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EDITORIAL

The loneliness of the local orthopaedic surgeon in disaster zones

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One year ago, on February 6, 2023, in a high-risk earthquake zone in the Mediterranean region of Turkey and Syria, the area was struck by two major earthquakes in a region where approximately 15 million people reside. According to official data, more than 50,000 persons died [1]. Many hospitals, and transportation facilities as roads in the area were damaged. The mean time under the rubble and before help arrived was an average of 30 h. For comparison, we must not forget that the International Space Station (ISS) crew is currently closer to a modern hospital centre than the wounded in some earthquakes, as in February 2023 in Turkey–Syria regarding hourly distance. After all, the capsules on Soyuz or Crew Dragon docked at the space station make a return to Earth possible in a few hours. The maximum time between a decision to evacuate and an admission to a hospital centre is estimated at 30 h for the space station [2]; therefore, the crew on board an orbital station is undoubtedly closer to a modern hospital centre than some people injured in lost areas or in conflict zones where movement is complex.

Amputation was performed in 30% of patients in February 2023 during the first days of the Turkey–Syria earthquake [3]. This paper is dedicated to orthopaedic surgeons who risk their lives whilst saving victims of uncontrollable natural disasters or military surgeons who also risk their lives in devastating wars. On the first day, this surgeon is usually alone, dealing sometimes with amputation, often considered a last resort, a desperate measure taken when injuries are severe and immediate intervention is required. He may not know the beginning of this history 30,000 years ago, nor the time elapsed between each word to arrive at a practice that can be summed up in six words during the first day: triage, amputation or external fixation, crush syndrome, and antibiotic. Where to begin? As said by the King in “Alice in Wonderland”: “Begin at the beginning, go on till you come to the end: then stop”.

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History of ancient warfare, amputation, fracture treatments, external fixation…

The oldest known amputation took place 30,000 years ago in the Indonesian part of Borneo, where researchers [4] uncovered the remains of a 20-year-old homo sapiens with a cut above the left ankle. Based on the atrophy of the leg bone, he would have been amputated during his childhood. The absence of any trace of bone infection also suggests a surgical procedure perhaps well thought out and, in any case, well carried out since the patient survived. These Palaeolithic surgeons may have had a better knowledge of anatomy and surgery experience than we think to do amputation in a child and avoid bleeding and fatal infections during the operation. They perhaps knew how to use plants with anti-infectious or analgesic effects.

The documentation of bone surgeons and military medical history begins with the war between Sumer (current Iraq) and Elam (contemporary Iran) near Basra in 2700 BC. This period was the first to develop the idea of professional bone doctors. The earliest written records of bone fracture treatment were found in Sumerian carvings [5].

During the Persian War (499 BC–449 BC), Hippocrates stated that war was “a proper school for surgeons and he who would become a surgeon should join the army and follow it”. He also used debridement and traction to treat fractures [6] and described the principle of external fixation [7].

Antibiotics in “pre-antibiotic societies”, as in Ancient Egypt, have been known for some time, particularly tetracyclines incorporated into rapidly growing calcified tissue [8], causing permanent staining and fluorescence in compact bone and dentition. This unique property has been utilised in studying the dynamics of bone formation. The samples from Sudanese Nubia mummies were subjected to an extensive

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histological analysis under fluorescence microscopy, and it was determined that the differential fluorescence was incorporated in the osteons in vivo rather than through mould infestation or other postmortem occurrences. The tetracycline is produced naturally in the fermentation liquors of several species of Streptomyces, Actinomycetes which thrive in hot, dry, alkaline soils. Several agricultural techniques, including grain storage, are possible vehicles by which tetracyclines could be introduced into the body sufficiently to cause bone fluorescence and antibiotic treatment.

Antibiotics, debridement, amputation, external fixation known 2000 years ago!

Hi Dominique, "What else?": triage!

Dominique Larrey was [9] the first to organise triage on the battlefield in France. Triage is a word of French origin, meaning "sorting" or "choosing". Its French definition is choosing after examination. The need for sorting war casualties emerged during the nineteenth century, after the enormous losses of battles in Europe (Austerlitz 1802: 4000 wounded). Dominique Larrey gave a perfect description of this in his memoirs. He clarified the importance of prioritising those with the most severe injuries, regardless of rank or other factors. Additionally, he outlined the different levels of care that define contemporary military Surgery.

