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Abstract

"Recommendations for the management of crush victims in mass disasters" aims to assist medics, paramedics and rescue team members who provide care during disasters. Development of the recommendations followed an explicit process of literature review and, also internet and face-to-face discussions. The chapters cover medical and logistic measures, to be taken both at the disaster field and in the hospitals, to cope with the problems created by a catastrophe. Recommendations were based on retrospective analyses and case reports on past disasters, and also expert judgment or opinion. Since there are no randomized controlled trials, no GRADE approach was used to develop the recommendations, and no strengths of recommendations or levels of evidence are provided.

Keywords: Crush syndrome; disaster victims; rhabdomyolysis; acute kidney injury; logistics, renal replacement therapy; European Renal Best Practice; Renal Disaster Relief Task Force; Médecins Sans Frontières

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Preface

Major earthquakes occur on a regular basis. Many densely populated cities, such as Tehran and Istanbul, as well as densely populated areas in countries such as those around the Mediterranean Basin, India, Indonesia, large sections of China, Japan and California are susceptible to such mega-disasters [1-3].

Crush syndrome, with or without subsequent acute kidney injury, is the second most common cause of death in immediate survivors of earthquakes, the first one being direct trauma. There are two major drawbacks to the effective treatment of renal complications of the crush syndrome after disasters:

1. Specialized facilities: Crush syndrome patients suffer from severe complications, which, ideally, necessitate the availability of a complex hospital infrastructure including trained health care professionals and necessary equipment; hence logistic support is vital.
2. Expertise: Crush syndrome is rare in daily practice. It is known that unapplied medical knowledge is easily forgotten; consequently, management errors are common in the treatment of these patients.

Nephrologists, therefore, must prepare their own disaster scenarios, make logistic plans, and establish clear and pragmatic 'guidelines' for the management of crush victims in disasters. However, there are methodological hurdles in generating such 'guidelines', which are based on evidence derived from well-designed, randomized, controlled trials (RCTs). Regrettably, nephrology is a discipline with few RCTs. [4] This is even more problematic in seismo-nephrology, the management of crush victims in major disasters [5], since there is no experimental model for its study, and information can only be obtained from a limited number of retrospective analyses, case reports, position statements, and expert judgment or opinion, all of which represent a low grade of evidence. This is the reason why this document is titled 'recommendations' rather than 'guidelines', in keeping with the suggested change in nomenclature by the European Renal Best Practice (ERBP) Advisory Board [6]. For the same reasons, this text does not contain grades of evidence or strengths of recommendations.

The present recommendations are intended not only for nephrologists, but also for other health professionals providing care during major disasters. Considering the broad target population and the chaotic conditions in the aftermath of most disasters, the recommendations included in this text are often simple and basic statements. We describe, step-by-step, what to do from the medical, logistic and coordination perspectives before, during and after disasters. The purpose is to offer easily accessible, pragmatic information, which can be applied directly in the field and hospitals under difficult circumstances, and to describe proactive measures that can be taken to prepare for such events. For reasons of clarity, the recommended medical interventions have been grouped according to rescue timeline, i.e. before, during and after the extrication of victims, which in some cases necessitates repetition of the same information spread over several sections.

Two issues need to be emphasized:

1. This text concentrates only on basic life-saving interventions in the disaster field with respect to nephrology; many other complications which occur in disaster-related crush victims are not discussed in detail, and consequently, the reader is referred for these topics to the appropriate sources.
2. The medical and logistic recommendations described apply mainly to mass disasters, and may therefore not always be applicable in small-scale disasters or non-disaster conditions, where problems can be coped with relatively easily by the local health care system.

We trust that the present document on this critical issue will be helpful in providing effective health care to disaster victims with renal problems.

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'Recommendations for the Management of Crush Victims in Mass Disasters'

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Section I: Definitions and Basic Concepts

Section I.1: Terminology related to disaster, crush syndrome and acute kidney injury (AKI) / acute renal failure (ARF)

Disaster: A situation in which widespread and severe damage, injury, and loss of life or property occur, necessitating special efforts to cope with the magnitude. During these episodes the affected society undergoes severe disruption of its activities and infrastructure.

Mass disaster: A disaster, in which the number of victims overwhelms the local system.

Natural disaster: A sudden major upheaval of nature, causing extensive destruction, death and suffering among the stricken community, and which is not due to man's action.

Man-made disaster: A disaster not caused by natural phenomena, but by the destructive action of humans.

Medical disaster: The result of a vast ecological breakdown in the relationship between humans and their environment on such a scale that the stricken community needs extraordinary efforts to cope with it at the medical level, often necessitating help from outside.

Victim: Any dead or living person who has sustained physical, material and/or psychological trauma due to outside aggression, be it natural or human.

Rhabdomyolysis: Damage to striated muscle cells of traumatic or nontraumatic etiology, which results in the release of intracellular components of muscle into the systemic circulation, and ultimately trigger the clinical and laboratory abnormalities. Although different threshold values (from 500 to 3000 U/L) of serum creatine phosphokinase (CK) have been proposed for diagnosis [7–9], in general, CK levels higher than fivefold the upper limit of normal values for a given laboratory are considered to indicate rhabdomyolysis [8, 10–13].

Extrication: Rescuing the trapped victim from under the rubble.

Compartment syndrome: Increased pressure (>20 mmHg) within a confined anatomic space resulting in ischemic changes to the concerned tissues. [14, 15]. Once a critical pressure is reached, microvascular flow is impaired, leading to worsening rhabdomyolysis and ischemic damage, especially of nerves and muscles. [16, 17]. If this is suspected, intracompartmental pressures can be assessed, either directly using a needle connected to a pressure monitor, or indirectly measuring an increase in limb circumference or clinical signs. In mass disasters, clinicians often rely on the clinical signs and increasing limb circumference rather than direct measurements [18]. Once ischemia develops, the 6 'P's of ischemia (**P**ain, **P**ressure, **P**aresthesia, **P**ulselessness, **P**aresis and **P**allor) will gradually appear [19]. Of these, pain is often severe and constant; appears early, and should prompt the recognition of the compartment syndrome. Pulselessness is a late sign indicating irreversible ischemia in many cases; thus, one should intervene either medically or surgically (see Section IV, p. i26) to decrease intracompartmental pressure, before this finding develops. This syndrome is completely different from the 'abdominal compartment syndrome', which is caused by intraabdominal hypertension due to injury or disease in the abdominopelvic region, such as abdominal trauma, major surgery, acute pancreatitis or a ruptured abdominal aortic aneurysm. The latter may cause multiple organ dysfunction including also acute kidney injury (see below).

Crush: Compression between opposing elements that result in organ damage or fracture.

Crush injury: A direct injury by collapsing material and debris causing manifest muscle swelling and/or neurological disturbances in the affected parts of the body [20].

Crush syndrome: Crush injury and systemic manifestations due to muscle damage [16, 21, 22]. Systemic manifestations may include acute kidney injury (AKI), sepsis, acute respiratory distress syndrome (ARDS), disseminated intravascular coagulation (DIC), bleeding, hypovolemic shock, cardiac failure, arrhythmias, electrolyte disturbances and psychological trauma [20, 23].

Renal disaster: A disaster where a substantial number of victims survive with major traumatic lesions, resulting in crush syndrome and renal failure [24]. Many of these patients survive the first hours of rescue, but may die at a later stage, especially if local dialysis facilities are damaged or overwhelmed. Crush syndrome is the second most frequent cause of death in immediate survivors, the first cause being direct traumatic impact [25]. Additionally, damage to local dialysis facilities places chronic maintenance dialysis patients in the region at major risk [26–28].

Kidney (renal) failure: A level of GFR <15 ml/min/1.73 m^2, accompanied in most cases by signs and symptoms of uremia, or a need to initiate renal replacement therapy (RRT) to avoid the complications of decreased renal function, which are an important cause of morbidity and mortality [29].

Oliguria: Urine output less than 500 ml/day.

Anuria: Urine output less than 50 ml/day.

Acute renal failure (ARF): An abrupt and sustained decrease in renal function resulting in retention of nitrogenous (urea and creatinine) and non-nitrogenous waste products [30]. This concept has undergone significant re-examination in recent years, and the concept of acute kidney injury/impairment (AKI) was introduced (see below), [31–32].

Acute Kidney Injury (AKI): This term encompasses the entire spectrum of acute changes in kidney function from minor changes in markers of renal function to requirement for RRT. It is quantified by means of the 'RIFLE' classification. The acronym RIFLE stands for increasing grades of severity from **R**isk, **I**njury, to **F**ailure; and the two outcome classes, **L**oss and **E**nd-Stage **K**idney **D**isease (ESKD). The three severity grades are defined on the basis of the changes in SCr or urine output where the worst of each criterion is used. The two outcome criteria, Loss and ESKD, are defined by the duration of loss of kidney function (Figure 1) [32]. In disaster crush victims, RIFLE classification can be useful to foresee the medical complications, need for therapeutic interventions and logistic support and also renal function at discharge, but probably not survival outcome [33].

Section I.2: Terminology related to diagnostic and therapeutic interventions

Triage: Sorting out and classification of victims to determine the priority of need and proper place of treatment to save as many lives as possible. The purpose of triage is to be selective so that medical resources are allocated to patients who will benefit most [34]. Triage can be performed at every stage and location: at the disaster field, at the field hospitals and at secondary or tertiary care centers.

Primary Survey: A basic survey to identify and simultaneously treat life-threatening conditions. For pragmatic reasons, the injuries are surveyed in an orderly fashion based on a simple mnemonic, **'A.B.C.D.E.'**: **A** is Airway maintenance, **B** is Breathing and ventilation, **C** is Circulation, **D** is Disability (or neurologic evaluation), and **E** is Exposure or completely undressing the victim (see Appendix – page i49).

Secondary Survey: This is a detailed evaluation of the trauma patient, which differs depending on the location where it is performed. At the disaster field, it consists of a quick but thorough check-up of the entire body to detect and treat any injuries overlooked during the primary survey. However, at hospital admission, it includes a complete history, detailed physical examination, the reassessment of all vital signs, and if possible, more sophisticated investigations, such as diagnostic imaging studies and laboratory tests.

Fasciotomy: A surgical incision through the fascia surrounding injured muscles to decrease intra-compartmental pressure.

Dialysis: Any method of blood purification for the treatment of kidney failure, where removal of uremic retention solutes is made possible by rinsing the blood by passage through a semi-permeable membrane. Available dialytic procedures include: intermittent hemodialysis or hemo (dia)filtration, peritoneal dialysis, continuous arteriovenous or venovenous hemodialysis or hemo(dia)filtration.

Disaster-response plan: An advance plan describing interventions by various parties involved in an overall disaster response. A medical disaster-response plan should organize health care providers into teams capable of delivering medical care as soon as possible. The goal of these teams is to stabilize the condition of victims in the field and to facilitate their transport to predefined evacuation sites or to intact local hospitals [35, 36]. The type and extent of intervention and the places where to intervene differ according to the severity and timing of a disaster, extent of

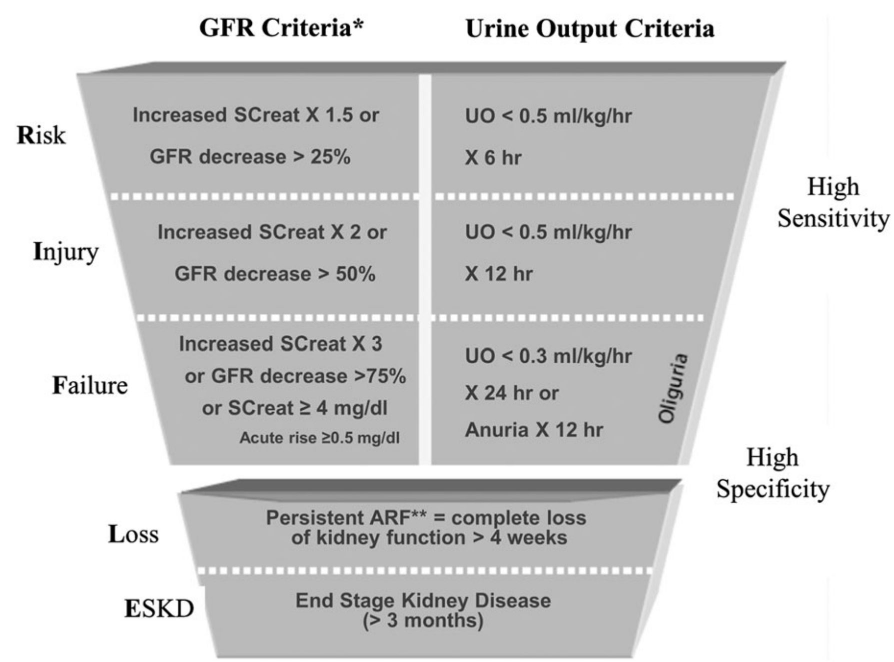

Figure 1. The RIFLE criteria for AKI (modified from [32] and reprinted with permission).
* Persistent ARF (loss) is defined as need for renal replacement therapy (RRT) for more than 4 weeks, whereas ESKD is defined by need for dialysis for longer than 3 months.
Abbreviations: ARF, acute renal failure; GFR, glomerular filtration rate; Screat, serum creatinine concentration; UO, urine output; ESKD, end stage kidney disease.

Table 1. Features of various locations and types of interventions at each location, where primary health care can be provided after mass disasters [36].

Place	Features	Type of intervention	Comments
Solo treatment areas	- Any place in the disaster area where intervention can be organized. - Reachable by health personnel within 0 to 1 h to initiate interventions.	- Stabilizing vital parameters	- Contribution to care is delivered by isolated health care workers. - Victims should be moved as soon as possible to disaster medical aid centers (see below).
Disaster medical aid centers	- Places to collect victims from solo treatment areas. - Each center should cover victims within a perimeter with a 3 to 4 km radius and contain an adjacent area for helicopter landing. - A team of at least 3 physicians per site should be available; 2 first-line rescuers for alternating 12- hour shifts and a third for backup.	- Delivery of primary medical care	- Rescuers in these centers should collect information about the operational status of the nearest victim collection points (see below) and surrounding hospitals.
Victim collection points	- Places to collect victims from solo treatment areas and disaster medical aid centers. - Large open spaces like parking areas of shopping malls, sport stadiums or golf courses can be useful for this purpose. - The chosen sites should be evenly dispersed (about 15 km apart) within the disaster area.	- Storage of medical supplies - Dispatching of personnel - Evacuation of patients - Triage and advanced medical care	- If possible, victims should be transferred to the hospitals from these centers at the earliest convenience by any available mode of transportation.

damage to the infrastructure, population density, potential efficacy of rescue activities, and the amount of preparation needed for an intervention [36, 37].

