy was to continue the training of surgeons. The parallels between systems for modern war surgery and the need for surgeons to train and research in both civilian and combat settings between Pirogov's and the modern era are clear [6].

Today, war surgery involves airway management, damage control resuscitation, mechanical and biochemical hemorrhage control, and damage control surgery in forward surgical units in the very heart of battle. Helicopter transfer with fully equipped critical care personnel to definitive care in designated military hospitals requires leadership, logistics, and the establishment of trauma systems that really work. Civilian training and preparedness alone is not enough for the pace, the volume, and the severity of military casualties with multiple penetrating trauma [11] and the added challenges of working under fire, providing staged care, and using limited resources to their greatest effect. Conversely, much in modern war surgery has informed civilian trauma care: damage control resuscitation (blood transfusion, platelet transfusion, and hemostasis), wound care, operational trauma systems, and, at the interface of civilian and military practice, the treatment of the injured after terrorist attacks [12–18].

The importance of learning from battles past and present is affirmed by Michael DeBakey [19] "As in civilian medical practice, only by recording and analyzing military medical experiences can we apply the lessons of the past to future medical practice and improve the care of medical personnel." He goes on to discuss what unites training in war surgery and surgery in disaster response, "Had certain problems in the First World War been recognized and addressed, their repetition in the Second World War could have been avoided. The end of hostilities brings such a sense of relief that we are inclined to want to put the experience behind us. But we must remain prepared for any natural emergency, and the one way to do this is to study the past and incorporate its lessons in future actions."

Sadly, we live in an era where there is no end to hostilities across the globe and we know that with climate change and worsening poverty, the incidence of disasters is increasing. What does this mean for surgical training, especially, in the era of specialization? It means that, as in the past, whether full time in the military or in civilian service, we must keep our basic science knowledge up-to-date, keep up with the literature coming out of conflict zones, and hone our operative skills in training and practice in busy civilian trauma units and also in conflict settings, not just to operate effectively on our patients but to operate within the most effective team we can be a part of in austere circumstances. What we gain from experience we augment with research, courses, and drills that keep us in a state of preparedness for war and disaster. Table 44.1 gives a list of courses and conferences used to prepare personnel for battlefield medicine.

Civilian trauma and war surgery are different, though. Civilian hospital staff on standby for mass casualty incidents almost always remain at their stations in hospital where they are most effective, rather than manning mobile forward surgical units in cities or suburbs. Rarely in civilian practice do we see white phosphorus burns. Handgun injuries seen in a trauma center cannot be compared to multiple high-energy penetrating trauma secondary to rocket-propelled grenades, tank fire, shells, mortars, and IEDs [11, 20–23]. Compared to 10 % penetrating trauma in civilians, almost 70 % combat injuries are secondary to multiple penetrating trauma [14]. Tables 44.2 and 44.3 describe what a war surgical unit might encounter and the skills required of a war surgical team. Clearly, a period of training in the theater of war is also necessary. The *Emergency War Surgery Handbook* [26] gives an excellent account of what to expect for any surgeon about to be deployed to a conventional war. It describes patterns of injuries, dispels myths, and is a practical guide covering all body systems.

Willy [22] and Willy [27] performed epidemiological analysis of injuries from 1949 up to the

Table 44.1 A selection of courses in various countries used to prepare healthcare personnel for the battlefield

War surgery and trauma courses for military sector		
Country (Military Branch)	Course	Affiliation
United States of America (All Branches)	Combat Casualty Care Course	San Antonio Military Medical Center
	Medical Management of Chemical and Biological Casualties	US Army Medical Research Institute of Infectious Disease
United States of America (Army)	Army Trauma Training Center	Ryder Trauma Center, University of Miami
	Extremity War Surgery Course	San Antonio Military Medical Center
	Joint Forces Combat Trauma Management Course	US Army Institute of Surgical Research, Brooke Army Medical Center
United States of America (Air Force)	Emergency War Surgery	San Antonio Military Medical Center
	Pre-Deployment Training at Centers for Sustainment of Trauma and Readiness Skills	University of Maryland, University of St. Louis, University of Cincinnati
	Trauma Outcomes Performance Improvement Course-Military, Critical Care Air Transport Team (CCATT) orientation, JTS orientation, Joint Theater Trauma Registry orientation, leadership training, and scenario-based training[a]	
United States of America (Navy)	Navy Trauma Training Center	Los Angeles County, University of Southern California Trauma Center
	Combat Casualty Care Course, Emergency War Surgery Course[b], Combat Extremity Surgery Course[c]	
Canada (Canadian Forces Health Services)	Emergency War Surgery	
United Kingdom (Army, Royal Navy, Royal Air Force)	Military Operational Surgical Training Course	Royal College of Surgeons of England
	2 predeployment hospital exercises, 5 days of lectures, a 48-hour "whole hospital" exercise	

[a]Only necessary for those who are being deployed as trauma chiefs at a role III facility (combat support hospital)
[b]Necessary for general surgeons or for those deployed to Afghanistan
[c]Necessary for orthopedic surgeons only

wars in Iraq and Afghanistan. Most injuries were secondary to explosives, rounds, and airplane crashes. Torso and brain injuries were most responsible for fatalities [22, 28] and vascular and thoracic surgical skills essential for war surgeons [21]. Although mortality in Iraq compared to Vietnam had halved, twice as many amputations were needed in Iraq as IEDs became a preferred weapon of attack. Almost 90 % of fatalities in Iraq occurred before the injured were transferred to a military treatment facility, a quarter of which might have been survivable. Almost all mortality was due to hemorrhage—mostly of the torso, then junctional, and then of the limbs. Analysis of military casualties has informed not simply the skills required of the medical teams but also the trauma systems needed to minimize mortality and indeed prevent injury. Improvements in body armor, Tactical Combat Casualty Care guidelines, forward surgical units, and preparedness of surgical teams all aim to mitigate the lethality of injuries. As a result, despite the enormous number of injuries, mortality due to the injuries has declined and more victims survive [29].

Table 44.2 A list of procedures done by UK military surgeons between 2006 and 2008. This table is a useful analysis for the types of skills needed by surgeons in modern war theaters [24]

Classification of procedures by surgical specialty [24]		
–	No. performed	%
Orthopedics	–	–
Debridement of limbs	607	27.4
Application of external fixator	63	2.9
Amputations	85	3.8
Insertion of skeletal traction pins	24	1.1
Fasciotomy	46	2.1
Split-thickness skin graft	46	2.1
Delayed primary closure	394	17.8
Hand surgery	142	6.4
Manipulation under anesthetic	56	2.5
General surgery	–	–
Debridement of torso	144	6.5
Laparotomy	106	4.8
Thoracotomy	31	1.4
Vascular	25	1.1
Minor surgery (non-battle)	75	3.4
Emergency surgery (non-battle)	84	3.8
Head and neck surgery	139	6.3
Neurosurgery	39	1.8
Burns	104	4.7
Total	2210	

The International Committee of the Red Cross, ICRC, has also had an important role in training war surgeons [30–32], especially in the developing world, in under-resourced settings, and in under-resourced healthcare systems in conflict zones. They have produced a war surgery manual and multiple publications on wound management and field hospitals that operate differently from traditional military facilities, offer more long-term care of patients, permitting definitive surgery and follow-up in the same unit and, crucially, the training of local medical personnel [33–36]. The annual War Surgery Seminar in Geneva includes a day of ballistics training. ICRC training seminars worldwide [33] are designed to improve outcomes in local hospitals coping often with an overwhelming burden of casualties of war or complex emergencies.

44.3 Training for Work in the Humanitarian Sector

For years, formal training in the humanitarian sector was not mandatory. Most organizations had in-house training programs that they developed through experience in the field and much was dependent on understanding the culture of operators in the humanitarian sector. Now, we have degree courses and tabletop exercises, even at the medical student level. The need for formal training grew out of an era of increasing professionalization of the humanitarian sector. This, in turn, evolved both from a change in working culture affecting every sector and, indeed, as we describe below, from painful lessons learned in the field.