Hi Antonio, "What else?": crush syndrome!

Professor Antonino D'Antona [10], an Italian surgeon at Naples University, documented, first in 1909 at the Messina earthquake the link between rhabdomyolysis and kidney injury. Handling 197 earthquake-injured patients, seven of whom were in shock, he unfortunately witnessed two fatalities due to uremia. Simultaneously [11], the concept of crush syndrome was introduced by Franz von Colmers, a German surgeon who also attended to patients affected by the Messina earthquake. Subsequently, in 1941, Bywaters presented four cases of crush syndrome not previously documented in English literature. He illustrated the degenerative alterations in the proximal convoluted tubules of the kidneys and the presence of pigment casts in the distal portion of the nephron.

Resources for disaster orthopaedics: they are huge in theory

Natural events include geophysical disasters like hurricanes or earthquakes, and man-made disasters include intentional and unintentional events. The ability to respond to large-scale disasters is recognised as an increasingly important obligation of physicians and surgeons. This has been underscored within the USA by events such as the terrorist attack on September 11/2001, large-scale wildfires in California, and Hurricane Katrina. The 2004 tsunami in Indonesia resulted in at least 230,000 deaths. The January 2010 earthquake in Haiti resulted in as many fatalities as the Indonesian tsunami and caused a massive number of musculoskeletal injuries in the survivors. All these events presented enormous challenges to the response organisations. The 7.8 magnitude earthquake that shook Turkey and Syria in February 2023 left more than 15,000 people dead and more than 70,000 with traumatic injuries.

Due to the increasing burden of climate change and mass casualty incidents across the globe, the World Health Organization (WHO) is emerging with solid commitments to emergency preparedness and response with the Emergency, Critical, and Operative Care Services resolution at the 76th World Health Assembly [12]. This renewed commitment by WHO and its member states underlies a critical call to action for national governments to identify and evaluate the deficiencies of their disaster preparedness strategies and channels for funnelling these financial and political commitments and investments into system-level changes.

It is clear from lessons learned by governmental associations of a country, WHO or MSF [13] (Medecins sans frontières), that the response keys are preparation plans across the country. A local emergency operations centre should coordinate information and resources. Foundations, businesses, or private persons also fund non-governmental Organisations. Some NGOs avoid formal funding and are run primarily by volunteers.

From a theoretical point of view, the resources are immense, with many International Orthopaedic Organisations and Resources, to cite one, the International Society of Orthopaedic Surgery and Traumatology (SICOT). Disaster objectives are a part of the training in most SICOT member countries and help create a common link in all nations. SICOT offers the Educational Objectives [14] as a basic orthopaedic training and education guide. They provide a benchmark for trainees to meet and guarantee sufficient understanding (http://www.sicot.org).

If we combine the National Orthopaedic Trauma Society, there are over a hundred of them worldwide. All the societies that claim the possibility of dealing with disasters are undoubtedly more than 200 societies of 1000 doctors who bring together more than 200,000 theoretically available doctors. Still, we immediately see the limits of these organisations because they include societies as varied as those treating osteoporosis, cartilage regeneration, sports medicine, etc., where practices are still very far from emergency care of a severe trauma patient.

However, organisations, hospitals, and local surgeons do not speak the same language during disasters. In a disaster, chaos reigns. The organisations, hospitals, and the solitary surgeon seem to be playing different instruments in a chaotic symphony, each creating its unique melody. Recognising the urgency, representatives from organisations, hospitals, and the local surgeon must collaborate to develop a set of standardised terms that everyone can understand. This effort extends beyond medical jargon to encompass emergency protocols, resource allocation, and disaster response strategies but usually needs several days.

The reality: difficult to have a standardised response on the first day of civil disasters

Hospitals and medical facilities in civil practice generally have better access to resources, including medical equipment, skilled personnel, and rehabilitation services. In disaster zones, resources are often scarce, and medical facilities may be overwhelmed. Orthopaedic surgeons must work with limited resources, adapt to challenging conditions, and make quick decisions to address immediate life-threatening injuries.