In a disaster response plan primary health care can be provided at different locations divided into three phases according to the time interval between disaster and intervention [36]:

- Solo treatment areas: hour 0 to 1;
- Disaster medical aid centers: hours 1 to 12; and
- Victim collection points: hours 12 to 72 (Table 1).

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Section II. Interventions at the Disaster Field

Section II.1: Determination of personal status of health care personnel
Section II.2: Planning of early intervention
Section II.3: Intervention before extrication
Section II.4: Intervention during extrication
Section II.5: General approach early after extrication
Section II.6: Fluid administration and urinary volume monitoring early after extrication
Section II.7: Other measures to be taken after extrication

Section II.1: Determination of personal status of health care personnel

II.1: Medical relief personnel with the potential ability to offer support should:

- **resolve their own disaster-related problems and plan for the housing and requirements of their own families before participating in relief operations.**
- **inform the coordinating authorities as soon as possible if they will not be able to contribute to the general disaster relief effort; and if so, consider participating temporarily in local rescue and medical activities.**

Rationale

II.1: *Medical relief personnel with the potential ability to offer support should:*

- *resolve their own disaster-related problems and plan for the housing and requirements of their own families before participating in relief operations.*

Circumstances after mass disasters are chaotic. Healthcare personnel may be overwhelmed with the heavy workload at the disaster field or the hospitals that they are assigned. Consequently, they may not return home for several days. Moreover, communication with their families may be hampered. Therefore, health care personnel should make sure that their own families will not need them in order to meet basic needs to survive in disaster circumstances. They should also make realistic plans for the housing, food and other requirements of their own family before getting fully engaged in rescue activities [38].

- *inform the coordinating authorities as soon as possible if they will not be able to contribute to the general disaster relief effort; and if so, consider participating temporarily in local rescue and medical activities.*

Following disasters, the performance of health care professionals may be hampered by physical and psychological concerns as many of them experience losses similar to those of other people in the region [28]. For example, in the aftermath of the Kobe and Marmara earthquakes, availability of support was affected by injuries to medical personnel and their families, as well as by transportation difficulties [25, 28, 39]. Even if medical personnel can reach hospitals, shock or grief may limit the efficacy of their work [37, 40, 41]. Therefore, it is critical that health care professionals inform coordinating authorities immediately if they are unable to function adequately, so that appropriate substitutes may be found in a timely manner.

Section II.2: Planning of early intervention

II.2: Individuals and organizations that are to offer support in a disaster must be prepared in advance about the location, type, and extent of interventions possible after a disaster.

Rationale

II.2: *Individuals and organizations that are to offer support in a disaster must be prepared in advance about the location, type, and extent of interventions possible after a disaster.*

In the aftermath of disasters, health professionals may serve at various locations; i.e. in the disaster field, in field hospitals, in emergency centers of hospitals, and on hospital wards [1, 37]. Consequently, medical personnel living in disaster-prone regions must have a predetermined idea of their role in the coordinated regional disaster response plan [42].

Field or field hospital practice is complex and physically and psychologically demanding, which often necessitates triage involving difficult decisions, such as abandoning patients with a low chance of survival or being forced to deal with the stress and aggressive behavior of victims or their relatives. Medical personnel who cannot handle such challenges in a catastrophe must recognize their limitations and withdraw without feelings of guilt, so that others can take care of necessary tasks [37]. Individuals without prior exposure to disaster care should work under the guidance of those who have previous experience with rescue activities.

It is important to determine the type and extent of potential local rescue activities. Consideration must be given to the overall circumstances of the disaster (severity, timing and population density of the affected area), damage to local infrastructure (communication possibilities, presence of electricity and tap water, transportation, status of hospitals), logistics (availability of rescue teams, availability of local as well as external resources and personnel) [43]. In addition, the specific features of locations where interventions can be organized, i.e. 'solo treatment areas', 'disaster medical aid centers' and 'victim collection points' must be taken into account [36] (see Table 1; page i6).

Section II.3: Intervention before extrication

II.3.A: Ensure own personal safety when approaching damaged buildings. Do not participate in the direct extrication of victims from partially or totally collapsed buildings. Focus on support and treatment of already rescued victims.

II.3.B: Be familiar with life support for entrapped victims, crush injury, fluid resuscitation, and crush-related acute kidney injury (AKI).

II.3.C: Begin medical evaluation of an entrapped victim as soon as contact is established, even before extrication.

II.3.D: Place a large bore venous access in any limb, even while the victim is still under the rubble. Initiate isotonic saline at a rate of 1000 mL/h in adults and 15–20 mL/kg/h in children for 2 h; then, reduce to 500 mL/h in adults and 10 mL/kg/h in children, or even lower. Avoid solutions containing even small amounts of potassium (e.g. Ringer's lactate).

II.3.E: Decide and plan the timing of extrication jointly with rescue and health care workers on site. Reevaluate victims during the progress of removal, if possible.

Rationale

II.3.A: *Ensure own personal safety when approaching damaged buildings. Do not participate in the direct extrication of victims from partially or totally collapsed buildings. Focus on support and treatment of already rescued victims.*

Heavily damaged buildings may collapse during aftershocks and injure rescuers trying to extricate entrapped victims. Medical and paramedical relief personnel, who are inexperienced in rescue activities can become victims themselves and should leave extrication to specialized rescuers [44]. Medical relief personnel are qualified for therapeutic intervention to which they must limit their activities. They are most useful in attending to already extricated victims [45].

II.3.B: *Be familiar with life support for entrapped victims, crush injury, fluid resuscitation, and crush-related acute kidney injury (AKI).*

Thirteen to 40% of early deaths can be avoided by simple, vigilant medical and surgical interventions such as proper airway control, prevention of blood loss, fracture stabilization, fluid resuscitation and control of hypothermia [46]. These concerns underscore the importance of participation of health care workers with experience in managing basic life support and fluid resuscitation for entrapped victims before and during the extrication process. Since medical relief personnel may not always be available, all rescue team personnel should be trained to recognize and treat problems associated with prolonged limb compression, and have appropriate fluid and medications to treat potential complications [47].

II.3.C: *Begin medical evaluation of an entrapped victim as soon as contact is established, even before extrication.*

After major earthquakes, up to 20% of deaths occur shortly after extrication [46]. Some of these include victims who were relatively stable before extrication, but deteriorate suddenly thereafter (*rescue death*). This likely occurs as a consequence of reperfusion of the traumatized extremity, with restoration of blood flow to the injured limbs and diffusion of tissue breakdown products into the systemic circulation [48, 49]. To prevent the complications related to this detrimental course of events, if possible, evaluate each entrapped person clinically while still under the rubble, with the intent of translating these observations into therapeutic decisions, especially regarding fluid administration. An entrapped person receiving medical treatment *in situ* will be better stabilized for the extrication process [50, 51].

When contact is first established, a full primary physical evaluation may not be possible. Nevertheless, make every attempt (by oral inquiry or direct examination) to determine the physical status of the victim (type and place of entrapment, position, presence of vital injuries or bleeding, estimation of volume status, and extent of subjective complaints) [46].

II.3.D: *Place a large bore venous access in any limb, even while the victim is still under the rubble. Initiate isotonic saline at a rate of 1000 mL/h in adults and 15–20 mL/kg/h in children for 2 h; then, reduce to 500 mL/h in adults and 10 mL/kg/h in children, or even lower. Avoid solutions containing even small amounts of potassium (e.g. Ringer's lactate).*

Inadequate volume replacement or delay in fluid resuscitation for more than 6 h after crush injury considerably increases the risk of developing AKI [52]. In many crush casualties, AKI can be prevented by appropriate early fluid resuscitation [53, 54], while those who develop AKI will need extensive subsequent treatment and possibly dialysis. Considering the limited availability of dialysis facilities in mass disasters, and the probability of not responding to late

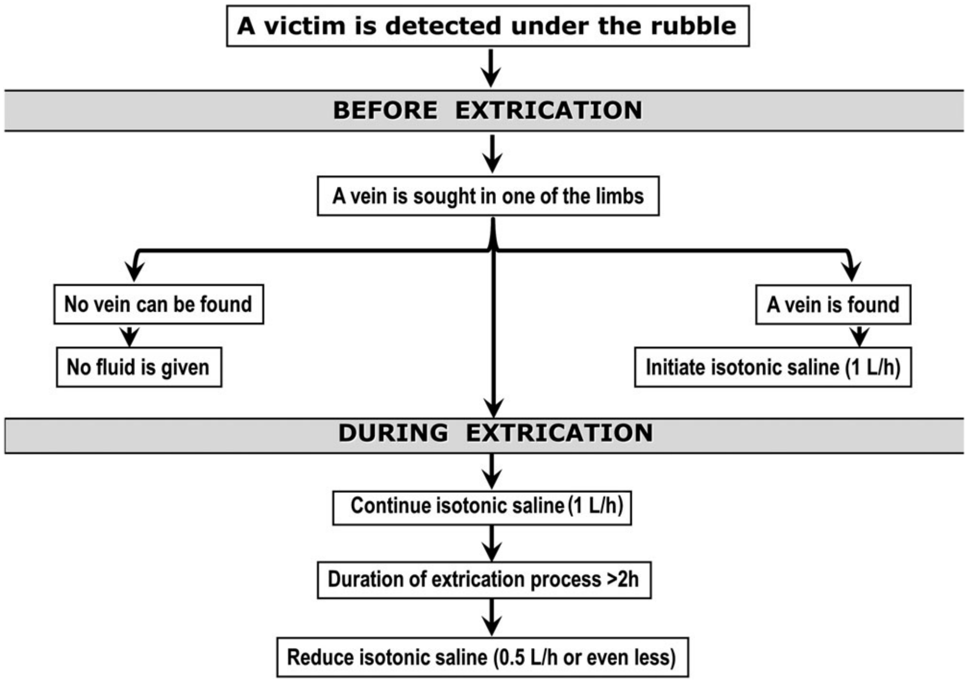

Figure 2. Fluid administration protocol in adults before and during extrication for entrapped victims of mass disasters.

fluid administration, some crush-related AKI victims might be denied appropriate treatment [55]. Avoid this at all cost.

Initiate isotonic saline as soon as possible, ideally while the victims are still buried under the rubble [50, 51]. An infusion rate of 1000 mL/h for adults (15–20 mL/kg of body weight per hour for children) is appropriate in most victims (Figure 2).

When peripheral venous access is impossible, consider intra-osseous infusion using commercial kits [e.g. 'EZ-IO® Intraosseous Infusion System' (Vidacare, San Antonio, TX, USA)]. However, this intervention may be impossible in chaotic disaster field conditions, because of unavailability of commercial kits and of medical personnel which has enough experience with this technique.

Consider hypodermoclysis (subcutaneous infusion of isotonic fluids) at a rate of approximately 1 mL/min if neither intraosseous nor intravenous access are possible. With hypodermoclysis, more than one access is possible, and up to 3 L/day of fluids can be given in a patient. This is not the ideal route for patients needing large volumes of fluids, but it is assumed to be 'better than nothing' in disasters. Patients with skin or bleeding disorders or peripheral edema may not be appropriate candidates for hypodermoclysis [56].

Always consider that isotonic saline is the first solution as it is readily available and highly effective for volume replacement [57, 58]. Although some studies report no effect of Ringer's lactate on serum potassium level [59, 60], these were conducted in patients with hypokalemia upon admission. In the classical crush victim at risk of AKI, the potential of fatal hyperkalemia dictates that any solution containing even small amounts of potassium (e.g. Ringer's lactate) should be avoided.

II.3.E: *Decide and plan the timing of extrication jointly with rescue and health care workers on site. Reevaluate victims during the progress of removal, if possible.*

In catastrophic earthquakes, the time period under the rubble (TPR) depends on several factors, such as severity of the disaster, population density of the affected area, structural quality of the buildings and efficacy of the rescue work. Victims have been rescued alive up to 13 days after a disaster [44, 61]. TPR directly affects morbidity and mortality [45, 62, 63] because of attendant delays in treatment. Literature on the impact of TPR on development of crush syndrome is contradictory. Some studies suggest that longer entrapment times increase risk of AKI [64–66], while others do not [61, 67, 68]. Indeed, shorter periods, i.e. 0.5–4 h, have resulted in crush-related AKI in many disasters [20, 69–71]. In the Marmara earthquake, kidney function was better preserved in patients who spent longer times under the rubble [72, 73]. This outcome may be attributed to selection bias, since entrapped victims who were rescued alive despite long entrapment, were likely less severely injured [65, 73, 74]. Therefore, the magnitude of muscle injury, rather than TPR *per se*, is a major determinant of the risk of AKI.

Since life-threatening complications such as major bleeding or airway obstruction may develop during entrapment, and secondary injuries may be sustained during the rescue efforts, consultation with rescue team members and other health care givers is necessary to plan the ideal timing and method of extrication. Continuous re-assessment of victims during the entire process of extrication is important, permitting rapid intervention in the case of an emergency situation (i.e. profuse bleeding).

Pay particular attention to victims trapped with their pelvis and feet above the heart level in whom energetic fluid resuscitation may lead to pulmonary congestion and secondary respiratory distress. In such victims, it is important to monitor respiratory rate and lung sounds, if possible.

Section II.4: Intervention during extrication

II.4.A: Administer intravenous isotonic saline at a rate of 1000 mL/h during the period of extrication (usually 45–90 min). If extrication takes longer than 2 h, reduce the rate of fluid administration so as not to exceed 500 mL/h, and adjust its rate depending on age, body weight, trauma pattern, ambient temperature, urine production, and amount of overall estimated fluid losses.

II.4.B: On-site amputation is indicated only for life saving interventions; i.e. to liberate the victim, but not to prevent crush syndrome.