44.4 Professionalization of the Humanitarian Sector

The practice of medicine has seen seismic changes over the last 30 years. Accountability to our patients and regulating bodies and the need to record and report our outcomes are now routine in our medical lives. The humanitarian sector has seen a similar transition as it has become incumbent on humanitarian agencies to be accountable to their beneficiaries and donors and to improve the effectiveness of the humanitarian response. Perhaps the stimulus for change came in the form of high-profile disasters such as the Ethiopian famine in 1984 which mobilized the public as never before and began a trend for increasing public engagement with the work of the humanitarian sector and donors. Further disaster and conflict resulted in humanitarian aid tripling during the 1990s [37]. Also crucial was the end of the Cold War, with the emergence of an epidemic of intrastate conflicts, complex emergencies, populations of internally displaced civilians trapped in poverty and political instability, and the growing acceptance of military humanitarian intervention, such as in the conflict in the Balkans. The role of humanitarian agencies, working deeper inside conflict zones, with uneasy relationships with local militia and politics, became

Table 44.3 A suggested set of skills for surgical teams used by Ramasamy [24] and Parker [25]

Suggested surgical team skill set [24, 25]			
Abdominal/vascular procedures	Thoracic procedures	Orthopedic procedures	Neurosurgical procedures
Aortic cross-clamping during resuscitative laparotomy (thoracic or abdominal)	Pulmonary tractotomy	Unstable pelvic ring fracture—pelvic binding or external fixation +/− pelvic packing	Intracranial bleeding emergent arrest and control
Simple ligation of any major vessel tear	Circum-hilar rotation for lung hemorrhage control	Junctional zone bleed control with urinary catheter tamponade	Adequate early exposure via a 4-into-1 burr hole technique
Liver laceration packing	En masse lobectomy	Articular fracture temporization with bridging external fixator	Intracranial hematoma evacuation/limitation of contamination
Small intestinal perforation stapling	Skin staple closure of cardiac wounds	Rapid amputation decision making and performance	CNS superficial bone/metal fragment removal
Colonic perforation control with terylene tape	En masse closure of chest wall muscles	Fracture reduction with approximate alignment	CNS infection control using early antibiotic therapy
Arterial injuries shunted/ligated + fasciotomy/cooling	Patch closure of thoracic wounds (using an IV fluid bag)	Soft tissue damage—rapid primary debridement with physiological control	CNS infection prevention with primary dural and scalp closure
Venous injury ligation or repair	Rapid emergency thoracotomy	Contamination minimized by high-volume fluid lavage	Postsurgical swelling control with decompressive craniectomy
Bladder ruptures catheterized and drained	Nonanatomically stapled lung resection	Musculoskeletal infection control using appropriate early antibiotics	–
Pancreatic bed leaks multiply drained	–	Compartment syndrome prevention—wide area fasciotomy of any compartment	–
Peritoneal soilage copiously irrigated and contained	–	Soft tissue coverage with temporary dressings	–
Abdomen temporarily and/or rapidly closed	–	Primary wound management with vacuum drainage packs	–
Visceral compartment syndrome treated with plastic sheet or IV fluid bag closure (Bogota bag)	–	Femoral fractural control with rapid unilateral frame external fixation or Thomas splint	–

more controversial and the subject of greater public and government scrutiny, needing clarification among the aid agencies themselves and their working partners and beneficiaries.

What crystallized the doubts and the worst fears of aid agencies becoming inadvertently complicit in conflict as they delivered aid was the crisis in 1994 in Rwanda. The epidemic proliferation of NGOs, lack of coordination of the relief effort, poor practice among staff and volunteers, lack of regulation or measurement of effectiveness, and, finally, the possible role of aid agencies in aiding combatants committing atrocities inside refugee camps all took place under the watchful gaze of the press, the public, and government donors who had contributed an unprecedented $1,418,000,000 in relief funds [38]. The findings of the Joint Evaluation of Emergency Assistance to Rwanda [39] and the urgent need to reform practice in the humanitarian sector set the precedence for standards and clear positions on working with nation states and non-state actors.

Table 44.4 Humanitarian and disaster relief courses

Country	Course(s)	Institution	Web address
United States of America	Missioncraft in Disaster Relief Operations	World Association for Disaster and Emergency Medicine	http://www.wadem.org
	International Preparedness and Response to Emergencies and Disasters	World Association for Disaster and Emergency Medicine	http://www.wadem.org
	Various online courses	Columbia University National Center for Disaster Preparedness Mailman School of Public Health	http://ncdp.crlctraining.org/catalog/?id=3
	Various online courses	Johns Hopkins Center for Public Health Preparedness	http://www.jhsph.edu/research/centers-and-institutes/johns-hopkins-center-for-public-health-preparedness/training/online/
	Humanitarian Academy at Harvard	Harvard University	http://www.humanitarianacademy.harvard.edu/
	Online courses in Emergency Preparedness	University of Pittsburgh Center for Public Health Practice	https://cme.hs.pitt.edu
	Online courses in Emergency Preparedness and Response	Pacific EMPRINTS, University of Hawaii	http://www.emprints.hawaii.edu/training/catalog.aspx?cid=1
	Online courses in Disaster Planning, Response, and Recovery	University of North Carolina Gillings School of Public Health	http://cphp.sph.unc.edu/training/training_list/?mode=view_cat_detail&cat_id=168
United Kingdom	Field Logistics in Emergencies, Needs Assessment in Emergencies, Essentials of Humanitarian Practice, Managing People and Projects in Emergencies, Certificate in Security Management	RedR UK in collaboration with Oxford Brookes University	http://www.redr.org.uk/en/Training/certified-courses.cfm
Sudan	Sudan Training Programme	RedR UK, RedR Sudan	http://www.redr.org.uk/en/where-we-work/sudan/index.cfm
Australia	International Humanitarian Action Program, International Humanitarian Protection Program	Australian Red Cross	http://www.redcross.org.au/training-courses.aspx

The Red Cross Code of Conduct ensued in 1994, followed by the People in Aid Code of Best Practice in 1997 and the launch of the Sphere project, with minimum standards for disaster response, in 2000 [40].

Though the larger humanitarian agencies had their own training systems for foreign aid and local workers, there was a call to professionalize the humanitarian sector and increase transparency of the philosophy and systems of working, accountability, and, finally, training. Universities and affiliated training organizations began to provide courses and develop degree programs, and now, there is a wide range of training courses available for medical and nonmedical personnel seeking careers in the humanitarian sector and disaster management. A selection of these courses is listed in Tables 44.4 and 44.5, but what is clear is that for anyone now seeking to work in disaster management and humanitarian

Table 44.5 Disaster medicine courses for medical professionals

Country	Course	Institution	Web address
United States of America	Disaster Medicine Elective within EM Residency	Brown University	http://www.brown.edu/cis/sta/dev/emergency_medicine/program_highlights.html
		Yale University	http://medicine.yale.edu/emergencymed/residency/electives.aspx
	National Disaster Life Support Programs Courses	National Disaster Life Support Foundation	http://www.ndlsf.org
	Disaster Medicine Track within EM Residency	St. Luke's Roosevelt Emergency Medicine Residency	http://www.slremresidency.org/tracks.php
	Disaster Medical Specialist	Disaster Medical Solutions	http://www.disastermedicalsolutions.com/item/253-advanced-course
	Wilderness Medicine Elective or Disaster Medicine Elective	University of South Alabama	http://www.longleafmedical.com/medical-electives.html
		University of New Mexico	http://hsc.unm.edu/emermed/UNMStudentWebsite/DisasterMedElective2009.shtml
Puerto Rico		Universidade Central de Caribe	http://www.uccaribe.edu/ertc/?page_id=1742
Israel	Emergency and Disaster Preparedness Course	Israel Ministry of Health, Medical Corps of Israel Defense Forces	http://apfmed.org/programs/emergency-disaster-course/
China	China Emergency Relief Training for Medical Professionals	China Emergency Relief Training	http://www.cert-centres.com/train/center/
United Kingdom	Disaster Response Course	Humanity First Medical	http://www.humanityfirstmedical.org/

relief or development, there is a need to know something of the full spectrum of all aspects of humanitarian work in order to provide quality and consistency in the humanitarian response (Figs. 44.2 and 44.3).