Triage: the more critical is permanent marker and paper

Various criteria can be used to classify situations [15–17]. Analysing and comparing disaster protocols can be challenging, with some classifications incorporating multiple criteria, potentially increasing complexity.

The important thing for triage is to have a permanent marker and paper. One of the authors remembers receiving a bus of 30 people alone in Africa; the reality is that when you are alone, you don't have time to use all the classification tables for triage. You also don't have time to check patients several times. So, after the patients' examination, the most important thing is to take a sheet of paper, staple this sheet to the patient's clothing, or write directly on the patient's skin, what you found and what you are going to do. Once you have done what you have to do, for example, an amputation, the second most important thing is to write on the dressing the day and time of the amputation for the patient in question. It will be helpful for the following surgeon or yourself if you remain alone after 24 h!

Amputation: doing it is more challenging than talking theory

One of the authors was for 30 years at the head of the department of one of the largest polytrauma centres in France. The decision to amputate is always tricky, and most of the surgeons (except vascular surgeons) have no real amputation experience. At the end of the twentieth century or the beginning of the twenty-first century, even in hospitals receiving a lot of polytrauma patients, the frequency of amputation does not exceed 15 amputations per year, even during the periods of civil attacks, as in the Bataclan [18]. For comparison, Larrey, Napoleon's surgeon, carried out more than 100 amputations per day to save soldiers during the Russian campaign, and this was without anaesthesia. We must remember that if the surgeon does not have experience of humanitarian disaster, previous earthquake, or war practice, the most experienced surgeon after 20–30 years will have less than 200 amputations in his experience, i.e., the equivalent of three days of Surgery for Larrey during the Russian campaign. In a survey in France, 95% of orthopaedic surgeons had never performed amputation, and 99% never in children.

The rules established in the nineteenth century by Larrey [9] have changed much less than one might think and deserve to be repeated. Given the impossibility of determining the precise boundaries of traumatic tissue damage and the risk of local and often generalised surgical infection, the use of any method of closing the wound surface is inadvisable. The stump should remain open. In case of doubt about the risk of infection, a guillotine method of amputation and/or disarticulation of the distal part of the limb is a first step before revision of amputation. This method allows prompt truncation of limbs in the first treatment phase and without blood loss. Subsequently, after the stabilisation of the general condition of the patient, a revision of the level of amputation can be discussed.

The main surgical treatment option for crush syndrome is amputation [1]. Mortality and crush syndrome severity are correlated with thigh injuries. In the case of crush syndrome, amputation is a lifesaver, and fasciotomy should not be preferred. This procedure ought to be the last resort that is usually done above the fracture in case of crush syndrome.

Amputation for an open fracture without crush syndrome is different from an amputation related to a crush syndrome. For an open fracture, the surgeon must follow principles of maximal sparing of viable tissues in the injured limb and maximally possible preservation of the length of the extremity. Amputation in children should not adhere to the generally accepted level of limb truncation. This is due to continued growth in this segment and the possible delay in the growth of the upper limb. Attention to the preservation of growth cartilage is necessary in children. It is crucial, for example, to amputate in the ankle joint, to be certain to preserve the distal growth plate of the distal tibia.

Amputation in civil practice is guided by established medical ethics, patient consent, and legal frameworks. The process involves collaboration between the patient, his family, and the medical team. In a disaster zone, the situation's urgency may require medical professionals to make rapid decisions, but here also, religious and family consent should be researched if the patient is not able to answer.

Usually, there is no external fixation or very few on the site of disaster

Stocks of external fixators are large worldwide, but only in manufacturers' cupboards. Experience has shown that the external fixators are often not where they need to be! Even in developed countries and even in places where one would think that they are in large numbers, like capital cities, the Bataclan experience showed to one of the authors (head of the department) that the reserves of external fixatives in civilian hospitals were low: no possibilities to make more than five assemblies using an external fixator in the same night in the same hospital. To have external fixators delivered on the weekend may take 30 h for a hospital in a European capital, that is to say, the same time as to return from the international space station (Fig. 1). It doesn't seem that this has changed in the last ten years. There seem to be more stock external fixators now, but no one knows precisely where they are! The unfortunate rule of experience and innovation also applies to disasters: "Experience is the sum of the mistakes one can make in one's life, but usually it is not transferable, and each generation must repeat its experience". "Innovation is sometimes simply a new experience that we are doing".