Rationale

II.4.A: *Administer intravenous isotonic saline at a rate of 1000 mL/h during the period of extrication (usually 45–90 min). If extrication takes longer than 2 h, reduce the rate of fluid administration so as not to exceed 500 mL/h, and adjust its rate depending on age, body weight, trauma pattern, ambient temperature, urine production, and amount of overall estimated fluid losses.*

The extrication period of entrapped victims varies significantly (usually 45–90 min, but sometimes 4–8 h), because of differing disaster severity, efficacy of relief logistics, and local and patient conditions. Therefore, administer fluids (preferably isotonic saline) at a rate of 1000 mL/h in order to prevent hypovolemia and correct volume depletion. Rapid fluid administration may result in volume overload in oliguric victims, especially if extrication lasts more than 2 h. In that case, decrease fluid administration rate by at least 50% (<500 mL/h) or adjust as appropriate (Figure 2) [75].

Other factors impacting volume of fluid administration are: age (older victims and children are more prone to volume overload), body mass index (more fluid is needed for victims with larger body mass), trauma pattern (more fluid is needed for victims with serious trauma), time period under the rubble (more fluid is needed for victims who are rescued with a considerable delay) and amount of estimated fluid losses (more fluid is needed in bleeding patients and in high ambient temperatures).

If known, consider other co-morbidities such as congestive heart failure or chronic kidney disease. In victims who are difficult to reach, try to assess urine production by feeling their underwear. If any moistness unrelated to bleeding is detected, assume that there is urine production and fluids may be administered at the suggested rates.

II.4.B: *On-site amputation is indicated only for life saving interventions; i.e. to liberate the victim, but not to prevent crush syndrome.*

Sometimes it may be impossible to liberate an entrapped limb, or there may be a need to disengage the victim quickly, e.g. in case of imminent risk for collapse of building structures [76, 77]. In such cases, guillotine amputation of an entrapped limb may be performed as distally as possible. In that case, subsequent to the procedure, position a tourniquet upstream the wound to prevent excessive bleeding; remove the tourniquet and achieve proper hemostasis once the patient has been extricated.

Seriously traumatized limbs with extensive tissue necrosis are a potential source of myoglobin release into the body; thus amputation may prevent crush syndrome as well. However, amputation is associated with mortality by itself in disaster victims [23]; on-site amputation carries even a higher risk, because of significant blood loss and secondary infection, and therefore should only be performed for life saving indications, and not to prevent crush syndrome [49, 76].

If amputation becomes necessary, intravenous ketamine (1–4.5 mg/kg over 1–2 min) is optimal for anesthesia as it provides profound sedation, analgesia, and amnesia, while preserving spontaneous ventilation and gag reflexes [78].

Section II.5: General approach early after extrication

II.5.A: Remove extricated victims as quickly as possible from the site of structural collapse. Check vital signs and perform a 'primary survey' to define the extent and type of medical interventions needed. Triage victims with a low potential of survival to determine who should receive priority for treatment.

II.5.B: Apply an arterial tourniquet only for life-threatening bleeding.

II.5.C: Perform a 'secondary survey' as soon as possible to diagnose and manage any injuries missed during the primary survey, including an inventory of injuries as well as prospective follow-up for late signs of crush syndrome (decreased urine output, dark urine, signs and symptoms of uremia) even in cases with mild injuries and no apparent initial signs of crush.

Rationale

II.5.A: *Remove extricated victims as quickly as possible from the site of structural collapse. Check vital signs and perform a 'primary survey' to define the extent and type of medical interventions needed. Triage victims with a low potential of survival to determine who should receive priority for treatment.*

Damaged buildings may collapse from aftershocks at any time after the primary shock. As such, it is risky to evaluate and treat victims close to damaged (or even apparently undamaged) buildings; move the victims to a safe place at the earliest opportunity.

Following rescue, perform an initial systematic assessment of the injured patient to identify and treat life-threatening injuries, and to prioritize urgent therapeutic needs.

Table 2. Order of processing during the primary survey

A	Airway maintenance with cervical spine protection
B	Breathing and ventilation
C	Circulation with hemorrhage control
D	Disability assessment of neurological status
E	Exposure and Environment (completely undress the patient unless there is a risk of hypothermia)

The Advanced Trauma Life Support (ATLS)® system advocates evaluating injuries in two stages: a quick 'primary survey' aimed at recognizing immediate potentially fatal injuries and a detailed 'secondary survey' for the fuller evaluation of an injured victim (see Section I.2, page i5 and Appendix, page i49) [79].

The *primary survey* is done according to a well-established protocol based on the mnemonic A.B.C.D.E., which allows for quick recognition of life-threatening injuries, and the prioritizing of treatment among victims encountered simultaneously (Table 2).

If the victim is alert, talking, oriented and moving all extremities, conclude that the airway is patent, oxygen is delivered to the brain and that there is no major central neurological injury. If the A.B.C.D.E.s do not reveal major lesions, start treatment as described below.

However, if the patient is unresponsive or suffering from visible, potentially life-threatening or penetrating trauma, consider logistic circumstances (severity of the disaster, population density of the affected area, extent of damage to infrastructure, availability of health care personnel, transport possibilities) and medical factors (characteristics of the victim, type and extent of trauma, severity of physical findings) for the decision to treat or not to treat, and perform triage.

Triage is 'sorting out and classifying the victims to determine the priority of need and proper place of treatment for saving as many lives as possible' (see Appendix, page i51). The guiding aim is to allocate all limited medical resources to patients for whom most benefit can be expected [34, 81]. In massive disasters, treat cases with at least 50% chance of survival in the field to preserve time and resources [36]. Victims with a low chance of survival include those with significant head injuries, multiple injuries, cardiac arrest, massive burns, and in hemorrhagic shock [82]. If transport and surgical care are not immediately available, consider palliative measures.

In an analysis of the Kobe earthquake crush victims, of the 13 risk factors that can be assessed in the field [i.e. patient characteristics (age, gender), hours (time for rescue, time for transportation), injured sites (upper extremities, lower extremities, limb, trunk, pelvic fracture), physical examination at initial evaluation (systolic blood pressure, pulse rate, respiratory rate, urine color)], only three variables (pulse rate $\geq$120/min, delayed rescue $\geq$3 h, and presence of abnormal urine color) were important for predicting hemodialysis or death [83].

However, if the disaster is not massive, and an adequate number of health care personnel are available, then provide optimal medical care to all victims, irrespective of the severity of injuries.

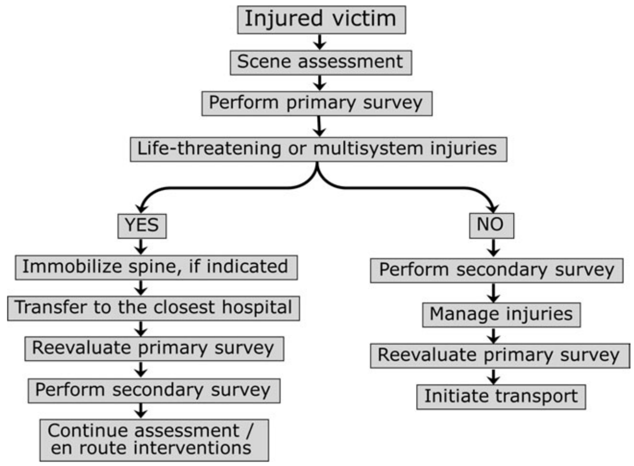

Figure 3. Overview of prehospital care at the disaster field (modified from [84]). (Primary and secondary surveys are defined in Section I.2, page i5.)

Consider that severe neurological deficiencies, such as sensory loss and flaccid paralysis immediately upon extrication, do not always indicate spine injury. They may also be due to peripheral neuropathy secondary to compression by the compartment syndrome, and in that case may be partially reversible [52, 69]. Nevertheless, always consider that all such victims have sustained spinal trauma, until proven otherwise.

A flowchart of a practical approach to victims at the disaster field is shown in Figure 3.

II.5.B: *Apply an arterial tourniquet only for life-threatening bleeding.*

Following extrication, reperfusion of the crushed extremity may lead to the release of myoglobin and other toxic metabolites into the systemic circulation [85]. Some authors suggest the application of a proximal tourniquet to the injured extremity as an adjunct to treatment of the buried victims [86].

The prolonged application of proximally placed tourniquets may unnecessarily expose the patient to increased risk of palsy, myonecrosis, thrombosis, rigor, abscess, blisters, abrasions, contusions, and pinching. Also, they may unnecessarily expose the patient to increased risk of myoglobinuria and AKI after the tourniquet is released.

Therefore, do not apply tourniquets to prevent crush syndrome, especially if there is a possibility of saving the extremity [76]. Use them only as a last resort, following failure to control bleeding by either direct pressure or other hemostatic measures [87–89]. Give evacuation priority at the disaster field to the patients in whom tourniquet application was unavoidable. Remove tourniquets as soon as possible to limit tissue ischemia and the risk of limb loss.

II.5.C: *Perform a 'secondary survey' as soon as possible to diagnose and manage any injuries missed during the primary survey, including an inventory of injuries as well as prospective follow-up for late signs of crush syndrome (decreased urine output, dark urine, signs and symptoms of* *uremia) even in cases with mild injuries and no apparent initial signs of crush.*

Predominant types of trauma may differ substantially due to local circumstances [7, 23, 74, 90–94]. Since mortality rate has been found to be significantly higher in victims with abdominal or thoracic trauma [20, 23, 94, 95] assess the overall trauma pattern in each victim by means of a *'secondary survey'* as soon as possible (see Section I.2, page i5).

The lower extremities contain the largest muscle groups; therefore, soft tissue trauma of the legs may result in more extensive rhabdomyolysis and a higher incidence of crush syndrome than that of other areas of the body [69]. Consider that injury to trunk muscles such as the latissimus dorsi can cause rhabdomyolysis as well, e.g. when the victim is lying on a hard surface and unable to move.

However, crush syndrome can occur following minor injuries as well [20, 23, 61]; consider every patient extricated from rubble at risk. Monitor patients even with mild injuries and no apparent initial signs of crush for late signs of crush syndrome, i.e. decreased urine output, dark urine, signs and symptoms of uremia.

Section II.6: Fluid administration and urine volume monitoring early after extrication

II.6.A: Administer continuous fluids to all victims as soon as possible after extrication to prevent crush-related AKI; the preferred fluid is isotonic saline for reasons of efficacy and availability.

II.6.B: Evaluate hydration status of victims to determine the volume of fluids required. If no intravenous fluid was given prior to extrication, initiate intravenous isotonic saline at a rate of 1000 mL/h for adults (15–20 mL/kg/h for children) as soon as possible after rescue. Check the victim for a six hour period regularly while administering 3–6 L of fluid. Individualize volume of fluids considering demographic features, medical signs and symptoms, environmental and logistic factors. Evaluate urinary volume and hemodynamic status to determine further fluid administration.

II.6.C: Monitor urine output closely; ask conscious patients to void in a receptacle; use condom catheters in males if controlled voiding is impossible. When no urine flow is observed following appropriate fluid resuscitation, insert an indwelling bladder catheter after excluding urethral bleeding and/or laceration.

II.6.D: In case of established anuria, after hypovolemia is excluded and there is no urine response to fluid resuscitation, restrict all fluids to 500–1000 mL/day in addition to a volume equivalent to all measured or estimated fluid losses of the previous day.

II.6.E: In the case of urinary response to intravenous fluid administration (urine volume above 50 mL/h), restrict fluids to 3–6 L/day if victims cannot be monitored closely. In case of close follow-up, consider administering more fluids than 6 L/day.

Rationale

II.6.A: *Administer continuous fluids to all victims as soon as possible after extrication to prevent crush-related AKI; the preferred fluid is isotonic saline for reasons of efficacy and availability.*

Rhabdomyolysis-induced AKI results from a combination of factors including pre-renal (ischemic) injury, tubular obstruction, and nephrotoxicity. After extrication, large amounts of fluid can be lost through bleeding, fluid shifts (third spacing) or other routes. Consequently, a positive fluid balance is necessary to prevent both hypovolemic shock and AKI in crush victims [54].

In determining the type of fluid to be used, consider the following issues (Table 3).

1. Purpose: The first priority is volume resuscitation and repletion. Reducing intracompartmental pressures is also important. Systemic alkalinization as a means to reduce acidosis and hyperkalemia is a lower priority.

2. Choice of fluids:

a) Medical factors:

- *Isotonic saline* is effective for volume replacement and prevention of AKI; it is usually the most readily available solution and carries the lowest risk of side effects in the chaos of mass disasters; therefore, prefer it as the first option. Side effects include volume overload, hypertension, congestive heart failure and acidosis.

- If available, administer *isotonic saline solution + 5% dextrose*, which provides the advantage of supplying calories and attenuating hyperkalemia. Side effect profile of this solution is similar to that of isotonic saline.

- *Sodium bicarbonate,* added to *half-isotonic solutions*, may be effective for alkalinizing the urine in order to prevent the tubular deposition of myoglobin and uric acid, to correct metabolic acidosis, and to reduce hyperkalemia [50, 96]. Administer alkaline solution to all victims as the solution of choice in small-scale disasters, unless symptoms of alkalosis are present, e.g. the presence of neuromuscular irritability, somnolence or paresis. Complications of excessive alkalinization include the promotion of symptomatic alkalosis, calcium deposition in soft tissues, worsening of hypocalcemia, and volume overload.

- *Mannitol* has diuretic, antioxidant and vasodilatory effects and, because of its tonicity, decreases muscle intracompartmental pressure [97–99]. Mannitol may also be useful in crush casualties by expanding extracellular volume, increasing urine output and preventing renal tubular cast deposition [100]. However, considering its side effects (congestive heart failure in case of overdose, and potential nephrotoxicity) [101], as well as inconsistent reports of its efficacy in traumatic rhabdomyolysis [102] there is no consensus among the work group experts regarding mannitol administration, although most suggest assessing response to a test dose (see below). Mannitol is contra-indicated in anuric patients.

Table 3. Intravenous fluids that can be used in disaster crush victims.