Above all, however, what humanitarian agencies value is experience; and, as in surgery, we see that civilian training and degree courses are only a small part of training for deployment in disaster and conflict zones, and the flexibility to work together toward a goal, be effective in austere and dangerous environments, and learn from our mistakes are what it really takes to work in this sector. For those of us already working as surgeons or training in surgery, seeking to work in disaster medicine, there are perhaps three things to learn: how to work quickly and effectively under pressure; how to ensure that our clinical and surgical decisions and skills are good enough to consistently get the best results for our patients; and, how to do all of these in conditions that may be far from ideal and with limited resources. The challenges in surgery are not so different from war surgery, but in disaster management, we may be called on to answer more pressing local needs such as providing emergency obstetric care, providing essential family medicine care, and replacing standard emergency room and general surgical services in local hospitals that are overwhelmed and poorly staffed or that have been destroyed by disaster. Accomplished general surgeons, able also to perform caesarian sections, treat fractures and deal with medical emergencies, therefore, gain their training in disaster management largely on mission. Rarely chosen for disaster missions are surgeons who do not have broad skill sets and who are unable to adapt to serve a need that may not have been planned for from the outset. Surgeons who have shown that they can manage are always in demand.

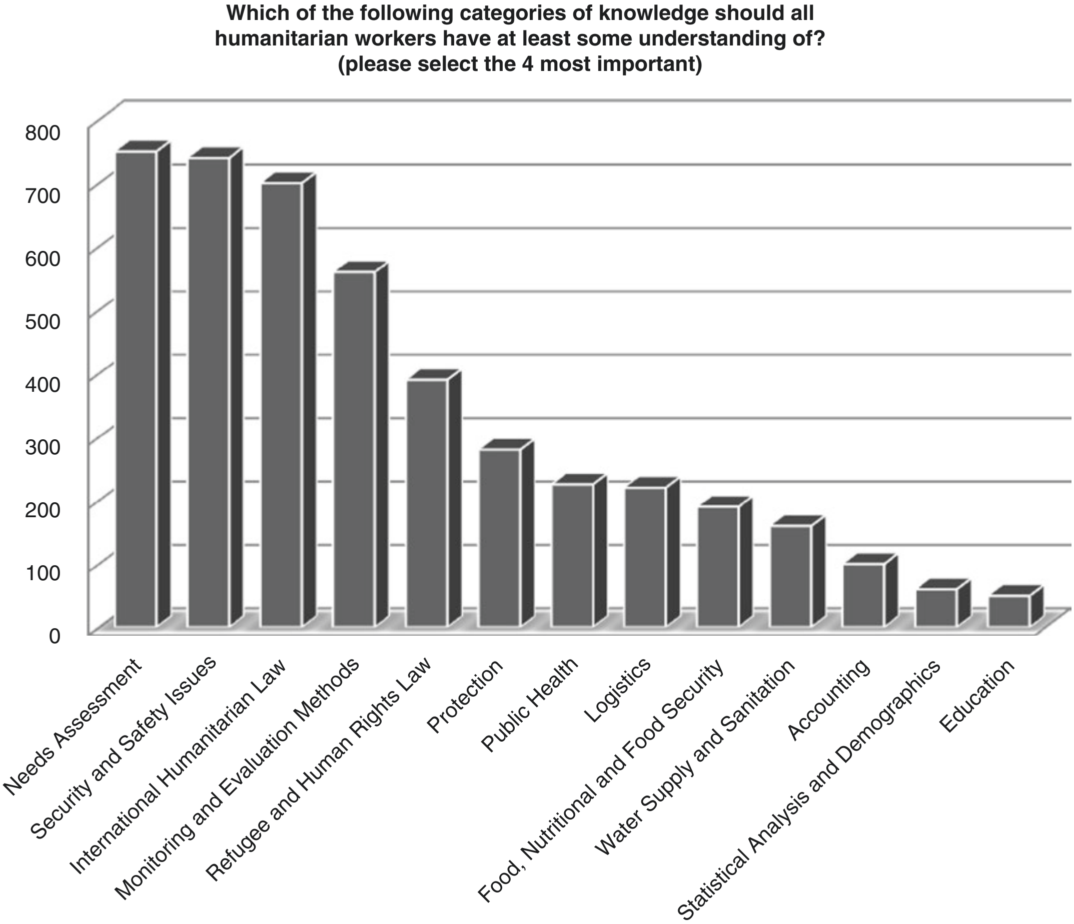

Fig. 44.2 A survey done by redR revealing the important and diverse knowledge needed by humanitarian workers (Reproduced with permission of redR)

44.5 Orthopedic Surgery Training in Disaster Preparedness and Management

The 2010 Haiti earthquake and experience from the field sparked huge interest in this evolving field of orthopedic trauma.

Major developments in educational programs have taken place in the USA.

Together with the Orthopaedic Trauma Association (OTA) and Society of Military Orthopedic Surgeons (SOMOS), the American Academy of Orthopaedic Surgeons (AAOS) developed a comprehensive disaster preparedness plan to enable an effective and efficient volunteer response. AAOS, in collaboration with OTA, SOMOS, and the Pediatric Orthopaedic Society of North America (POSNA) administers training courses specifically designed to help prepare orthopedic surgeons for the unique patient care requirements presented by the austere environments of disaster. A two-day course covers important topics for orthopedic surgeons operating in austere environments. Course graduates are licensed to be AAOS—registered disaster responders.

At the international level, major orthopedic organizations have developed hands-on training programs.

In 2011, the *Global Risk Forum* and *AO Foundation* launched the Disaster Surgery Workshop that is taking place in Davos, Switzerland.