Don't forget plaster and debridement!

In 970, Abu Mansur Muwaffak, a Persian pharmacologist, suggested in his pharmacology book that for fractures and other bone injuries, applying plaster to the limb would be beneficial [19]. Trueta [20] later innovated by introducing the concept of open fracture care using plaster of Paris. Trueta challenged prevailing opinions by asserting that the primary risk of infection was in the muscle rather than the bone. His recommended approach involved debridement of the wound, excision of bruised tissue, drainage with sterile absorbent gauze, and allowing the wound to heal by secondary intention, followed by the application of a plaster cast to the limb. Additionally, the technique of using pins in plaster, especially for open fractures, was a simple method applicable worldwide, as plaster is commonly found in medical kits.

Antibiotic resources are limited, and bacterial contamination is a constant

The medical kit

It may sometimes have a tourniquet [21] and a wide range of antibiotics. However, the risk of infection is accentuated by the combination of several factors: in a hostile environment, the transmission of pathogens is facilitated because the immune defences of the injured are immediately weakened due to stress and shock. Furthermore, we must not forget that the active medicinal ingredients may have become ineffective simply because the cold chain was broken during transport or simply during the storage of these medicines, which have sometimes travelled with difficulty several hundred or even thousands of kilometres.

Watch out for aggressive bacteria in open fractures

Bacteria like viruses, have no borders, and wanting to believe that in some areas of the world, bacteria have not yet developed resistance to antibiotics is undoubtedly a utopia.

A bacteria can develop resistance through mutations or the acquisition of resistance genes that give the resistance to one or more antibiotics. Bacteria can exchange genes. These exchanges are particularly problematic in the case of genes making the bacteria that host it resistant

Fig. 1 Difference between kilometric and hourly distances

to antibiotics. Indeed, the acquisition of resistance by mutation is rare (one bacteria in a hundred million). But resistance genes can be exchanged between bacteria at a very high frequency (up to one bacteria in 100). Estimation shows that the typical adult human body [22] consists of about 38 trillion bacteria (half cells, half bacteria); therefore, exchanging resistance genes for bacteria in a humanity of 8 billion people is simple and quick! Antibiotic resistance is not specific to the “disease-causing” bacteria. It also affects the beneficial and non-pathogenic bacteria that colonise us and constitute our microbiome which are essential to our good health. These resistant bacteria then represent a reservoir of resistance genes which can be transmitted to pathogenic bacteria.

It is a global phenomenon. Antibiotic resistance affects all countries and is also present in animals and the environment. Antibiotic-contaminated environments, veterinary care, and human medicine all contribute to the rise in resistance. Humans, animals, and the environment can all contract resistant bacteria and genes through direct contact, as well as through ingestion of food or water. The “European Center for Disease Control and Prevention” (ECDC) has calculated that throughout Europe 33,000 deaths could be caused [23] by infections with bacteria resistant to antibiotics. The CDC in Atlanta reports an equivalent excess mortality in the USA. Data is lacking for low-income countries [24]. Still, the increase in resistance in these countries, combined with the lack of access to safe antibiotics—when they are needed—is likely responsible for many deaths.

Contaminants in crush injuries can come from various sources, including soil, vegetation, and microorganisms present in the environment. The risk of contamination may be higher in situations where individuals are trapped beneath debris for an extended period. The environmental conditions following a landslide, including the presence of mud, water, and other debris, can significantly contribute to bacterial contamination in crush injuries. Prolonged entrapment under rubble may increase the risk of acute compartment syndrome [25] and secondary infection.

The risk of contamination underscores the importance of appropriate medical care and time. Antibiotic administration as early as possible, wound cleaning, and surgical debridement are common strategies to mitigate the risk of infection in open fractures. Despite early treatment (in the first hours), most of them will become infected and often not be suspected [26, 27], as in many situations in surgery [28]. The precise strategy, however, might change depending on the particulars of every injury scenario and external fixation used after the acute period [29, 30]. Antibiogo, a smartphone app that assists non-expert laboratory technicians [31] in low-resource settings in measuring and interpreting Antibiotic susceptibility tests (AST) may help clinicians prescribe accurate antibiotics in a second instance.