	Solution (1000 ml)	HCO3 to be added	Mannitol to be added
Crystalloids	Isotonic saline	N/A	N/A
	Isotonic saline + 5% Dextrose	N/A	N/A
	Half-normal saline + bicarbonate	50 mmol to each litre	N/A
	Mannitol-alkaline solution[a] (Basal solution: Half-normal saline)	50 mmol to each litre	50 ml 20% mannitol to each litre
Colloids	Albumin[a]	N/A	N/A
	Hydroxyethyl starch (HES)[a]	N/A	N/A

[a]Although there was consensus among the work group members about the appropriateness of both saline and bicarbonate, there was none about mannitol, albumin and hydroxyethylstarch, because of no benefit (albumin, hydroxyethylstarch) or overt negative effects (mannitol) (see text below for more details).
Abbreviation: N/A, not applicable.

- *Colloids* can be used as initial management for expansion of intravascular volume in patients at risk of or with AKI. However, crystalloids are generally preferred over colloids for fluid resuscitation considering no major benefit of colloids on morbidity and mortality, a higher risk of side effects such as anaphylaxis or coagulation abnormalities, a risk of tubular injury at high doses (starch preparations), and higher costs (see also Section III.1.D, page i18) [103–109].

b) Logistic circumstances: Logistic circumstances are closely related to the dimensions of the disaster and the level of preparedness.

- For simplicity, consider plain isotonic saline as the ideal (and also, likely the only available) solution in the case of mass disasters.
- If resources are available and advance planning has been made, i.e. stores are available for immediate transport, there is enough medical personnel for rescue activities, and chaos or panic are not overwhelming, consider the use of more complex solutions, including dextrose and/or bicarbonate added to hypotonic saline. Preparation of combined solutions is, however, time consuming and carries the risk of contamination and errors in preparation in chaotic circumstances.
- Consider mannitol only if close monitoring is possible.

3. Application: Addition of bicarbonate to hypotonic solutions makes them almost isotonic. In rhabdomyolysis the average need for bicarbonate is 200–300 mmol/day.

If mannitol is to be used, 60 mL of 20% mannitol is given intravenously over 3–5 min as a test dose to determine urine response [98, 110]. If there is no significant increase in the urine output, do not continue mannitol. However, if urine output increases by at least 30–50 mL/h above baseline levels, add mannitol to the solutions mentioned above. The usual dosage of mannitol is 1–2 g/kg per day [total, 120 g/day] at a rate of 5 g/h [1].

II.6.B: *Evaluate hydration status of victims to determine the volume of fluids required. If no intravenous fluid was given prior to extrication, initiate intravenous isotonic saline at a rate of 1000 mL/h for adults (15–20 mL/kg/h for children) as soon as possible after rescue. Check the victim for a 6-h period regularly while administering 3–6 L of fluid. Individualize volume of fluids considering demographic features, medical signs and symptoms, environmental and logistic factors. Evaluate urinary volume and hemodynamic status to determine further fluid administration.*

Assess the volume status of each victim to determine the quantity of fluids required. Consider the following variables when evaluating volume status of a mass-disaster victim:

- Vital signs (i.e. blood pressure, pulse, heart rate, cardiac/pulmonary auscultation),
- Medical signs and symptoms (i.e. cold, moist, cyanotic or pale extremities, vomiting, unconsciousness limiting oral fluid intake, oliguria or anuria, dry axillae, decreased jugular venous pressure),
- Bleeding from wounds and third spacing in the extravascular compartments,
- Environmental factors (i.e. high ambient temperature causing excessive sweating),
- Logistic factors (chaos of the disaster and high patient load with limited number of health care personnel restricting adequate monitoring).

A clinically useful test, when the patient's condition permits, is the leg-raising test. If this maneuver results in an increase in pulse pressure or systolic blood pressure by more than 10%, consider the patient as fluid responsive [111]; in that case, he/she may benefit from fluid resuscitation.

When hypovolemia is present, assess the potential causes and initiate appropriate therapy. If present, control blood losses and, in case of severe anemia, start blood transfusion [112]. If no blood is available, administer any other intravenous fluids (Table 3), except potassium-containing solutions. Fatal hyperkalemia can occur in crush patients even without AKI; consequently, do not use potassium-containing solutions in patients with crush injury unless no alternative is available. Consider that blood transfusion may raise potassium, sometimes resulting in life-threatening hyperkalemia [113].

If victims did not receive intravenous fluids before rescue (inability to obtain access to a limb, inability to find a vein, unavailability of fluid or trained personnel), immediately initiate intravenous isotonic saline, preferably by means of 18 or 21 gauge needles, at a rate of 1000 mL/h for adult victims and 15–20 mL/kg/h for children (Figure 4).

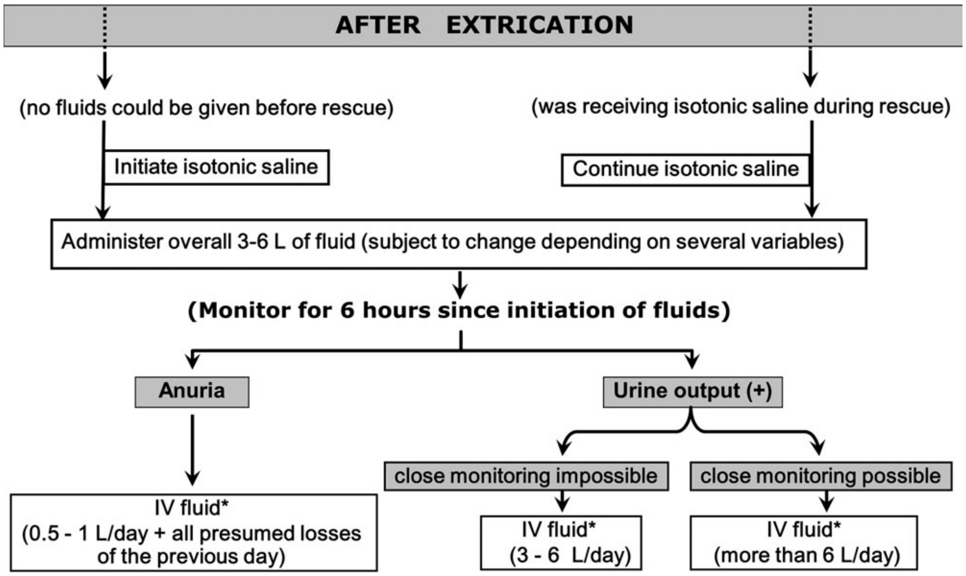

Figure 4. Algorithm for fluid resuscitation to prevent crush-related AKI in entrapped victims of mass disasters early after extrication.
Abbreviations: IV, intravenous; L, liters.
*IV fluid: for the fluid to be used see Section II.6.A. Isotonic saline is the first choice.

When peripheral venous access is impossible, consider intraosseous route or hypodermoclysis (see Section II.3.D, page i8). If the patient can drink, and abdominal trauma and imminent anesthesia have been excluded, fluids can be administered orally as well [114].

In small-scale disasters, when available, consider using half-normal saline + bicarbonate instead of isotonic saline both during and after extrication of the victim. Importantly, this solution can be useful in preventing acidosis and hyperkalemia, both of which contribute to rescue death (see Sections II.6.A, page i12 and III.1.D, page i18).

For the further planning of fluid administration evaluate hydration status of victim and monitor urinary output for 6 h, while administering overall 3–6 L of fluid. Thereafter re-evaluate the patients' condition to determine further strategy. Individualize volume of fluids considering demographic features, medical signs and symptoms, environmental and logistic factors.

II.6.C: *Monitor urine output closely; ask conscious patients to void in a receptacle; use condom catheters in males if controlled voiding is impossible. When no urine flow is observed following appropriate fluid resuscitation, insert an indwelling bladder catheter after excluding urethral bleeding and/or laceration.*

Maintaining high urine flow rate (above 50 mL/h) is the best way to prevent crush-related AKI. If adequate numbers of trained staff are available, calculate fluid balance, i.e. losses from urine, sweating, bleeding, vomiting as well as fluid administered and taken orally, to determine the ongoing fluid requirements. In comatose patients, consider wet diapers or sheets as a sign of urine production.

Insert an indwelling bladder catheter to follow urine flow. Take care to prevent urinary tract infection when placing the catheter in the presence of poor hygienic field conditions. Avoid this intervention in patients with urethral lacerations, which are characterized by blood at the meatus. In case of urinary retention in the bladder, and a contraindication of urethral catheterization, consider suprapubic catheter placement.

Remove urethral catheters after 48 h, or as soon as they offer no more useful information, e.g. if a patient is definitely anuric or if there is clear-cut and stable urine production in a conscious patient able to void.

II.6.D: *In case of established anuria, after hypovolemia is excluded and there is no urine response to fluid resuscitation, restrict all fluids to 500–1000 mL/day in addition to a volume equivalent to all measured or estimated fluid losses of the previous day.*

If a patient remains anuric, consider further fluid loading. In this case, take into account two possibilities: (a) the patient still may be volume depleted and could be fluid responsive and (b) he/she may already suffer from established AKI, and energetic fluid administration carries the risk of hypervolemia. Make final decision considering environmental factors, demographic features and clinical findings. Always consider that fluid resuscitation may be harmful if it is started too late. In the Marmara earthquake, crush victims who needed dialysis support received more fluids as compared to the nondialyzed ones [115]. This was likely because in the victims with already established AKI, aggressive fluid administration resulted in hypervolemia and a higher need for dialysis. In fact one of the most frequent indications for dialysis was hypervolemia [12].

If anuria persists despite adequate volume resuscitation, consider the possibility of acute tubular necrosis; in this case, there is risk of volume overload and related complications if uncontrolled volume resuscitation is continued [116]. In such patients, administer isotonic saline with or without glucose at a maximum of 500–1000 mL/day, in addition to the estimated fluid losses of the previous day.

If available, half-normal saline + bicarbonate can be used to reduce the risk of hyperkalemia and acidosis. Restrict oral potassium and fluid intake as well.

II.6.E: *In the case of urinary response to intravenous fluid administration (urine volume above 50 mL/h), restrict fluids to 3–6 L/day if victims cannot be monitored closely. In case of close follow-up, consider administering more fluids than 6 L/day.*

In the case of urinary response to intravenous (and if the patient is drinking, to oral) fluid administration (urine volume above 50 mL/h), consider local circumstances for further fluid policy. If there is no possibility of close monitoring, continue isotonic saline, at a maximum of 3–6 L/day. Individualize this volume of fluids considering clinical and logistic conditions; i.e. age, body weight, trauma pattern, ambient temperature, extent of urine output, presumed fluid losses and monitoring possibilities (Figure 4).

If close clinical monitoring is possible, administer fluids more than 6 L/day, even up to 12 L/day in an adult with documented appropriate urinary response. In general, up to 8 L of urinary output can be expected for 12 L of fluid administration, because of sequestration of fluid in injured tissues and extra-renal losses [54]. Volumes described above are for a body weight of 70 kg; add or subtract 0.5 L for every 5 kg above or below this weight. Individualize the final volume based on ongoing assessment of volume status; always consider that elderly and children are more prone to volume overload than adults.

If possible, use half-isotonic saline + bicarbonate solution at this stage as well. Do not continue to administer intravenous fluid, if patients are capable of taking fluid orally.

In general, fluids can be administered more liberally in victims rescued during the first days of the disaster [51], while a more conservative approach is justified for victims rescued at a later phase, since risk of established acute tubular necrosis (ATN) (with oliguria) is higher in the latter [115].

Continue this intensive fluid protocol until myoglobinuria disappears (practically until normalization of the urinary color), which usually occurs within 2–3 days following trauma, if AKI has successfully been prevented [54].

Administration of so-called vasodilator or renal doses of dopamine [117–119] or diuretics [120], for the prophylaxis or treatment of AKI has not been shown to improve outcome and even may cause life-threatening complications [121].

Use loop diuretics with caution as, theoretically, they may increase the risk of cast formation in crush syndrome by acidifying the urine and worsen already existing hypocalcemia by inducing hypercalciuria [16, 122]. Judicious use of loop diuretics, however, may be justified, in volume overloaded victims.

Section II.7: Other measures to be taken after extrication

II.7.A: Treat additional problems, either related or unrelated to AKI, which include, but are not limited to airway obstruction, respiratory distress, pain, hypotension, hypertension, myocardial ischemia and infarction, cardiac failure, fractures and contaminated wounds.

II.7.B: Diagnose and treat hyperkalemia as early as possible.

II.7.C: Once stabilized, prepare the patient for transport to a hospital at the earliest convenience.

II.7.D: If patients are sent home early due to shortage of hospital beds, instruct them to check the color and volume of their urine daily at least for the next 3 days, and to seek immediate medical advice if signs suggesting crush syndrome such as oliguria, dark-colored urine, edema or nausea are noted.

Rationale

II.7.A. *Treat additional problems, either related or unrelated to AKI, which include, but are not limited to, airway obstruction, respiratory distress, pain, hypotension, hypertension, myocardial ischemia and infarction, cardiac failure, fractures and contaminated wounds.*

Patients with crush injuries may suffer from many additional problems, some of which may be life-threatening. Appropriate treatment is mandatory at the disaster field, before transportation. Such problems include, but are not limited to, airway obstruction, pain, hypotension, hypertension, myocardial ischemia and infarction, left ventricular failure, fractures and contaminated wounds. Management of some of these complications is summarized in Table 4.

II.7.B: *Diagnose and treat hyperkalemia as early as possible.*

In crush victims, fatal hyperkalemia may occur at any time even in the absence of renal failure; the risk is even higher in male victims [129]. Most of these cases are overlooked, and patients die from hyperkalemia at the disaster scene, field hospitals, during transportation, or shortly after admission to hospitals. Since biochemical evaluation is difficult at the disaster scene, other diagnostic tools are necessary. Portable electrocardiography (ECG) devices have been used for this purpose, although specificity and sensitivity of ECG findings in the case of hyperkalemia have been questioned (see also Section III.2.C, page i20; Figure 5 and Table 7, page i21) [130, 131]. In the 2010 Haiti earthquake, point-of-care devices (e.g. iSTAT^{R}, Abbott, USA) were invaluable in disaster field conditions providing direct electrolyte and creatinine measurements [132]. Use these devices or ECG for the early detection of hyperkalemia.