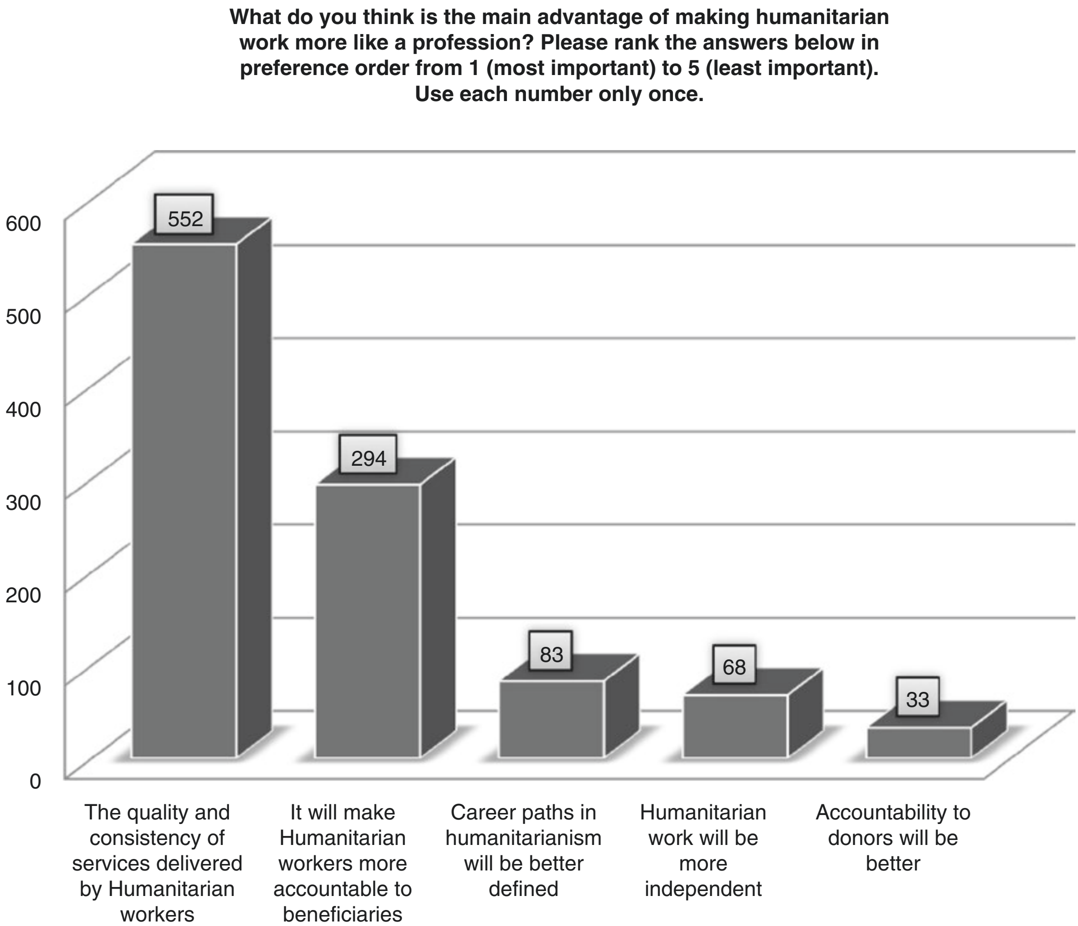

Fig. 44.3 A survey done by redR revealing the advantages of professionalizing the humanitarian sector (Reproduced with permission of redR)

SICOT, Société Internationale de Chirurgie Orthopédique et de Traumatologie, one of the oldest international nonprofit associations, with members from 110 nations, developed an educational program in the field of Orthopaedic Injuries in Natural Disasters and Mass Casualties in 2011.

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45 Terminology and Resources for Disaster Orthopedics

Nikolaj Wolfson and Guhanand Venkataraman

45.1 Introduction

This last chapter of this book serves to augment the available resources that have already been presented in previous chapters. These resources include a brief section describing the most common terminology in disaster medicine, a list of various types of institutions providing information and training in this area, research articles investigating disaster medicine, and a list of training programs for medical personnel and axillary staff.

45.2 Terminology: Mass Casualty Incident Hospital Planning

The following section of disaster and relief planning terminology is mainly adopted from the US Department of Health and Human Services, *Medical Surge Capacity and Capability: A Management System for Integrating Medical and Health Resources During Large-Scale Emergencies* (September 2007); *Medical Surge Capacity and Capability: The Healthcare Coalition in Emergency Response and Recovery* (May 2009); and *Mass Casualty and Mass Effect Incidents: Implications for Healthcare Organizations* (February 2012).

Community Healthcare System Partners Community healthcare system partners combine public and private community health and medical partners to include public health, hospitals and other healthcare providers, emergency medical service providers, long-term care providers, mental/behavioral health providers, private entities associated with healthcare (hospital associations, etc.), specialty service providers (dialysis, pediatrics, woman's health, stand-alone surgery, acute/urgent care, etc.), support service providers (laboratories, pharmacies, blood banks, poison control, etc.), primary care providers, community health centers, tribal healthcare, and federal entities (National Disaster Medical System (NDMS), Veterans Administration (VA) hospitals, Department of Defense (DoD) facilities, etc.).

Disaster ("Major") As defined in the Robert T. Stafford Act, a "major disaster" is any natural catastrophe (including any hurricane, tornado, storm, high water, wind-driven water, tidal wave, tsunami, earthquake, volcanic eruption, landslide, mudslide, snowstorm, or drought) or, regardless of cause, any fire, flood, or explosion, in any part

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_45

of the United States. "Major disaster," in the determination of the president, causes damage of sufficient severity and magnitude to warrant major disaster assistance under this act to supplement the efforts and available resources of states, local governments, and disaster relief organizations in alleviating the damage, loss, hardship, or suffering caused thereby.

Emergency (Federal) As defined in the Robert T. Stafford Act, emergency is any occasion or instance, for which, in the determination of the president, federal assistance is needed to supplement state and local efforts and capabilities to save lives and to protect property and public health and safety or to lessen or avert the threat of a catastrophe in any part of the United States.

Emergency Management Emergency management describes the science of managing complex systems and multidisciplinary personnel to address emergencies or disasters across all hazards and through the phases of mitigation, preparedness, response, and recovery.

Emergency Operations Center (EOC) EOC is the physical location from which the coordination of information and resources to support domestic incident management activities normally takes place. The use of EOCs is a standard practice in emergency management and is one type of Multiagency Coordination Center (MACC). The EOC is used in varying ways at all levels of government and within private industry to provide coordination, direction, control, or support during emergencies.

Emergency Operations Plan (EOP) EOP is the "response" plan that an entity (organization, jurisdiction, state, etc.) maintains for responding to any hazard event. It provides action guidance for management and emergency response personnel during the response phase of Comprehensive Emergency Management.

Emergency Support Function (ESF) As defined in the National Response Framework, an ESF refers to a group of capabilities of federal departments and agencies to provide the support, resources, program implementation, and services that are most likely to be needed to save lives, protect property, restore essential services and critical infrastructure, and help victims return to normal following a national incident. An ESF represents the primary operational level mechanism to orchestrate activities to provide assistance to state, tribal, or local governments or to federal departments or agencies conducting missions of primary federal responsibility.

First Responder First responder refers to individuals who at the early stages of an incident are responsible for the protection and preservation of life, property, evidence, and the environment, including emergency response providers, as defined in Section 2 of the Homeland Security Act of 2002 (6 U.S.C. 101). It includes emergency management, public health, clinical care, public works, and other skilled support personnel (equipment operators) that provide immediate support services during prevention, response, and recovery operations.

Hazard Hazard is a potential or actual force, physical condition, or agent with the ability to cause human injury, illness, and/or death; significant damage to property, the environment, critical infrastructure, agriculture, and business operations; and other types of harm or loss.

Hazard Vulnerability Analysis (HVA) HVA is a systematic approach to identifying all hazards that may affect an organization. It assesses the risk (probability of hazard occurrence and the consequence for the organization) associated with each hazard and analyzes findings to create a prioritized comparison of hazard vulnerabilities. The consequence, or vulnerability, is related to both the impact on organizational function and the likely service demands created by hazard impact.

Healthcare Coalition Healthcare Coalition is a group of individual healthcare organizations in a specified geographic area that agree to work together to enhance their response to emergencies or disasters. The Healthcare Coalition, being composed of relatively independent organizations that voluntarily coordinate their response, does not conduct command or control. Instead, the coalition operates consistent with multiagency coordination system (MAC system) principles to support and facilitate the response of its participating organizations.

Healthcare Coalition Notification Center (or Coalition Notification Center) Healthcare Coalition Notification Center (or Coalition Notification Center) is the entity that provides notification services for the coalition. Requirements include 24/7 staffing and appropriate technologies to support the notification activities. The Coalition Notification Center remains operational during incident operations and is folded under the Operations Section.

Homeland Security Presidential Directive-5 (HSPD-5) HSPD-5 is a presidential directive issued on February 28, 2003, and is intended to enhance the ability of the United States to manage domestic incidents by establishing a single, comprehensive National Incident Management System.

Incident Incident is an actual or impending hazard impact, caused either by human or by natural phenomena, that requires action by emergency personnel to prevent or minimize loss of life or damage to property and/or natural resources.

Incident Action Plan (IAP) IAP is the document in ICS that guides the response for that operational period. It contains the overall incident objectives and strategy, general tactical actions, and supporting information to enable successful completion of objectives. The IAP may be oral or written. When written, the IAP may have a number of supportive plans and information as attachments (traffic plan, safety plan, communications plan, and maps). There is only one IAP at an incident. All other "action plans" are subsets of the IAP and their titles should be qualified accordingly. For example, the jurisdiction primarily impacted usually develops the IAP. Action plans developed below the level of the jurisdiction could be referred to as "Operations Plans" (Summary Hospital Operations Plans or Individual Hospital Operations Plans).