Early and careful debridement is as important as antibiotics

A recent international study [32] from 61 countries confirms the statement of Trueta [19] done in 1939 about debridement. Examining 10,651 fractures, the likelihood of infection rose by 0.17% with each six h delay in debridement. Gustilo-Anderson type-III injuries exhibited a higher infection probability, increasing by 0.23% every six h, compared to 0.13% for Gustilo-Anderson type I or II injuries. The infection risk also varied between tibial and femoral fractures, with a 0.18% increase every six h for tibial fractures compared to 0.13% for femoral fractures.

Mobile phones and artificial intelligence are not efficient on the first day

Addressing the challenge of the geographical separation between local surgeons and surgical experts is paramount. Whilst mobile phones may seem like a solution, the unpredictable nature of disaster medicine introduces regular disruptions in telephone signals, hindering effective communication. Moreover, critical situations amplify urgency, leading to potential interpretation errors and cognitive biases. The language barrier, arising from differences in mother tongues amongst those involved, further complicates decision-making exchanges, adding a layer of confusion.

War surgery and disaster management in the twenty-first century

It is no irony that many of the advances in surgery have resulted from advances in technologies used in war or, indeed, as necessities to deal with the casualties of war, with injuries that are more penetrating and more destructive.

Today, war surgery [33] involves airway management, damage control resuscitation, mechanical and biochemical haemorrhage control, and damage control surgery in forward surgical units in the 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 work. Rarely in civilian practice do we see white phosphorus burns. Handgun injuries seen in a trauma centre cannot be compared to multiple high-energy penetrating trauma secondary to rocket-propelled grenades, tank fire, shells, and mortars. Compared to 10% penetrating trauma in civilians, almost 70% of combat injuries are secondary to multiple penetrating trauma.

International Red Cross rules international humanitarian database

These traumas are widespread amongst noncombatants and civilians. It is here that modern military and civilian surgical practice has come to overlap, particularly with the International Red Cross Rules that are an integral part of the International Humanitarian Database, embodying principles that guide humanitarian action during armed conflicts and other emergencies.

These rules, established by the International Committee of the Red Cross (https://ihl-databases.icrc.org/en/customary-ihl/v1/rule25), outline key provisions for protecting and assisting victims of armed conflicts, ensuring the humane treatment of those not taking part in hostilities, and establishing a framework for delivering humanitarian aid, including principles of neutrality, impartiality, and independence. The rules emphasise the importance of respecting and protecting individuals, medical personnel, and facilities, as well as the essential role of the Red Cross and Red Crescent emblems as symbols of protection. The International Red Cross Rules play a crucial role in upholding the dignity and rights of those affected by crises, providing a foundation for humanitarian organisations to operate effectively and ethically in complex and challenging environments.

Performing surgery in an era of persistent global conflict: humanitarian challenges

Sadly, at this moment, across the globe, there is no end to hostilities. The contribution of surgeons in these areas, particularly in under-resourced environments, overwhelmed with work and facing the same threats as the injured around them, is immense. We honour them in this editorial, knowing that much of the world's conflict and disaster is focused on the poorest areas and that the conflict matches the efforts in healthcare development [34].