For the treatment / prevention of hyperkalemia in disaster field conditions apply potassium binding resins [i.e. Na^{+} or Ca^{++} polystyrene sulfonate (kayexalate)] and transfer the patients as soon as possible for dialysis. Prefer Na^{+}kayexalate over Ca^{++}kayexalate, because the latter can contribute to pronounced hypercalcemia at a later stage. Side effects of kayexalate include nausea, vomiting,

Table 4. Treatment of life-threatening or serious complications at the disaster field in the crush victims of mass disasters [12, 46, 123–128]

Complication	Treatment	Comments
Airway obstruction	- Jaw thrust, Mayo cannula providing free airway, aspiration of secretions, administration of oxygen, tracheal intubation (if possible)	- Should be considered as first-line measures because of their life-saving capacity. - Transport to a hospital as early as possible.
Pain	- Narcotics, ketamine	- Morphine should be given IV since the response to IM morphine is unpredictable. - Nonsteroidal anti-inflammatory agents should not be used for analgesia.
Hypotension	- Administration of I.V. fluids, transfusion of blood or blood products - Treatment of ischemic heart disease, electrolyte abnormalities and infection(s)	- Active bleeding should be stopped by any means. - Need for fluids may be high in crush cases because of sequestration in the tissues.
Hypertension	- Calcium antagonists and nitrates - Diuretics in victims with urine production	- Excessive fluid administration is to be avoided in oligoanuric victims. - Psychologic support can be helpful in patients with severe stress.
Myocardial ischemia and infarction	- Relief of pain, treatment of hypertension and anxiety, administration of short acting nitrates, oxygen inhalation	- Transport to a hospital as early as possible.
Left ventricular failure	- Short acting nitrates, diuretics, oxygen	- Patients should be placed in a sitting position. - Transport to a hospital as early as possible. - Application of intermittent venous tourniquets may be useful.

Abbreviations: IV, intravenous; IM, intramuscular.

hypokalemia and rarely intestinal necrosis (see also Section III.2.D, page i21, and Table 8, page i22).

II.7.C: *Once stabilized, prepare the patient for transport to a hospital at the earliest convenience.*

Once stabilized, transport the patient to a hospital as soon as possible. Take into account time that will be spent for performing minor procedures such as splinting of minor fractures and bandaging of wounds against the advantages of transporting the patient to a functional hospital immediately. If transport times are short, avoid prolongation of field or field hospital stay. However, if transportation will be delayed, patients will benefit from bandaging and splinting of minor wounds, since these are important for comfort and safety. During transport, take measures for full spinal immobilization for patients with spinal trauma.

Transfer the victims to 'victim collection points' or 'disaster medical aid centers' [36], and thereafter to field or conventional hospitals at the earliest convenience to initiate appropriate therapeutic interventions (see Section I.2, page i5). In major disaster conditions, however, transportation may not always be possible [34, 71], necessitating institution of therapy on-site in spite of limited resources until victims can be transferred or more effective intervention becomes available.

II.7.D: *If patients are sent home early due to shortage of hospital beds, instruct them to check the color and volume of their urine daily at least for the next 3 days, and to seek immediate medical advice if signs suggesting crush syndrome such as oliguria, dark-colored urine, edema or nausea are noted.*

Crush syndrome may develop irrespective of the severity of trauma, and even mildly injured victims are at risk [20, 23]. In many disasters limitation of hospital beds is a reality and mildly injured patients are sent home or to shelters. Instruct these individuals to watch the color and the volume of their urine daily for at least 3 days, and to seek medical care as soon as possible if symptoms of AKI such as weight gain, edema, dyspnea and nausea are noted.

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Section III: Interventions on Admission to Hospital

Section III.1: General approach to all victims at the time of admission

Section III.2: Specific approach to crush syndrome patients at the time of admission

Section III.1: General approach to all victims at the time of admission

III.1.A: Triage victims to the appropriate treatment zone.

III.1.B: Follow accepted trauma and AKI guidelines for management of crush patients.

III.1.C: Evaluate fluid status by physical examination. Consider that, if available, absolute values for central venous pressure (CVP) are not useful, while relative changes may better reflect body fluid status.

III.1.D: In hypovolemic victims, identify and treat the underlying cause(s); prefer crystalloids over colloids.

III.1.E: Assume all open wounds are contaminated. Consider surgical debridement in addition to antibiotics in the presence of necrosis or significant infection. Obtain cultures prior to initiation of antibiotics. Administer tetanus toxoid to all patients with open wounds, unless in those who have definitely been vaccinated within the last 5 years.

III.1.F: Correct hypothermia, if present.

III.1.G: Keep patient records for medical, social and legal reasons.

Rationale

III.1.A: *Triage victims to the appropriate treatment zone.*

Triage affects not only the immediate, but also the final outcome of victims. It is therefore vital to direct victims to the appropriate hospital service and site for optimal treatment.

To accomplish triage at hospital admission, designate specific sections close to the patient receiving areas. Identify five primary victim receiving areas by color-coded tags, according to severity of injury and medical status of the victims [133]:

(1) *Red zone,* reserved for life-threatening, but potentially curable conditions.
(2) *Yellow zone*, designated for less serious, but still urgent problems.
(3) *Green zone,* for patients with mild conditions who are able to walk.
(4) *Gray zone,* where terminal patients are observed and kept comfortable.
(5) *Black zone*, reserved for those dead on arrival.

Repeat triage at hourly intervals, and move victims to the proper triage zone with changing clinical condition.

III.1.B: *Follow accepted trauma and AKI guidelines for management of crush patients.*

Follow accepted trauma guidelines for medical and logistic management of disaster victims [79,134] (see also Appendix, page i49).

1. Conduct a primary survey [79].
2. Start resuscitation immediately if a life-threatening condition (such as shock or asphyxia) is present. Examine patients rapidly in cases of severe penetrating or blunt trauma. Treat emergencies by any means available; i.e. stop major external bleeding by applying direct pressure on the bleeding site, try stapling or suturing, and initiate blood transfusion in the victims with severe anemia or evidence of severe blood loss. However, always consider that blood transfusion is a temporary measure, and mostly a surgical procedure is needed to stop bleeding in a hypotensive crush syndrome patient.

   Indications for transfusion are not clear-cut; in critically ill patients with hemodynamically stable anemia, a 'restrictive' strategy of red blood cell transfusion (transfuse when Hb is <7 g/dL) may be as effective as a 'liberal' transfusion strategy (transfuse when Hb is <10 g/dL) with the exception of patients with acute myocardial infarction or unstable myocardial ischemia in whom a 'liberal' strategy is suggested [112, 135]. If no blood or blood products are available, and if hypotension is present, use crystalloids or colloids as an alternative (Table 3).
3. Obtain a brief history either from the victim or any accompanying person. Attempt to determine the identity of each victim, their address, location where the trauma occurred, the timing of rescue, the time spent under the rubble, therapeutic intervention(s) administered before admission, pregnancy, allergies and medications taken, and any prior or existing comorbidity.
4. Draw blood for laboratory tests, including blood group determination, hemoglobin, white blood cell count,

serum urea, creatinine, creatine phosphokinase (CK) and electrolytes and determination of blood gases (venous blood sample is sufficient). Weigh time spent performing these tests against the number of victims needing simultaneous treatment, especially considering those with clinical suspicion of severe blood loss or crush syndrome. Hence, draw blood only if you have time or there is enough support for sample collection and assessment and implementation of the therapeutic consequences; otherwise neglect it.

5. For victims who were not treated effectively at the disaster field initiate an intravenous fluid challenge (Table 3, Figure 4). Although colloids or crystalloids can be used for this purpose, crystalloids are always preferred (see below).

Administer crystalloid infusions at 15–20 mL/kg/h in children and adults (10 mL/kg/h in elderly victims), adjusting the rate as indicated by vital signs and urine output [46, 136].

Although hypotonic or hypertonic crystalloids may be used in specific clinical circumstances, the choice of non-isotonic solutions is generally dictated by considerations other than intravascular volume expansion (for example, hypernatremia or hyponatremia) [109].

III.1.C: *Evaluate fluid status by physical examination. Consider that, if available, absolute values for central venous pressure (CVP) are not useful, while relative changes may better reflect body fluid status.*

Hypovolemia is common in trauma victims due to bleeding, shock, compartmental fluid shifts (third spacing) and sweating. Hypoperfusion results in dysfunction of all visceral organs, especially the kidneys; therefore, correct hypovolemia promptly.

Physical examination to assess fluid status is of limited value, but should always be performed. Thirst, dry mucosal membranes, impaired capillary refill time, dry axillae, furrowed tongue, decreased skin turgor over the forehead and sternum, increased heart rate, decreased blood pressure, orthostatic hypotension, and rise of blood pressure (or changes in arterial pressure wave form) with passive leg raising may all indicate fluid loss or sequestration [109, 137, 138].

Although frequently used to determine volume status, CVP measurements can be misleading and often do not predict the response to volume infusion, especially in critically ill patients [139]. Absolute values are increased not only in hypervolemia, but also in disease states, such as cardiac failure, while relative changes may be more useful than absolute values in reflecting intravascular volume status [111, 140].

III.1.D: *In hypovolemic victims, identify and treat the underlying cause(s); prefer crystalloids over colloids.*

After identifying the underlying cause(s) initiate appropriate fluid replacement. Individualize replacement solutions guided by clinical findings such as skin turgor, edema, blood pressure measurements, or laboratory data (serum sodium, potassium and bicarbonate) and take into account the following properties of fluids.

- *Isotonic saline* is preferred for hypotensive victims. It distributes throughout the extracellular compartment, of which in healthy subjects 25% is intravascular and 75% interstitial. Therefore, approximately one-fourth of the infused volume remains intravascular [141]. In addition, isotonic saline is inexpensive, readily available and safe. However, large volumes of saline may cause hyperchloremic metabolic acidosis.
- *Half-isotonic (*or *hypotonic) (0.45%) saline* can be used in victims with only mild volume depletion and in cases of hypernatremia, in whom free water deficit exists. However, the restoration of intravascular volume is less effective compared with isotonic solutions. Hypotonic 5% dextrose in water can also be used in hypernatremic patients, again with limited efficacy in volume restoration.
- *Colloid solutions (albumin, hydroxyethyl starch, gelatins, dextrans)* contain oncotically active molecules which should, in theory, retain water in the vascular compartment. However, colloids are best avoided because:

a). At least in some studies in ICU patients, albumin [103] or colloid HES [105] revealed no major benefit over crystalloids. A Cochrane review concluded that there is no evidence from randomized controlled trials (RCTs) that resuscitation with colloids, instead of crystalloids, reduces the risk of death in patients with trauma, burns or following surgery [108].

b). Colloids have a higher risk of side effects such as anaphylaxis or coagulation abnormalities as well as AKI at high doses [106, 107] or even an increased risk of death [142, 143].

c). Colloids are more expensive and less likely to be available in disaster circumstances.

KDIGO AKI guidelines recommend crystalloid fluid resuscitation to prevent AKI for all hypotensive or hypovolemic patients [109].

III.1.E: *Assume all open wounds are contaminated. Consider surgical debridement in addition to antibiotics in the presence of necrosis or significant infection. Obtain cultures prior to initiation of antibiotics. Administer tetanus toxoid to all patients with open wounds, unless in those who have definitely been vaccinated within the last 5 years.*

Following earthquakes, soft tissue injury is caused by structural collapse and debris; hence wounds are always dirty. Therefore, wash dirty wounds with water and a bactericidal soap. Afterwards, gently irrigate with sterile water and cover with a simple clean dressing. Do not pour antibacterial agents like betadine on the wound.

If possible, try to perform extensive debridement of tissue including muscle and bone, and regularly recheck the wound for 24–48 h after the first debridement, because clear differentiation between necrotic and viable tissue can be difficult at the first procedure [134].

Treatment delay is common, increasing the likelihood of open wounds becoming contaminated with Gram-positive, Gram-negative and anaerobic bacteria, especially Clostridium spp, including *Clostridium tetani* (Table 5).

Since the most frequent pathogens in crush wounds are streptococci, staphylococci and anaerobic organisms, β-lactam/β-lactamase inhibitors are the preferred agents for empirical treatment.

Cultures are best obtained before the start of antibiotic therapy; however, consider that they may be negative even in case of infection, especially (for culture of content of wounds) if local antiseptics have been applied prior in the same area. On the other hand, do not delay treatment if cultures cannot be taken.

In ideal circumstances, follow the CDC guidelines for prophylaxis of tetanus. Always consider that the best protection against tetanus is cleaning the wound of debris and proper surgical debridement of dead tissue.

To decide upon tetanus prophylaxis, an accurate and immediately available history regarding previous active immunization against tetanus is required [134, 144]. Immunization in adults requires at least three injections of toxoid. A routine booster of adsorbed toxoid is indicated every 10 years thereafter. In children under seven, immunization requires four injections of toxoid. Thereafter a routine booster of tetanus is indicated at 10-year intervals [134].

In the injured victims of mass disasters, consider the following issues (Table 6):

I. Previously immunized individuals, i.e. for patients who have been previously fully immunized and the last dose of tetanus toxoid was given within 10 years:

a. For non-tetanus-prone wounds: no booster required.

b. For tetanus-prone wounds (Table 5) and if more than 5 years have elapsed since the last dose, give 0.5 mL of adsorbed toxoid intramuscularly.

II. Individuals NOT adequately immunized i.e. patients having received less than three prior injections of toxoid with an interval since the previous injection of more than 10 years for non-tetanus-prone wounds or of more than 5 years for tetanus-prone wounds (Table 5), or with unknown immunization history.

a. For non-tetanus-prone wounds, give intramuscularly 0.5 mL of adsorbed toxoid.

b. For tetanus-prone wounds:

i. Give 0.5 mL adsorbed toxoid.

ii. Give 250 units of human tetanus immune globulin (500 units for wounds that are heavily contaminated or have been caused more than 12 h before, or in patients weighing more than 90 kg) intramuscularly or intravenously (depending on the specific preparation that is to be injected).

iii. Consider providing antibiotics, although the effectiveness of antibiotics for prophylaxis of tetanus remains unproven.

iv. Use different syringes and sites of injection for toxoid, immune globulin and antibiotics.

v. Administer tetanus toxoid boosters after 2 and 6 months to allow full immunization.

In children and adolescents, administer toxoid together with diphtheria toxoid (Td) as a double antigen or together with both diphtheria and pertussis toxoid (Tdap) as a triple antigen.