Incident Command System (ICS) ICS is the combination of facilities, equipment, personnel, procedures, and communications operating within a common organizational structure, designed to aid in the management of resources for emergency incidents. It may be used for all emergencies and has been successfully employed by multiple response disciplines. ICS is used at all levels of government (local, state, tribal, and federal) to organize field-level operations (adapted from NIMS).

Joint Information Center (JIC) JIC is a center established to coordinate the public information activities for a large incident. It is the central point of contact for all news media at the scene of the incident. Public information officials from all participating federal agencies collaborate at the JIC, as well as public information officials from participating state and local agencies (adapted from NIMS).

Mass Casualty Incident Mass casualty incident is an incident that generates a sufficiently large number of casualties whereby the available healthcare resources, or their management systems, are severely challenged or unable to meet the healthcare needs of the affected population.

Mass Effect Incident Mass effect incident is an incident that primarily affects the ability of an organization to continue its normal operations. For healthcare organizations, this can disrupt the delivery of routine healthcare services and hinder their ability to provide needed surge capacity. For example, a hospital's ability to provide medical care to the victims of an earthquake is compromised if it must focus on relocating current patients because a section of the facility was destroyed.

Memorandum of Agreement (MOA) A Memorandum of Agreement (MOA) defines the general area of conditional agreement between two or more parties, but one party's action depends on the other party's action. The MOA can be complemented with support agreements that detail reimbursement schedules and specific terms and conditions (adapted from FEMA's National Preparedness Directorate, Memorandum of Agreement/Memorandum of Understanding Template and Guidance; March 2009).

Memorandum of Understanding (MOU) MOU is a formal document embodying the firm commitment of two or more parties to an undertaking, and setting out its general principles, but falling short of constituting a detailed contract or agreement (Oxford Dictionary of Law, 2006).

Mitigation Mitigations are activities designed to reduce or eliminate risks to persons or property or to lessen the actual or potential effects or consequences of a hazard. Mitigation involves ongoing actions to reduce exposure to, probability of, or potential loss from hazards. Examples include zoning and building codes, floodplain buyouts, and analysis of hazard-related data to determine where it is safe to build or locate temporary facilities. Mitigation can include efforts to educate governments, businesses, and the public on measures they can take to reduce loss and injury (adapted from NIMS).

Multijurisdictional Incident Multijurisdictional incident is an incident that extends across political boundaries and/or response disciplines, requiring action from multiple governments and agencies to manage certain aspects of an incident. These incidents may best be managed under unified command (adapted from NIMS).

Mutual Aid Agreement Mutual Aid Agreement is a written instrument between agencies and/or jurisdictions in which they agree to assist one another upon request, by furnishing personnel, equipment, supplies, and/or expertise in a specified manner. An "agreement" is generally more legally binding than an "understanding."

National Incident Management System (NIMS) NIMS is a system mandated by HSPD-5 that provides a consistent nationwide approach for federal, state, tribal, and local governments, the private sector, and nongovernmental organizations to work effectively and efficiently together to prepare for, respond to, and recover from domestic incidents, regardless of cause, size, or complexity. To provide for interoperability and compatibility among federal, state, and local capabilities, NIMS includes a core set of concepts, principles, and terminology. HSPD-5 identifies these as the Incident Command System, multiagency coordination systems, unified command, training, identification and management of resources (including systems for classifying types of resources), qualifications and certifications, and the collection, tracking, and reporting of incident information and incident resources (adapted from NIMS).

National Response Framework (NRF) NRF is a guide to how the nation conducts all-hazard response—from the smallest incident to the largest catastrophe. This key document establishes a comprehensive, national, all-hazard approach to domestic incident response. The *framework* identifies the key response principles, roles, and structures that organize national response. It describes how communities, states, the Federal Government, and private sector and nongovernmental partners apply these principles for a coordinated, effective national response. And it also describes special circumstances where the Federal Government exercises a larger role, including incidents where federal interests are involved, and catastrophic incidents where a State would require significant support. It allows first responders, decision-makers, and supporting entities to provide a unified national response.

Nongovernmental Organization (NGO) NGO is an organization that is neither a part of a government nor a conventional for-profit business.

Usually set up by ordinary citizens, NGOs may be funded by governments, foundations, businesses, or private persons. Some NGOs avoid formal funding and are run primarily by volunteers. NGOs are highly diverse groups of organizations engaged in a wide range of activities and take different forms in different parts of the world. Some may have charitable status while others may be registered for tax exemption based on recognition of social purposes. Others may be fronts for political, religious, or other interest.

Planning (Incident Response) Planning (incident response) is an activity that supports the incident management process, including completing the incident action plan and support plans and accomplishing incident information processing. This is in contrast to preparedness planning, which is designed to ready a system for response.

Preparedness Preparedness is the range of deliberate, critical tasks and activities necessary to build, sustain, and improve the capability to protect against, respond to, and recover from hazard impacts. Preparedness is a continuous process. Within NIMS, preparedness involves efforts at all levels of government and the private sector to identify threats, to determine vulnerabilities, and to identify required response plans and resources. NIMS preparedness focuses on establishing guidelines, protocols, and standards for planning, training and exercise, personnel qualifications and certification, equipment certification, and publication management (adapted from NIMS).

Preparedness Organization Preparedness organization is an organization that provides coordination for emergency management and incident response activities before a potential incident. These organizations range from groups of individuals to small committees to large-standing organizations that represent a wide variety of committees, planning groups, and other organizations (Citizen Corps, Local Emergency Planning Committees, and Critical Infrastructure Sector Coordinating Councils) (NIMS).

Prevention Prevention is an action to avoid a hazard occurrence or to avoid or minimize the hazard impact (consequences) if it does occur. Prevention involves actions to protect lives and property. Under HSPD-5, it involves applying intelligence and other information to a range of activities that may include such countermeasures as deterrence operations; heightened inspections; improved surveillance and security operations; investigations to determine the full nature and source of the threat; public health and agricultural surveillance and testing processes; immunizations, isolation, or quarantine; and as appropriate specific law enforcement operations aimed at deterring, preempting, interdicting, or disrupting illegal activity and apprehending potential perpetrators and bringing them to justice (adapted from NIMS).

Public Health Emergency Public health emergency is defined by the Model State Emergency Health Powers Act (MSEHPA) as "An occurrence or imminent threat of an illness or health condition that is believed to be caused by: (1) bioterrorism, (2) the appearance of a novel or previously controlled or eradicated infectious agent or biological toxin, (3) a natural disaster, (4) a chemical attack or accidental release, or (5) a nuclear attack or accident. It must pose a high probability of a large number of deaths or serious long-term disabilities in the affected population, or widespread exposure to an infectious or toxic agent that poses a significant risk of substantial future harm to a large number of people in the affected population". (the Center for Law and the Public's Health at Georgetown and Johns Hopkins Universities).

Public Information Officer Public information officer is an official at headquarters or in the field responsible for preparing and coordinating the dissemination of public information in cooperation with other responding federal, state, tribal, and local agencies. In ICS, the term refers to a member of the Command Staff responsible for interfacing with the public and media and the Joint Information Center.

Recovery Recovery is the phase of Comprehensive Emergency Management that encompasses activities and programs implemented during and after response that are designed to return the entity to its usual state or to a "new normal." For response organizations, this includes return-to-readiness activities.

Resiliency Resiliency is the ability of an individual or organization to quickly recover from change or misfortune.

Resources Resources are all personnel and major items of equipment, supplies, and facilities available, or potentially available, for assignment to incident or event tasks on which status is maintained.

Response Response is an activity that addresses the direct effects of an incident. Response includes immediate actions to save lives, protect property, and meet basic human needs. Response also includes the execution of emergency operations plans as well as activities designed to limit the loss of life, personal injury, property damage, and other unfavorable outcomes. As indicated by the situation, response activities may include applying intelligence and other information to lessen the effects or consequences of an incident; increased security operations; continuing investigations into nature and source of the threat; ongoing public health and agricultural surveillance and testing processes; immunizations, isolation, or quarantine; and specific law enforcement operations aimed at preempting, interdicting, or disrupting illegal activity and apprehending actual perpetrators and bringing them to justice (adapted from NIMS).