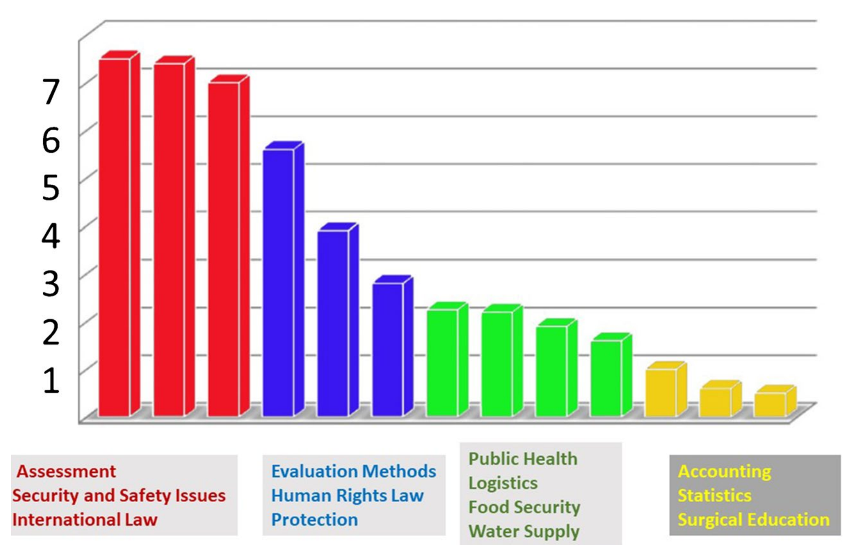
Consequently, the importance and diverse knowledge needed by military surgeons and humanitarian workers have changed. We probably need to adapt the programme in many International Orthopaedic Organisations and Resources. A survey done by the Red Cross (Fig. 2) reveals that education in Surgery [35–37] ranks last amongst the thirteen parameters. The most essential items are "Assessment Security, Safety Issues, International Law, Evaluation Methods, Human Rights Law, Protection", all things that are not usually in the teaching programme! Above all, however, what military surgeons (as humanitarian agencies) value is experience; the 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 towards a goal be effective in austere and dangerous environments.

Be quick, effective under pressure, and flexible with limited resources

Reflecting on historical instances, such as the Vietnam War, where direct transportation of wounded individuals from Vietnam to American bases in Japan occurred in less than 48-h delay, it is essential to recognise the limits and strategic pitfalls of such evacuations. Evacuating a condition that could be treated on-site is one risk, whilst underestimating the severity of an infection, potentially leading to death without rapid intervention, poses another. It is crucial to distinguish between kilometric and hourly distances, as illustrated in Fig. 1.

There are perhaps other words to add to the few words of the title (triage, amputation or external-fixation, crush-syndrome, debridement, plaster, antibiotic): be quick, effective under pressure, and flexible with limited

Fig. 2 What is important for disaster is different from surgery knowledge on a scale from 1 to 10



resources. The challenges in war surgery, as in disaster management, is a general answer to local needs such as providing emergency obstetric care, essential family medicine care, and replacing standard emergency room and surgical services in local hospitals that are overwhelmed and poorly staffed or destroyed by disaster. It is not a "specialist" but rather an accomplished general surgeon, able to perform caesarian sections, treat fractures, and deal with necessary medical emergencies.

Bullets are not sterile

Bacterial contamination in injuries resulting from gunshot fractures in civil or military areas is constant. Bullets are never sterile and when possible should be removed during debridement. Gunshot injuries typically involve high-velocity projectiles that can cause fractures, tissue damage, and open wounds. Bacterial contamination often comes from the external environment or clothing, and the nature of the wound allows for direct exposure to contaminants. Gunshot fractures result in open injuries, where the projectile creates an entrance and exit wound, exposing the internal tissues to external contaminants. This increases the risk of bacterial contamination.

Conclusion

The local orthopaedic surgeon in disaster zones after a long history of human killings and natural catastrophes, lots of blood and pain—could count on many recommendations—but in the end, it all comes down to very few words: triage, amputation or external-fixation, crush-syndrome, debridement, plaster, and antibiotic, as in all the recent examples.

Clinics and hospitals must possess the minimum necessary resources. Demographics, geography, or time do not bind disasters and war. Adopting a global perspective in patients' treatment [38], as in large world events, is indispensable, accounting for the injury's pathology and considering the region's healthcare system and cultural nuances. Even the best-prepared countries are not immune from these disasters [39]. At the moment when this paper is written (January 2sd 2024), the death toll rises to at least 55 after a powerful earthquake in Japan (https://www.nytimes.com/interactive/2024/01/01/world/asia/japan-earthquake-map.html). Managing a large influx of patients simultaneously, particularly in severe trauma situations, can be overwhelming. Modern technology may not always be available, emphasising the need for adaptability alongside fundamental medical knowledge in austere environments. Adapting becomes as critical as possessing core medical expertise in the face of disaster.

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