On the other hand, with severely injured patients, questioning about the last tetanus dose may be impossible; therefore, give a booster dose of toxoid to all such victims. The preparation (T, TD, DPT) is not critical, use whichever is available.

III.1.F: *Correct hypothermia, if present.*

Hypothermia is defined as a core temperature below 35°C (95°F), and classified as mild [32–35°C (90–95°F)], moderate [28–32°C (82–90°F)] or severe [below 28°C (82°F)] [145]. Clinical signs of hypothermia include tachypnea, hyperventilation, hypotension, arrhythmias (tachycardia, atrial fibrillation, sinus bradycardia, ventricular tachycardia, ventricular fibrillation), coagulation abnormalities and neurological symptoms, including areflexia and coma. In trauma patients, a core temperature (measured by a rectal thermometer) less than 32°C is associated with a very high mortality, and any decrease in temperature below 35°C is a poor prognostic sign [146]. Hypothermia can occur in disaster victims, especially if they were subjected to low ambient temperatures. Since standard oral thermometers do not read below 34°C (93°F), where available, use a low-reading core thermometer, if hypothermia is suspected. If a low-reading core thermometer is not available, the lowest reading on the oral thermometer should be taken to mean hypothermia.

Avoid hypothermia in the extraction phase with space blankets, if available. After extrication, treat hypothermia as an emergency; remove wet clothes, infuse warmed crystalloids (42°C or 108°F) and perform external warming

Table 5. Features of wounds that carry high risk for tetanus

Clinical feature	High risk
Lag time since trauma	More than 6 h
Type of wound	Open wounds with irregular borders
Depth	More than 1 cm
Evidence of infection	If present
Necrotic tissue	If present
Foreign bodies	If present
Ischemic tissue	If present

Table 6. Tetanus prophylaxis protocol [144]

Previous doses of adsorbed tetanus toxoid	Clean and minor wound		All other wounds[a]	
	Tetanus toxoid	*TIG*	*Tetanus toxoid*	*TIG*
Uncertain or <3 doses	Yes[c]	No	Yes[c]	Yes[b]
3 or more doses	Only if last dose given ≥10 years ago	No	Only if last dose given ≥5 years ago	No

[a] Such as, but not limited to, wounds contaminated with dirt, feces, soil, or saliva; puncture wounds; avulsions; wounds resulting from missiles, crushing, burns, or frostbite.
[b] 250 units intramuscularly at a different site than tetanus toxoid; intravenous immune globulin should be administered if TIG is not available.
[c] The vaccine series should be continued until completion as necessary. (Adapted from [144], with permission)
Abbreviation: TIG, tetanus immune globulin.

(e.g. by placing blankets below and above the patient), dialysis, and ventilation with warmed air or oxygen [147, 148]. However, always consider that what really warms the hypothermic patients is their own metabolism; therefore, minimize additional heat loss by any means.

III.1.G: *Keep patient records for medical, social and legal reasons.*

In the overwhelming chaos after mass disasters, many victims are transported to hospitals by public vehicles unaccompanied by family members or acquaintances. Nevertheless, establishing the identity and medical history of the victim is essential, not only for proper therapy, but also for social and legal reasons. If possible, take photographs of deceased victims for the record.

Document medical status, physical findings and all interventions that have been performed already. If possible, obtain assistance from medical students, nurses or any other available health personnel to accomplish this. Consider placing arm or wrist bands or labels on patients containing essential medical information.

Section III.2: Specific approach to crush syndrome patients at the time of admission

III.2.A: Follow all disaster victims, even those with mild injuries, for signs and symptoms of crush syndrome.

III.2.B: Check all fluid infusions. Avoid potassium-containing solutions.

III.2.C: Determine serum potassium levels as soon as possible. Where laboratory facilities are not available or when laboratory test performance will be delayed, use a point-of-care device (e.g. iSTAT®) or perform an electrocardiogram to detect hyperkalemia.

III.2.D: Treat hyperkalemia immediately and take urgent measures followed by more definitive second-line interventions. 1) Urgent measures are: calcium gluconate, glucose-insulin infusion, sodium bicarbonate and β-2 agonists. 2) Second-line measures are: dialysis and kayexalate.

III.2.E: After excluding urethral bleeding and/or laceration, insert a bladder catheter to all crush victims to follow urine flow. Unless otherwise indicated, remove the catheter once the patient has established oligoanuric AKI or recovers normal kidney function.

III.2.F: Perform a urinalysis by dipstick testing. If possible, examine urinary sediment.

III.2.G: If oliguric victims are volume overloaded, restrict fluid administration and initiate ultrafiltration with or without dialysis, depending on individual needs.

III.2.H: Treat co-existing emergencies such as acidosis, alkalosis, symptomatic hypocalcemia and infections.

Rationale

III.2.A: *Follow all disaster victims, even those with mild injuries, for signs and symptoms of crush syndrome.*

Crush syndrome mostly occurs after trauma to large muscle groups, especially in the lower extremities. However, minor injuries to the upper extremities can also result in crush syndrome; therefore, consider all disaster victims to be at increased risk [12, 20]. The presence of oliguria, dark-brownish discoloration of the urine, hypertension, edema, dyspnea, nausea and vomiting suggest crush-related AKI. Assess changes in the circumference of traumatized extremities regularly as one of the first signs of crush syndrome is the occurrence of compartment syndrome.

Perform a careful physical examination since it may provide hints of the ultimate prognosis. In the Kobe earthquake crush victims, four factors (tachycardia $\geq$120/min, presence of abnormal urine color, white blood cell count $\geq$18.000/mm^3 and hyperkalemia $\geq$5 mmol/L) were significant predictors of severe or fatal crush syndrome in a medical facility [83].

III.2.B: *Check all fluid infusions. Avoid potassium-containing solutions.*

In many victims fluid administration is initiated in the field or during transportation; but contrary to recommendations, these solutions may contain potassium. In the Marmara earthquake, 10% of the victims with renal injury were receiving potassium-containing solutions on admission to hospital, which significantly increased the risk of life-threatening hyperkalemia [12, 149]. Therefore, check the type of fluid on admission and replace potassium-containing solutions immediately.

If no fluids were given, initiate intravenous isotonic or half-isotonic saline depending on the patient's clinical status; if available, add bicarbonate to this solution (see Section II.6.A, page i12; Table 3, page i13).

III.2.C: *Determine serum potassium levels as soon as possible. Where laboratory facilities are not available or when laboratory test performance will be delayed, use a point-of-care device (e.g. iSTAT®) or perform an electrocardiogram to detect hyperkalemia.*

In crush victims, fatal hyperkalemia may occur in the absence of renal failure and can emerge at any time. The most reliable, accurate and least labor-intensive approach to estimate serum potassium is biochemical evaluation. Always rule out spurious hyperkalemia due to non-free flow sampling, erythrocytosis and long waiting time for blood samples to be centrifuged or measured. If available, use a point-of-care device (e.g. iSTAT®) or blood gas analysis devices if classical laboratory approaches are not possible or will be delayed [150].

If urgent biochemical evaluation is impossible, electrocardiography (ECG) is the most useful alternative tool for detecting signs of hyperkalemia (Figure 5, Table 7).

ECG changes (high, sharp and narrow T-waves, loss of P-waves, pseudo-infarction patterns, bundle branch blocks, significant bradycardia or atrioventricular dissociation, loss of P-QRS relationship, widening of the QRS complexes

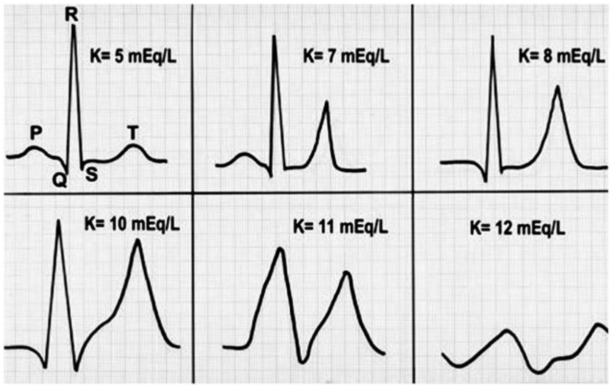

Figure 5. Electrocardiographic findings in hyperkalemia. The profiles are schematized; the potassium levels are only estimates (adapted from [12] with permission). These ECG changes are only indicative and not specific for hyperkalemia; similar changes may occur at different levels of hyperkalemia.

Table 7. Electrocardiographic findings at various stages of hyperkalemia

Serum potassium level	ECG findings
6-7 mEq/L	High, sharp and narrow T waves
8 mEq/L	Loss of P waves or loss of P – QRS relationship
10 mEq/L	Wide, aberrant QRS complexes
11 mEq/L	Biphasic deflections (merging of QRS-ST-T waves)
12 mEq/L	Ventricular fibrillation or cardiac standstill

and/or biphasic deflections) are only a rough indicator of serum potassium levels. All these findings disappear after correction of hyperkalemia [131, 152].

Absence of ECG abnormalities does not exclude hyperkalemia. Also, ECG changes associated with hyperkalemia are not always specific: peaked T-waves may be observed in healthy individuals, myocardial infarction, intracranial bleeding, myocardial rupture and hemopericardium [130, 131]. In chaotic and emergency conditions, however, treat these findings as hyperkalemia until proven otherwise. Confirm potassium levels by blood tests as soon as possible.

If there is any finding suggestive of hyperkalemia, initiate empiric antihyperkalemic treatment without waiting for the laboratory results (Table 8).

III.2.D: *Treat hyperkalemia immediately and take urgent measures followed by more definitive second-line interventions. 1) Urgent measures are: calcium gluconate, glucose-insulin infusion, sodium bicarbonate and β-2 agonists. 2) Second-line measures are: dialysis and kayexalate.*

The treatment of hyperkalemia depends on its severity and the interval between detection and initiation of treatment. Treat serious hyperkalemia (>7 mmol/L) immediately by administering intravenous calcium gluconate, glucose–insulin infusions, and sodium bicarbonate or inhalation of β-2 agonists. Consider that the efficacy of bicarbonate in decreasing serum potassium in the absence of acidosis or urine output has been questioned (Table 8) [153, 154].

The beneficial effects of most, if not all, of these immediate measures are temporary and hyperkalemia may recur after the intervention. Thus, do not preclude the subsequent initiation of dialysis, which is the most effective treatment of hyperkalemia. Because of the lag time until the start of dialysis, use the other options whenever urgent correction of hyperkalemia is needed.

Hemodialysis can remove about 80–140 mmol of potassium per session, depending on the initial serum potassium concentration, dialysis adequacy and the potassium concentration of the dialysate [155]. Plasma potassium falls by 1–1.3 mmol/L in the first 60 min of hemodialysis and a total of 2 mmol/L by 180 min, after which it tends to level off [154, 156]. Dialysis with potassium dialysate below 2 mmol/L is more efficient in treating hyperkalemia; however, this approach carries the potential of inducing cardiac arrhythmias in cases of rapid decline of serum potassium [154, 157]. This can be avoided by a stepwise decrease of dialysate potassium. Another option is long-lasting dialysis sessions with 2 mmol/L potassium bath; however, this may not be applicable in mass disasters due to the number of patients in need of the limited dialysis facilities.

Potassium rebound always occurs after dialysis, with 35% of the reduction being abolished after an hour and nearly 70% after 6 h [158]; therefore, continued monitoring of serum potassium is essential after dialysis.

Because of its low clearance rates, peritoneal dialysis (PD) is not a first option to treat hyperkalemia. However, if it is the only available modality, perform frequent PD exchanges simultaneously with other antihyperkalemic therapies [159].

Prescribe a low potassium diet and oral kayexalate in hyperkalemia-prone crush victims. Although the efficacy of kayexalate has been questioned [160], considering the high risk of life-threatening fatal hyperkalemia, the work group recommends its use in disaster crush victims.

Kayexalate prevents intestinal absorption of dietary potassium; each gram of this resin removes approximately 1 mmol of potassium ion even if there is no food intake. Its effect starts within 2–6 h of oral administration [155]. Oral daily dosage varies between 15 and 60 g, combined with 1/3 of this dose of sorbitol to prevent constipation. As an alternative osmotic laxative to sorbitol, administer macrogol (polyethylene glycol) (Movicol®, Miralax®, GoLYTELY®) to avoid toxic effects of sorbitol on the intestinal epithelium.

If oral kayexalate causes nausea or vomiting, or if oral administration is contraindicated or impossible, use a retention rectal enema (Table 8) [154]. Avoid kayexalate enemas in case of ileus or following abdominal surgery, since this drug has been associated with bowel perforations.