Response Organization A response organization provides a structure and functions to manage emergency decision-making, decision implementation, and overarching coordination of resources and actions in the emergency context. Response organizations can include entities that conduct response management for a larger organization (private and for-profit or not-for-profit), an agency or department, a government jurisdiction, or a collection of like organizations such as a Healthcare Coalition or a regional response center. Most response organizations are organized under NIMS as an Incident Management Team or as a multiagency coordination system (ICDRM/GWU Emergency Management Glossary of Terms).

45.3 International Orthopedic Organizations and Resources

45.3.1 International Society of Orthopaedic Surgery and Traumatology (SICOT)

SICOT is dedicated to the improvement of orthopedic surgery throughout the world. SICOT offers the Educational Objectives as a guide to basic orthopedic training and education, with the hope that these Educational Objectives will form a part of the training in most SICOT member countries and help to provide a common link between universities or teaching hospitals in all our nations. They set a standard for trainees to achieve and assure of an acceptable level of knowledge and can inform examiners of what a candidate should know at the end of training. Regional and local knowledge requirements can be added to reflect the incidence of endemic disease (http://www.sicot.org).

45.3.2 AO Foundation

The AO Foundation is a nonprofit organization led by an international group of surgeons specialized in the treatment of trauma and disorders of the musculoskeletal system. Founded in 1958 by 13 visionary surgeons, AO today fosters one of the most extensive networks of more than 12,000 surgeons, operating room personnel, and scientists in over 100 countries.

AO mission is to foster and expand its network of healthcare professionals in education, research, development, and clinical investigation to achieve more effective patient care worldwide.

In 2011, AO Foundation and Global Risk Forum launched Disaster Surgery Workshop that is taking place in Davos, Switzerland.

45.3.3 Canadian Orthopaedic Trauma Society

This is a group of Canadian Orthopaedic Association members who have banded together to perform randomized prospective multicenter trauma research studies. There are currently more than ten ongoing studies, supported by industry grants and peer-reviewed grants from numerous organizations. COTS research has received some of the highest praise and presentation acceptance associated with orthopedic outcome research. For more information about the Canadian Orthopaedic Trauma Society (COTS), visit their web site http://cots.medicine.dal.ca.

45.3.4 International Conference on Preparedness and Response to Emergencies and Disasters (IPRED)

This is one of the largest international conferences on the subject of Preparedness and Response of Healthcare Systems to Emergencies and Disasters that takes place in Israel.

45.3.5 Italian Society of Orthopaedics and Traumatology (SIOT)

The Italian Society of Orthopaedics and Traumatology was founded in Rome in 1892. Currently, there are 4,700 members and the society's mission is to promote the continuous education of its members through the sponsorship of the more relevant congresses and the organization of masters and seminars. A number of affiliated specialty associations have been founded and then have been developed within SIOT over the last 15 years (http://www.siot.it/pagine/index.html).

45.3.6 World Orthopaedic Concern (WOC)

World Orthopaedic Concern is an international society for orthopedic education and care in developing countries.

World Orthopaedic Concern (WOC) is dedicated to improving the standard of orthopedic and reconstructive surgery in all developing countries—in the tropics, subtropics, and anywhere where there is a need.

WOC membership records are maintained in Singapore.

There is also World Orthopaedic Concern of UK.

WOC publishes a newsletter that is electronically distributed to its subscribers and members:

www.worldortho.com & www.wocuk.org.

45.3.7 Johanniter International (JOIN)

Johanniter International is a partnership of 16 national charity organizations in Europe and the Middle East dedicated to excellence in the field of emergency assistance and prevention, first aid training, as well as implementation and support of health and orthopedic projects worldwide. Member organizations provide national and international activities such as emergency medical services, first aid, social care, youth work, and international assistance, in addition to services for old, poor, and disabled people in need. Organizations that are part of JOIN and the Order of St John currently operate in more than 50 countries around the world (www.johanniter.org).

For projects with an orthopedic focus, to be implemented in developing countries, Johanniter collaborates with Otto Bock Healthcare GmbH, a MedTech company located in Duderstadt, which offers an array of orthopedic services, including equipment, prosthetics, and consumables (www.ottobock.de).

45.3.8 Extended Listing of Orthopedic-Related Organizations

International Organizations

Institution of Mechanical Engineers (IMechE)
International Sports Medicine Science and Performance (ISMSP)
International Collaboration of Orthopaedic Nursing (ICON)

International Osteoporosis Foundation–World Congress on Osteoporosis (IOFWCO)
International congress on Biotechnologies for Spinal Surgery (Biospine)
Combined meeting of Orthopaedic Research Societies (COMORS)
Contemporary Issues in Partial Knee Arthoplasty (CIPKA)
World Orthopaedic Concern (WOC)
International Sports Science and Sports Medicine Conference (ISSSMC)
International Society for Clinical Densitometry (ISCD)
Physical and Rehabilitation Medicine Congress (PMRC)
Combined Meeting of Orthopaedic Research Societies (ORS-Combined)
Bone and Joint Decade World Congress (BJDWC)
International Congress for Joint Reconstruction (ICJR)
ICJR–Sports Medicine and Total Hip and Knee meeting (ICJR–SM/TJR)
International Federation of Paediatric Orthopaedic Societies (IFPOS)
International Society for Technology in Arthroplasty (ISTA)
International Society of Arthroscopy, Knee Surgery, and Orthopaedic Sports Medicine (ISAKOS)
Asia Pacific Arthroplasty Association (APAS)
Association for Study and Application of Methods of Ilizarov (ASAMI)
International Musculoskeletal Regeneration and Research Society (IMRRS)
International Society for Hip Arthroscopy (ISHA)
International Cartilage Repair Society, Instructional Course (ICRS)
International Federation of Foot and Ankle Surgeons (IFFAS)
International Society for Fracture Repair (ISFR)
Spine Arthroplasty Society (SAS)
International Meeting on Advanced Spine Techniques (IMAST)
International Research Society of Spinal Deformities (IRSSD)
Computer Assisted Radiology and Surgery (CARS)
Asia Pacific Orthopaedic Association (APOA)
International Congress of Shoulder and Elbow Surgery (ICSES)
Asia Pacific Spine Arthroplasty Society (APSAS)
International Federation of Sports Medicine (FIMS)
International Society for Prosthetics and Orthotics (ISPO)
International Society for Computer Aided Surgery (ISCAS)
Combined Orthopaedic Associations (COMOC)
World Sports Trauma Conference (WSTA)
International Society of Physical and Rehabilitation Medicine (ISPRM)

European Organizations

Scoliosis Research Society (SRS)
European Federation of National Associations of Orthopaedics and Traumatology (EFORT)
European Orthopaedic Research Society (EORS)
European Foot and Ankle Society (EFAS)
European Paediatric Orthopaedic Society (EPOS)
International Society of Orthopaedic Surgery and Traumatology (Belgian) (SICOT)
European Society of Sports traumatology Knee surgery and Arthroscopy (ESSKA)
Federation of the European Societies for the Surgery of the Hand (FESSH)
European Society for Surgery of Shoulder and Elbow (ESSSE)
European Federation of National Associations of Orthopaedic Sports Traumatology (EFOST)
European Society of Trauma and Emergency Surgery (ESTES)
Groupe D'Etudes pour La Chirurgie Osseuse (French) (GECO)
Societa Italiana di Chrurgia del Ginocchio, Artroscopia, Sport, Cartilagine e Tecnologie Ortopediche (SIGASOFT)
International Osteoporosis Federation–European Congress on Clinical and Economic Aspects of Osteoporosis and Osteoarthritis (IOF–ECCEO)
European League Against Rheumatism (EULAR)
European Trauma Society (ETS)
European Association of Tissue Banks (EATB)