III.2.E: *After excluding urethral bleeding and/or laceration, insert a bladder catheter to all crush victims to follow urine flow. Unless otherwise indicated, remove the catheter once the patient has established oligoanuric AKI or recovers normal kidney function.*

An indwelling urinary catheter allows accurate measurement of hourly urine output, a parameter useful to

Table 8. Treatment of hyperkalemia in crush syndrome victims [123, 155, 164–167][a]

Intervention	Start / duration of the effect	Mode of action	Intervention	Comments
Calcium gluconate (10%)	1–2 min / 1–2 h	- Restores membrane excitability of the myocardium.	- 10 mL of 10% solution, IV, within 2–3 min. - Infusion to be discontinued when clinical signs of hyperkalemia disappear.	- Should be used only in the presence of life-threatening arrhythmia. - Close monitoring with ECG is necessary during injection. - Contraindicated (or to be used very cautiously) in patients on digitalis or related compounds. - Calcium might be stored in the traumatized muscles, which may contribute to hypercalcemia during recovery phase. - May cause tissue necrosis in case of extravasation.
Sodium bicarbonate (8.4%)	0.5–1 h / 1–2 h	- Corrects acidosis. - Drives potassium into the cell.	- 50 mL of 8.4% $NaHCO_3$ diluted in 50–100 mL of 5% dextrose or 0.45 % NaCl to be administered IV within 0.5–1 h.	- Can lead to volume overload and enhance hypocalcemic symptoms. - May be combined with dextrose-insulin solutions. - There are concerns regarding efficacy in the short term.
Insulin and dextrose	1 h / 4–6 h	- Drives potassium into the cell.	- 25 U (10 U in case of renal failure) of regular insulin in 500 mL of 20% dextrose administered IV at a rate of 250 mL/h.	- May be ineffective in crush victims, because potassium shift into injured muscle cells is limited. - Hypertonic dextrose should be administered into a central vein. - When this infusion is stopped, it should be followed by 5% dextrose administration without insulin to prevent hypoglycemia.
Beta-2 adrenergic agonists (Salbutamol; albuterol)	0.5–1 h / 2–4 h	- Drives potassium into the cell.	- 10– 20 mg administered by nebulizer in 4 mL of saline over 10 min, or 0.5 mg IV.	- Can lead to tachycardia, cardiac arrhythmia or angina pectoris. - May be risky in patients with active coronary heart disease. - May be risky in patients who have arrhythmia.
Hemodialysis	0.5 h / 5–6 h	- Eliminates potassium from the body by dialysis.	Applied by a dialysis team.	- The most effective treatment modality. - Can be performed several times during the same day, if indicated. - Necessitates anticoagulation and creation of a vascular access. - Rebound hyperkalemia post-dialysis should be monitored.
Kayexalate (oral, enema)	2–6 h /	- Eliminates potassium from the body by stools.	- *Oral:* 15–60 g mixed with 5–20 g sorbitol in water. - *Enema:* 30–50 g of resin is mixed with 10–18 g sorbitol and 150–200 mL of tap water; then given into the rectum by a Foley catheter. By inflating the catheter balloon, the (retention) enema is left in the rectum for 2–3 h. Before the catheter is taken out, the colon is irrigated with a non sodium-containing solution.	- Oral doses can be repeated every 4-6 h; enemas can be repeated every 2–4 h, if necessary. - Effect of enemas is faster, however less pronounced than with oral kayexalate. - Each enema can lower serum potassium, by about 0.5–1 mmol/L. - Efficacy has been questioned recently. - Infrequent but serious toxicity. - Not an ideal treatment in the case of rapidly rising serum potassium.

[a]The result of the treatment should be checked by frequent biochemical control, or if the latter is not available, by frequent ECG monitoring.
Abbreviations: h, hour; min, minute; IV, intravenously; ECG, electrocardiography.

monitor the initial response to fluid resuscitation until the intravascular volume is adequately restored. Catheters carry a risk of infection, especially in the chaos accompanying most disasters [161]. Therefore, unless there is an obligatory indication such as unconsciousness, pelvic trauma, possible urethral obstruction, immobilization or surgery, remove the catheter once the patient has established oligoanuric AKI or achieves normal kidney function and monitoring urine production provides no further useful information.

III.2.F: *Perform a urinalysis by dipstick testing. If possible, examine urinary sediment.*

Routine dipstick testing and microscopic analysis of urine are helpful in determining the cause of AKI.

- A normal urinalysis in the setting of AKI suggests a pre- or post-renal cause and an abnormal urinalysis indicates a 'renal' cause.
- Lack of urinary red cells, despite a positive dipstick reaction for blood, is typical of AKI induced by myoglobinuria or hemoglobinuria [162].
- A high specific gravity and a low urine sodium favor prerenal azotemia. Rhabdomyolysis-induced AKI may also be characterized by a low urinary sodium even with established ATN, predominantly due to the severe renal vasoconstriction while distal tubule function is still intact [163]. For a detailed discussion of biomarkers in the early diagnosis, differential diagnosis, and prognosis of AKI, the reader is referred to the KDIGO AKI guidelines [109].

III.2.G: *If oliguric victims are volume overloaded, restrict fluid administration and initiate ultrafiltration with or without dialysis, depending on individual needs.*

Victims who are oliguric or develop oliguria and who receive large volumes of fluid may become volume overloaded. Hypervolemia may result in potentially life-threatening hypertension and severe pulmonary edema [116]. Since most of these individuals do not respond to diuretics, initiate ultrafiltration as soon as possible [168]. Isolated ultrafiltration can be performed; however, the addition of dialysis offers the advantage of also removing toxic solutes, especially potassium.

Peritoneal dialysis may not be appropriate for ultrafiltration purposes because of its low efficacy and the potential to aggravate cardiac and respiratory failure, in case of drainage problems or abdominal or thoracic trauma [169]. Therefore, wherever available, hemodialysis is the preferred treatment, if ultrafiltration is needed.

III.2.H: *Treat co-existing emergencies such as acidosis, alkalosis, symptomatic hypocalcemia and infections.*

In addition to AKI, other frequent complications, which require immediate treatment in crush victims, are acidosis, alkalosis, symptomatic hypocalcemia and infections.

Acidosis: Metabolic acidosis with a high anion gap is more common in rhabdomyolysis-induced AKI than in AKI due to other etiologies, as a result of [9, 122, 124, 162]:

- Release of organic acids (i.e. sulphuric and phosphoric acids) from the necrotic muscle cells,
- Uremic retention of organic acids due to AKI,
- Lactic acidosis, which is more common when the patient is hypovolemic,
- Release from the injured muscles of nucleic acids, which subsequently are converted into uric acid,
- Influx of bicarbonate into the cells, resulting in an increased distribution volume and a decrease in serum concentration.

Respiratory acidosis due to hyperkalemic paralysis of the respiratory muscles, asphyxia due to chemical irritation of the lungs after inhalation of dust, or direct injury to the diaphragm and intercostal muscles, also contribute to metabolic acidosis.

Severe acidemia is a medical emergency as it causes: decreased myocardial contractility, a fall in cardiac output and blood pressure, altered cellular and enzymatic functions, and increased risk of drug toxicity [170].

Try to address the underlying causes in the treatment of acidosis. Whenever possible, prefer hemodialysis as the most effective treatment. If dialysis is not available use intravenous sodium bicarbonate. However, indications for intravenous bicarbonate administration are controversial [171]. The work group suggests the cautious administration of bicarbonate at least in case of blood levels of pH $\leq$7.1, while continuing to search for dialysis availability [170, 172]. Therapy with sodium bicarbonate can be associated with electrolyte abnormalities (hypernatremia, hypokalemia) and can result in overshoot alkalosis if not administered carefully.

Alkalosis: Metabolic alkalosis is rare in crush victims; it is mostly due to excessive sodium bicarbonate loading during treatment with alkaline solutions [12, 122]. Also, hemodialysis with high bicarbonate dialysate may be at the origin of alkalosis. The most common cause of respiratory alkalosis is hyperthermia.

Alkalosis increases calcium-protein binding, thus reducing ionized calcium, and inducing tetany even when total serum calcium is normal. The risk of metastatic extra-osseous calcification increases when the blood pH exceeds 7.45. To avoid alkalosis, measure urine and blood pH frequently, if possible, in all patients on bicarbonate. When urine pH decreases below 6.0 and/or plasma pH exceeds 7.45, give 500 mg acetazolamide intravenously to enhance bicarbonaturia [54, 64]. The regular dialysate bath for hemodialysis contains a high concentration of bicarbonate (32–36 mmol/L) and may cause alkalosis; therefore, use dialysis with low dialysate bicarbonate (20–28 mmol/L) in cases of persistent alkalosis.

Hypocalcemia: Precipitation of calcium phosphate in muscles and other tissues (metastatic calcification), direct effect of hyperphosphatemia, suppression of calcitriol synthesis by hyperphosphatemia, and resistance of bones to PTH may contribute to hypocalcemia in crush cases [16, 123, 162, 173, 174].

Do not treat hypocalcemia unless patients are symptomatic, because calcium may precipitate in muscles and is released during recovery, leading to subsequent hypercalcemia [173–176]. However, symptomatic hypocalcemia is a medical emergency, necessitating rapid correction. The symptoms include paresthesia, carpopedal spasm, tetany, hypotension, seizures, positive Chvostek and Trousseau signs, bradycardia, impaired cardiac contractility, and prolongation of the QT interval [177].

Treat symptomatic hypocalcemia with intravenous calcium gluconate (10% solutions in 10 mL vials contain 90 mg of elemental calcium). Start intravenous calcium (1–2 g of calcium gluconate, equivalent to 90–180 mg elemental calcium, in 50 mL of 5% dextrose) over 10–20 min [177]. More rapid administration enhances the risk of cardiac dysfunction and cardiac arrest. Thereafter, add a solution containing 10 vials (100 mL) of calcium gluconate, which corresponds to 900 mg of elemental calcium, to 900 mL of 5% dextrose. Administer this solution at a rate of 50 mL/h. If serum calcium does not rise, increase the rate of infusion. Reduce infusion rate again when hypocalcemia subsides [178]. The serum calcium of a 70 kg patient will increase by 2–3 mg/dL when 15 mg/kg of elemental calcium is administered. Do not administer calcium solutions through the same line as bicarbonate, because of the risk of precipitation of calcium carbonate.

Crush victims frequently need blood transfusions, which contain citrate as an anticoagulant. Should the patient develop symptomatic hypocalcemia during blood transfusion, administer additional calcium.

Infections: Many patients with crush injury die from wound infections [161, 179]. Treatment includes a combination of antibiotic treatment and surgical debridement instituted as early as possible [134].

The term ‘prophylaxis of infections’ indicates procedures to prevent bloodstream or tissue invasion, and specifically points to measures taken prior to surgical interventions, such as fasciotomy or laparotomy. If tissues are contaminated, however, the use of antibiotics is defined as ‘pre-emptive’ treatment. Do not administer prophylactic antibiotics for more than 24 h; continue pre-emptive antibiotic treatment for 5 days after local wound management.

The most frequent pathogens in crush wounds are streptococci, staphylococci or anaerobic organisms. β-lactam/β-lactamase inhibitors are preferred for empiric treatment. Suggested empiric antibiotics for various types of wounds are shown in Table 9.

Cefazolin, a first generation cephalosporin effective mainly against Gram-positive cocci and some Gram-negative rods, is useful in the majority of crush victims. Gentamicin offers excellent coverage of Gram-negative rods commonly encountered in abdominal injuries and in severe open fractures, but is best avoided in crush patients because of nephrotoxicity. Ciprofloxacin can be used instead of an aminoglycoside, with dose adjustment according to GFR, although there is controversial data concerning inappropriate bone healing in patients treated with quinolones. Ceftriaxone offers good coverage of Gram-negative rods; it may be given intramuscularly if crushed zones are avoided and if sufficient hygiene can be guaranteed to exclude the risk of introducing infection. Amoxicillin/clavulanic acid is a valid alternative and allow continuation if therapy is downscaled to oral administration.

The choice of an antibiotic should also take into account the chaotic conditions that usually accompany disasters, so that it is not always possible to depend on their regular administration. Antibiotics that are effective at only once daily administration or even less, due to their pharmacokinetics (e.g. ceftriaxone) or reduced excretion in case of AKI (e.g. cefazolin, vancomycin, teicoplanin) are preferred. In case of hemodialysis, administration may be restricted to the dialysis unit, ideally following dialysis. Vancomycin can provide therapeutic levels for up to 5 days in established oliguric AKI. If available, vancomycin levels should be measured to adjust dosing intervals.

Intravenous dosages of several antibiotics in case of impaired renal function are provided in Table 10.

Do not use antibiotics unless signs of inflammation (rubor, calor, dolor and tumor) are present, since contamination or colonization may result in positive wound cultures. Although superficial infections without cellulitis may be treated by debridement and drainage alone, systemic antibiotics are indicated even if the signs mentioned above are absent in case of need for extensive debridement of deeper tissues, which otherwise often cause systemic infection [186]. Consider local and in-hospital patterns of resistance when selecting an antibiotic, and adjust the dosage to kidney function and dialysis. Administer normal loading doses even in the presence of renal failure.

Table 9. Suggested prophylactic/preemptive antibiotic treatment protocols in wound infections of traumatized victims [180–184]

Type of the trauma	Possible pathogens	Commonly accepted treatment[a]	Alternative
Head trauma	Staphylococci	Cefazolin	Ampicillin-sulbactam[b]
Maxillofacial fractures	Staphylococci	Cefazolin	Ampicillin-sulbactam
Chest thoracostomy	Staphylococci, streptococci	Cefazolin	Ampicillin-sulbactam
Abdominal injury	Gram-negative bacilli, anaerobes	Ceftriaxone + Metronidazole	Ampicillin-sulbactam
Bone fractures, closed	Staphylococci	Cefazolin	Ampicillin-sulbactam
Bone fractures, open	Staphylococci, Gram-negative bacilli	Cefazolin + Ciprofloxacin	Ampicillin-sulbactam
Fasciotomy	Staphylococci, Gram-negative bacilli, anaerobes	Cefazolin + Ciprofloxacin	Ampicillin-sulbactam
Crush with AKI	Staphylococci, Gram-negative bacilli, anaerobes	Cefazolin	Ampicillin-sulbactam
Burns	*Staphylococcus aureus, Pseudomonas aeruginosa, Acinetobacter* spp., fungi	Topical antimicrobials	

[a]For patients allergic to penicillin, substitute cefazolin and ampicillin-sulbactam by clindamycin. If possible pathogens include Gram-negatives, however (i.e. cases with abdominal injury, open fractures, fasciotomy wounds), moxifloxacin or tigecycline monotherapies should be considered in place of beta lactams.
[b]Oral amoxycillin-clavulanate may be used in place of parenteral ampicillin-sulbactam.
Abbreviation: AKI, Acute Kidney Injury.