Asian Organizations

Asia Pacific Orthopaedic Association (APOA)
Asia Pacific Arthroplasty Association (APA)

Asia Pacific Association of Surgical Tissue Banking (APASTB)
International Osteoporosis Foundation–Asia Pacific Osteoporosis Meeting (IOF–APOM)

American Organizations
Limb Lengthening and Reconstruction Society (LLRS)
Eastern Orthopaedic Association (EOA)
North American Spine Society (NASS)
American College of Surgeons (ACS)
American Association of Neurological Surgeons (AANS)
American Society of Bone and Mineral Research (ASBMR)
American Association of Tissue Banks (AATB)
Association of Children's Prosthetics-Orthotic Clinics (ACPOC)
Western Orthopaedic Association (WestOA)
Mid-America Orthopaedic Association (MidAmOA)
Hawaii Orthopaedic Association (HaOA)
American Orthopaedic Foot and Ankle Society (AOFAS)
American College of Sports Medicine (ACSM)
Southern Orthopaedic Association (SouthOA)
Arthroscopy Association of North America (AANA)
American Association of Orthopaedic Surgeons (AAOS)
Orthopaedic Trauma Association (OTA)
Orthopaedic Research Society (ORS)
American Orthopaedic Association (AOA)
American Orthopaedic Society for Sports Medicine (AOSSM)
American Shoulder and Elbow Surgeons (ASES)
The Knee Society (AKS)
Pediatric Orthopaedic Society of North America (POSNA)
American Association of Hip and Knee Surgeons (AAHKS)
Musculoskeletal Tumor Society (MSTS)
American Spinal Injury Association (ASIA)
American Society for Surgery of the Hand (ASSH)

British Organizations
British Elbow and Shoulder Society (BESS)
British Orthopaedic Association (BOA)
British Association for Surgery of the Knee (BASK)
British Hip Society (BHS)
British Orthopaedic Foot and Ankle Society (BOFAS)
British Society for Surgery of the Hand (BSSH)
British Trauma Society (BTS)
British Association of Sports and Exercise Medicine (BASEM)
London Hip Meeting (LHM)
British Society for Children's Orthopaedic Surgery (BSCOS)
British Society for Rheumatology (BSR)
British Association of Day Surgery (BADS)
London Knee Meeting (LKM)
Sports and Exercise Medicine UK (UKSEM)
Indian Orthopaedic Society UK (IOS UK)
International Society of Prosthetics and Orthotics (ISPO UK)
British Cervical Spine Society (BCSS)
British Society of Computer Aided Orthopaedic Surgery (CAOSUK)
British Association of Tissue Banks (BATB)
British Limb Reconstruction Society (BLRS)
British Orthopaedic Oncology Society (BOOS)
British Orthopaedic Research Society (BORS)
British Scoliosis Society (BSS)
Society for Back Pain Research (SBPR)
British Association of Spine Surgeons (BASS)
British Orthopaedic Specialists Society (BOSA)
British Orthopaedic Sports Trauma Association (BOSTA)

45.4 Resources for Disaster Preparedness

45.4.1 National Disaster Medical System

The National Disaster Medical System (NDMS) is a federally coordinated system that augments the nation's medical response capability. The overall purpose of the NDMS is to supplement an integrated national medical response capability for assisting state and local authorities in dealing with the medical impacts of major peacetime disasters and to provide support to the military and the Department of Veterans Affairs medical systems in caring for casualties evacuated back to the

United States from overseas armed conventional conflicts. The National Response Framework utilizes the National Disaster Medical System (NDMS), as part of the Department of Health and Human Services, Office of Preparedness and Response, under Emergency Support Function #8 (ESF #8), Health and Medical Services, to support federal agencies in the management and coordination of the federal medical response to major emergencies and federally declared disasters including natural disasters, major transportation accidents, technological disasters, and acts of terrorism including weapons of mass destruction events (http://www.phe.gov/ndms).

The NDMS comprises of several response teams, including the Disaster Medical Assistance Team (DMAT), Disaster Mortuary Operational Response Team (DMORT), International Medical Surgical Response Team (IMSURT), and National Veterinary Response Team (NVRT).

45.4.1.1 Disaster Medical Assistance Team (DMAT)

A DMAT is a group of professional and paraprofessional medical personnel (supported by a cadre of logistical and administrative staff) designed to provide medical care during a disaster or other event. NDMS recruits personnel for specific vacancies, plans for training opportunities, and coordinates the deployment of the teams.

DMATs are designed to be a rapid response element to supplement local medical care until other federal or contract resources can be mobilized, or the situation is resolved. DMATs deploy to disaster sites with sufficient supplies and equipment to sustain themselves for a period of 72 h while providing medical care at a fixed or temporary medical care site. The personnel are activated for a period of 2 weeks.

In mass casualty incidents, their responsibilities may include triaging patients, providing high-quality medical care despite the adverse and austere environment often found at a disaster site, patient reception at staging facilities, and preparing patients for evacuation.

Under the rare circumstance that disaster victims are evacuated to a different locale to receive definitive medical care, DMATs may be activated to support patient reception and disposition of patients to hospitals. DMATs are principally a community resource available to support local, regional, and state requirements. However, as a national resource, they can be federalized.

NDMS/DMAT personnel are required to maintain appropriate certifications and licensure within their discipline. When personnel are activated as federal employees, licensure and certification are recognized by all states. Additionally, DMAT personnel are paid while serving as intermittent federal employees and have the protection of the Federal Tort Claims Act in which the Federal Government becomes the defendant in the event of a malpractice claim.

45.4.1.2 International Medical Surgical Response Team (IMSURT)

The International Medical Surgical Response Team (IMSURT) is a National Disaster Medical System (NDMS) team of medical specialists who provide surgical and critical care during a disaster or public health emergency. Originally conceived to address the needs of US citizens injured overseas, the IMSURT role has expanded over the years to include both domestic deployments, including the World Trade Center Bombings and Hurricane Katrina, and international deployments, including the earthquakes in Bam, Iran, and Port au Prince, Haiti.

IMSURT personnel are federal employees used on an intermittent basis to deploy to the site of a disaster or public health emergency and provide high-quality, lifesaving surgical and critical care. As federal employees, IMSURT personnel are protected by the Uniformed Services Employment and Reemployment Rights Act (USERRA), Federal Tort Claims Act, and Worker's compensation. Additionally, IMSURT employees' personal state licenses and certifications are recognized both nationally and internationally when deployed as federal employees.

IMSURT deployments often occur in austere environments where many of the conveniences of modern life are limited or unavailable. Personnel are deployed normally in 14 day periods or longer until local medical resources are sufficiently recovered or have been supplemented by other organizations.

Between deployments, the IMSURT works closely with other NDMS teams to recruit, train, and prepare experienced medical providers for deployment.

45.4.2 Emergency System for Advance Registration of Volunteer Health Professionals (ESAR-VHP)

The Emergency System for Advance Registration of Volunteer Health Professionals (ESAR-VHP) is a federal program created to support states and territories in establishing standardized volunteer registration programs for disasters and public health emergencies. The program, administered on the state level, verifies health professionals' identification and credentials so that they can respond more quickly when disaster strikes. By registering through ESAR-VHP, volunteers' identities, licenses, credentials, accreditations, and hospital privileges are all verified in advance, saving valuable time in emergency situations (http://www.phe.gov/esarvhp).

45.4.3 Medical Reserve Corps (MRC)

The mission of the Medical Reserve Corps (MRC) is to improve the health and safety of communities across the country by organizing and utilizing public health, medical, and other volunteers. MRC units are community based and function as a way to locally organize and utilize volunteers who want to donate their time and expertise to prepare for and respond to emergencies and promote healthy living throughout the year. MRC volunteers supplement existing emergency and public health resources (https://www.medicalreservecorps.gov).

45.4.4 US Public Health Service Commissioned Corps

The US Public Health Service Commissioned Corps is an elite team of more than 6,500 full-time, well-trained, highly qualified public health professionals dedicated to delivering the nation's public health promotion and disease prevention programs and advancing public health science. Driven by a passion for public service, these men and women serve on the frontlines in the nation's fight against disease and poor health conditions (http://www.usphs.gov/).

45.4.5 American Nurses Association (ANA)

ANA considers disaster preparedness and response a part of nursing practice. For nurses, it has become part of the curriculum at many institutions of nursing education, better enabling future nurses with the skills to prepare for and respond to emergencies. In addition, nurses can find continuing education and competency development offered by several nursing and non-nursing organizations, drawing from textbooks and articles written by nurses. ANA strongly recommends that RNs take a formal class or certification course, enabling them to keep up with the latest skill development and education by reviewing nursing journals and other nursing literature or just keeping up with disaster preparedness and response organizations' web sites. (http://www.nursingworld.org/MainMenuCategories/WorkplaceSafety/Healthy-Work-Environment/DPR/Education).

45.4.6 Orthopaedic Trauma Association (OTA)

The Orthopaedic Trauma Association provides an online syllabus of lectures, written and edited by the membership, to support comprehensive orthopedic trauma resident education. These presentations were created for use by educators and are supplied in a fashion that specifically allows for modification. The OTA respectfully requests that proper credit be given to the original author as well as the OTA when the talks are presented, even in modified form. These talks represent a combination of the literature, as cited, and current practices, as reported by member-authors. Version III is updated as of November 2011 (http://ota.org/education/resident-resources/core-curriculum/).

45.4.7 American Association of Orthopedic Surgeons (AAOS)

In response to the bombing attempts in the United Kingdom and warnings about the possibility of terrorist attacks against the United States, the Journal of the AAOS (JAAOS), in order to help educate orthopedic surgeons about responding to disasters and mass casualties, published a two-part article: *Disasters and Mass Casualties: I. General Principles of Response and Management* (July 2007) and *Disasters and Mass Casualties: II. Explosive, Biologic, Chemical, and Nuclear Agents* (August 2007). Parts I and II of the article explore key concepts involved in managing disasters and treating the injuries resulting from natural disasters and terrorist attacks.

In addition, AAOS offers several training modules (required and supplemental) for AAOS-Registered Disaster Responders.

Disaster Response Course
Developed by SOMOS, Co-sponsored by AAOS, OTA, and POSNA
(**15 AMA PRA Category 1 Credits**™)

This training course is designed specifically to help prepare orthopedic surgeons for the unique patient care requirements and personal challenges presented by the austere environments of disaster. Orthopedic care techniques critical to disaster-inflicted injuries and treating the wounded in austere environments are taught in a full day of lectures and a half day in a cadaveric skills lab. Topics addressed include Clinical skills orthopaedic surgeons need in austere environments, Personal and team preparation, Cultural sensitivity, Ethics in medicine, Overview of disaster response structures (US Federal Government and NGOs), and Lessons learned in previous disasters.

Following are supplemental courses that are offered several times a year.

Disaster Management and Emergency Preparedness (DMEP)
American College of Surgeons
(**8.25 AMA PRA Category 1 Credits**™)

This course targets acute care providers and addresses disaster planning and triage, injury patterns, and considerations for special populations (https://www.facs.org/quality-programs/trauma/education/dmep).

Core Disaster Life Support ® version 3.0 (CDLS)
American Medical Association/National Disaster Life Support Foundation
(**3.5 AMA PRA Category 1 Credits**™)

The overarching aim of the CDLS Course is to provide participants from diverse professions, disciplines, and backgrounds with a common lexicon, vocabulary, and knowledge in disaster-related medicine and public health that can be reinforced and expanded in the Basic Disaster Life Support™ (BDLS®) and Advanced Disaster Life Support™ (ADLS®) courses (http://register.ndlsf.org/?PN=/CDLS).

Basic Disaster Life Support ® (BDLS)
American Medical Association/National Disaster Life Support Foundation
(**3.5 AMA PRA Category 1 Credits**™)

BDLS ® targets multiple disciplines and is a review of the all-hazard topics including natural and accidental man-made events, traumatic and explosive events, nuclear and radiological events, biological events, and chemical events. Also included is information on the healthcare professional's role in the public health and incident management systems, community mental health, and special needs of underserved and vulnerable populations (http://register.ndlsf.org/?PN=/CDLS)-po.

45.4.8 Federal Emergency Management Agency (FEMA) Disaster Training Modules

Department of Health and Human Services (HHS) and/or the Federal Emergency Management Agency (FEMA) Disaster Training Modules are required for members of National Disaster Medical System (NDMS) teams.

FEMA Emergency Management Institute Independent Study Program Courses (http://training.fema.gov/IS/crslist.aspx)

FEMA Emergency Management Institute National Incident Management System (NIMS) Courses (http://training.fema.gov/IS/NIMS.aspx)

45.4.9 Association of American Medical Colleges (AAMC)

Medical schools in many parts of the world have begun to incorporate disaster-related topics into their curricula. In 2003, the Association of American Medical Colleges (AAMC) in the United States recommended that bioterrorism education be included in all medical school programs (Association of American Medical Colleges (2003) Training future physicians about weapons of mass destruction: Report of the expert panel on bioterrorism education for medical students. Washington DC, AAMC. Available via. http://www.aamc.org/newsroom/bioterrorismrec.pdf. Accessed 28 June 2009). In response to this directive, Pfinninger et al. developed a comprehensive curriculum for incorporating disaster medicine as part of regular medical school education (Ernst G. Pfenninger EG, Domres BD, Stahl W, Bauer, Houser CM, Himmelseher S. Medical student disaster medicine education: the development of an educational resource. Int J Emerg Med 2010, 3:9–20)

45.5 Other Resources

Following are the lists of various resources for specific topics and aspects of disaster response, classified according to the source, and nature of resource.

45.5.1 Government and State Resources

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3. Institute of Medicine (U.S.) Committee on the Future of Emergency Care in the United States Health System. Hospital-based emergency care: at the breaking point. Washington, DC: National Academies Press; 2007.
4. Institute of Medicine. Committee on the Future of Emergency Care in the U.S. Health System. Emergency Medical Services: at the crossroads. Washington, DC: The National Academies Press; 2006.
5. Institute of Medicine. Committee on the future of emergency care in the U.S. Health System. Pediatric emergency care: growing pains. Washington, DC: The National Academies Press; 2006.
6. U.S. Department of Health and Human Services, Office of the Assistant Secretary for Preparedness and Response. Framework for the NHSS www.phe.gov/Preparedness/planning/authority/nhss/Pages/framework.aspx. Accessed 24 Oct 2011.
7. Department of Homeland Security. National Response Framework. January 2008.
8. Department of Homeland Security. National Incident Management System. December 2008.
9. National Center for Injury Prevention and Control. In a moment's notice. Surge capacity for terrorist bombings. Atlanta: Centers for Disease Control and Prevention; 2007.
10. Centers for Disease Control and Prevention. FluSurge. http://www.cdc.gov/flu/flusurge.htm. Accessed 19 April 2011.
11. U.S. Department of Health and Human Services, U.S. Department of Homeland Security. Guidance on Allocating and Targeting Pandemic Influenza Vaccine.

45.5.2 Medical Decision Making

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45.5.3 Terrorism and Bioterrorism

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45.5.4 Pandemics and Outbreaks

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Erratum to: Chapters 10 and 21 of Orthopedics in Disasters

Nikolaj Wolfson

Erratum to:
N. Wolfson et al. (eds.), Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events, DOI 10.1007/978-3-662-48950-5

Author name in chapters 10 and 21 was spelled incorrect. Correct name is:

William Henry Boyce

The updated original online versions for the two chapters can be found at DOI 10.1007/978-3-662-48950-5_10 and DOI 10.1007/978-3-662-48950-5_21

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N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5_46

Index

N. Wolfson et al. (eds.), *Orthopedics in Disasters: Orthopedic Injuries in Natural Disasters and Mass Casualty Events*, DOI 10.1007/978-3-662-48950-5

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