Table 10. The dosages of antibiotics in patients with kidney dysfunction [185]. Doses must be adapted depending on the type of dialysis and residual renal function

Antibiotic	Usual nonuremic dose	CrCl > 30ml/min	CrCl 10-30 ml/min	CrCl <10 ml/min	Comments for patients on dialysis
Amoxicillin / Clavunate	875/125 mg q12h or 250/125 to 500/125 mg q8h	No change Do not use 875 mg tablet or extended release tablets	250 – 500/125 mg q12h	250 – 500/125 mg q24h	- Moderately dialyzable. - 250/125 – 500/125 mg q24h. - On dialysis days dose AD.
Ampicillin / sulbactam IV, IM	1.5 – 3g q6 – 8h	No change	1.5 – 3 g q12h	1.5 – 3 g q24h	- Dose as for CrCl < 10 ml/min. - On dialysis days dose AD.
Cefazolin	1 – 2g q8h (up to 2 g q8h)	No change	1 g q12h	1 g q24 - 48h	- Moderately dialyzable. - 1 g q24h. - On dialysis days dose AD.
Ceftazidime	1 – 2 g q8 – 12h	1 g q12h	1 g q24h	1 g q48h	- Dialyzable - Dose as for CrCl < 10 ml/min. - On dialysis day supplement 1 g AD
Ceftriaxone	1 – 2 g q24h	No adjustment in renal failure			- No adjustment. - On dialysis days dose AD.
Ciprofloxacin IV	200 – 400 mg q12h	No change	200 – 400 mg q24h	200 – 400 mg q24h	- 250 mg q12h or 200 – 400 mg q24h. - On dialysis days dose AD.
Ciprofloxacin PO	250 – 750 mg PO q12h	No change	250 – 750 mg q24h	250 – 500 mg q24h	- 200 mg q12h or 250 – 500 mg q24h. - On dialysis days dose AD.
Daptomycin	6 mg/kg q24h	No change	6 mg/kg q48h	6 mg/kg q48h	- 6 mg/kg q48h
Gentamicin	Severe infections: 2 – 2.5 mg/kg q8 – 12h	No change	2 – 2.5 mg/kg q24h	Loading dose (2 – 3 mg/kg), then monitor levels	- Dialyzable. - Loading dose (2 – 3 mg/kg) AD and follow levels.
Metronidazole	500 mg q6 – 8h	No change	No change	500 mg q8 – 12h	- 500 mg q8 – 12h. - On dialysis days dose AD.
Vancomycin	500 mg q6h or 1g q12h	20 mg/kg q36h	20 mg/kg q48 - 60h	20 mg/kg q96 - 144h	- The initial dose should be no less than 15 mg/kg. - Not dialyzable, but can be removed by high-flux membranes; so give 1 – 2 g post HD and then 500 mg given over the last 30 min of each dialysis run.

Abbreviations: CrCl: creatinine clearance; AD: after dialysis; IV: intravenous; IM: intramuscular; PO: oral; HD: hemodialysis.

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Section IV: Fasciotomies and Amputations in Crush Syndrome Victims

Section IV.1: Fasciotomies

Section IV.2: Amputations

Section IV.1: Fasciotomies

IV.1.A: Unless clearly indicated by physical findings or intracompartmental pressure measurements, do not perform fasciotomies routinely to prevent compartment syndrome.

IV.1.B: Unless contraindicated, consider mannitol administration as a preventive measure to treat increasing intracompartmental pressures.

Rationale

IV.1.A: *Unless clearly indicated by physical findings or intracompartmental pressure measurements, do not perform fasciotomies routinely to prevent compartment syndrome.*

Fasciotomy is effective in reducing intracompartmental pressure and treating compartment syndrome, but is often the cause of complications.

Fasciotomy may prevent:

- Deterioration of rhabdomyolysis due to related vascular compression and distal ischemia and necrosis [187, 188],
- Renal failure, the severity of which is related to the extent of rhabdomyolysis [189–191],
- Irreversible neurological damage and dysfunction of extremities and ischemic Volkmann's contracture [61, 187, 192],
- Soft tissue and bone infection [191, 193].

However, fasciotomy carries the risk of serious complications that include:

- Infection. Crush injuries are most often closed, and skin is an ideal barrier against infection. Fasciotomy creates open wounds, increasing the risk of infection and sepsis [19, 52, 194], which increase mortality of crush victims [23].
- Local infection caused by fasciotomy may increase the risk of amputation [69].
- Fasciotomy wounds are prone to leakage of plasma and to bleeding as capillary wall sieving capacity is lost due to trauma and acidic environment [69, 195], further complicating the labile hemodynamic status of the patient.
- Fasciotomy may result in long-term severe sensory and motor disturbances [196].

As such, fasciotomy is discouraged as a routine intervention by many authors [19, 52, 92], and is even considered a contraindication in patients with closed acute muscle crush compartment syndrome, in which case, it neither improves the outcome of the limb, nor that of the kidneys [195].

Due to these controversial elements, fasciotomy has been performed with varying frequency (13–80%) in disaster crush victims [20, 48, 197].

Intracompartmental pressure measurement is the only available objective criterion supporting the decision to perform fasciotomy. When pressure exceeds 30 mmHg and shows no tendency to decrease within 6 hours, surgical fasciotomy should urgently be performed [54, 162, 190, 192, 198, 199]. In addition, fasciotomy should also be performed if compartmental pressure and diastolic blood pressure differ by less than 30 mmHg, since this condition will likely cause serious perfusion problems. The proposed threshold for fasciotomy varies between 30 and 50 mmHg among different authors [200]. On the other hand, even experts who discourage routine fasciotomy, support it in the presence of specific clinical indications such as the absence of distal pulses and any condition requiring radical debridement of necrotic muscle tissue [52, 199].

When definitely indicated, perform fasciotomy as soon as possible. In crush injury, muscle damage starts immediately, long before compartment pressures become elevated. The benefit of fasciotomy decreases while the disadvantages increase considerably the later fasciotomy is performed. If carried out early (preferably within the first 12 h of muscle swelling), the risks of soft tissue and bone infection, delayed wound healing, subsequent amputation and permanent functional sequellae are lower [195, 199]. In a retrospective study of 66 cases of acute compartment syndrome, in 44 patients who were treated by fasciotomy, 68% of the victims who underwent fasciotomy within 12 h recovered without any sensory or motor deficit, while only 8% of patients fasciotomized later recovered without permanent residual sensorial motor damage [187].

IV.1.B: *Unless contraindicated, consider mannitol administration as a preventive measure to treat increasing intracompartmental pressures.*

In patients with compartment syndrome, mannitol administration reduces muscle edema, intracompartmental pressure and pain [97–99]. Efficacy of mannitol can be detected within 40 min by the relief of symptoms, reduction of limb swelling and recovery of motor function [51]. It has been suggested, although not proven, that this approach may eliminate the need for surgical fasciotomy and prevents its complications [98]. Mannitol may at least provide extra time to avoid performing fasciotomies in suboptimal conditions. Therefore, unless contraindicated (oliguria despite volume resuscitation, hypervolemia, hypertension, heart failure), consider mannitol as a preventive measure in treating increasing intracompartmental pressures which have not yet reached critical levels [98, 201] (see also section II.6.A, page i12). Consider surgical fasciotomy if mannitol causes no marked improvement within 1 h. Improvement is defined as a decrease of: 1) circumference of the affected limb, 2) tension in the affected muscles, 3) compartmental pressure, and 4) pain.

Section IV.2: Amputations

IV.2.A: Amputate a compromised limb if it jeopardizes the patient's life.

IV.2.B: Perform amputations only based on strict indications.

IV.2.C: When clearly indicated, have amputations performed as early as possible.

Rationale on Section IV.2

IV.2.A: *Amputate a compromised limb if it jeopardizes the patient's life.*

Limb injury in disasters is usually the consequence of collapsed buildings. The two aims of treatment of limb injuries include saving life and restoring or preserving function, i.e. providing a limb with both a sensitive plantar area and sufficient motor power to move the limb. Thus, patients undergoing limb salvage often undergo repeated and sometimes prolonged interventions. In patients suffering from crush injury, seriously traumatized limbs with extensive tissue necrosis are a potential source of myoglobin and potassium release into the circulation. They also are a source of infection, sepsis and death [16, 48]. Therefore, amputations may save lives, and survival chances should not be compromised by desperate and inefficient attempts to save a limb [16, 48, 199].

IV.2.B: *Perform amputations only based on strict indications.*

The frequency of amputations in disaster victims ranges from 2.9 to 58.6% [20, 179, 202]. Medical and logistic factors such as severity of trauma, timing and effectiveness of rescue activities, status of local medical facilities, and experience of medical teams contribute to these differences [12, 202].

The factors that indicate when an injured extremity should be amputated have been a matter of extensive debate. Most surgeons consider the following elements as indicators that success of limb salvage is unlikely: loss of bone, extensive soft tissue loss, loss of distal sensation and motor function related to major peripheral nerve damage, or major vascular injury requiring vascular reconstruction to restore flow. However, all these symptoms and findings may serve only as a rough guide, and are controversial [203]. The decision should be made by the expert on site.

Amputations *per se* are very demanding interventions, and may be followed in many cases by an acute deterioration of the general condition. Hence, clearly weigh the potential benefits against the risks when trying to salvage a severely injured limb [204]. Do not perform amputations to prevent crush syndrome, but only when there are clear indications such as:

1). The necessity to abandon a limb that can no longer be rescued, or

2). Life-threatening sepsis or systemic inflammatory response syndrome originating from a limb.

IV.2.C: *When clearly indicated, have amputations performed as early as possible.*

In patients with clear indications, it is best to carry out amputations as soon as possible, because this intervention is tolerated better, both physiologically and emotionally, when performed early after trauma [16, 48].

In critically ill victims, in whom surgical intervention is life-threatening, the extremity can be garroted and cooled with ice (physiologic amputation), aiming to provide pain relief, prevention of dissemination of infection, and release of toxic material. Definitive anatomic amputation can then be carried out when the condition of the patient has been stabilized [16].

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Section V: Prevention and treatment of AKI in crush syndrome victims

Section V.1: Prevention of crush-related AKI
Section V.2: Conservative treatment of crush-related AKI during the oliguric phase
Section V.3: Dialytic treatment of crush-related AKI
Section V.4: Treatment of crush-related AKI during the polyuric phase
Section V.5: Long term follow-up

Section V.1: Prevention of crush-related AKI

V.I.A: Consider the same principles for prevention and initial management in crush-related AKI as in AKI in general:

V.I.A.1: Initiate early and rapid fluid resuscitation to ensure euvolemia in hypovolemic victims; maintain hydration in euvolemic victims with adequate urine output.

V.I.A.2: Avoid interventions of unproven benefit for prevention of crush-related AKI, such as application of continuous renal replacement therapy, loop diuretics and dopamine.

Rationale

V.1.A: *Consider* the same *principles for prevention and initial management in* crush-related AKI *as in AKI in general.*

AKI due to crush injuries ranges from reversible hypovolemia-induced (prerenal AKI) to severe parenchymal damage (renal AKI), especially if hypovolemia cannot be corrected in the early stages. Overall principles valid for evaluation and initial management of AKI in general [30, 109, 205, 206] apply to crush-related AKI as outlined below.

V.1.A.1: *Initiate early and rapid fluid resuscitation to ensure euvolemia in hypovolemic victims; maintain hydration in euvolemic victims with adequate urine output.*

The underlying pathology in crush-related (rhabdomyolysis-induced) AKI is acute tubular necrosis (ATN), in which hypovolemic (ischemic) and nephrotoxic factors play a role [162, 207–209]. Therefore, in considering prevention, try to expand intravascular volume by using crystalloids (rather than colloids) as initial management and also treat hypotension by vasopressors in patients with vasomotor shock [109, 210–212]. In addition, avoid nephrotoxic medication, in particular, non-steroidal anti-inflammatory drugs (NSAIDs), aminoglycosides, intravenous contrast agents and high doses of loop diuretics.

On the other hand, consider that the following factors may jeopardize appropriate prevention of AKI in crush victims of mass disasters.

- Third-spacing of fluid into muscle compartments and oozing of plasma through open injuries at the early stage as well as release of fluid from the muscle compartment into the circulation and oozing of plasma through surgical wounds at the late stage obviate the correct assessment of fluid balance.
- Chaotic disaster conditions may generate inaccuracies and errors in patient follow-up.
- NSAIDs, anesthetics, aminoglycosides, radiocontrast agents, blood products and colloids used in the treatment or diagnosis of other complications may detrimentally affect kidney function in trauma victims.

In a retrospective analysis of a large series of acute post-traumatic AKI, nephrotoxic drugs played an important role in at least one third of the patients [213]. Aminoglycoside antibiotics and NSAIDs were used abundantly in the management of crush syndrome patients following the Marmara earthquake as well [12]. Therefore, check each patient's medication list carefully during every encounter and discourage the use of nephrotoxic medications.

V.1.A.2: *Avoid interventions of unproven benefit for prevention of crush-related AKI, such as application of continuous renal replacement therapy, loop diuretics and dopamine.*

A number of preventive strategies have been suggested to prevent AKI, but efficacy is questionable.

Continuous renal replacement therapy: In crush-related AKI, a number of endogenous compounds cause kidney damage. These include myoglobin, uric acid and other muscle breakdown products. Myoglobin is a relatively large solute (MW approximately 16 000), excreted in the urine, which in oliguric individuals can only be removed by dialysis strategies with high-flux membranes of large enough pore size [214, 215]. Continuous hemo(dia)filtration may thus help clearing some myoglobin, but the slow rate of extracorporeal removal relative to the rapid rate of endogenous generation [162, 215, 216] makes this approach questionable [217].

New super-flux membranes (e.g. Polyflux P2SH; Gambro Dialysatoren, Hechingen, Germany) have been suggested to clear myoglobin more effectively than standard high-flux membranes and proposed as a preferred option for the removal of myoglobin in AKI [218, 219]. However, their effect on outcomes remains to be proven in clinical trials. Therefore, for the time being, do not use continuous renal replacement therapy (CRRT) or superflux membranes in disaster victims to remove myoglobin. In addition, note that high-flux membranes carry an additional risk of transferring dialysate impurities into the patient's blood and may result in albumin loss.

Loop diuretics. Theoretically, loop diuretics could limit renal injury by increasing tubular fluid flow, flushing out obstructive debris, converting oliguric AKI into non-oliguric AKI, reducing active tubular sodium reabsorption, and decreasing renal oxygen consumption, thereby limiting ischemic damage [210, 220–223]. In fact, however, several studies and meta-analyses have shown that loop diuretics are not beneficial in AKI [120, 210, 224, 225], or even may be associated with a higher risk of mortality and delayed recovery of kidney function [121]. Specifically in crush-related AKI, loop diuretics could acidify the urine [50], and increase the risk of cast formation, as well as aggravate hypocalcemia by inducing calciuria. Therefore, do not use loop diuretics routinely for prevention or treatment of AKI [109]. These agents may, however, be useful in the management of volume overload, especially as a temporizing measure until dialysis is available. If a loop diuretic is to be used, give a test dose of furosemide (120–200 mg) intravenously. If urine output increases significantly within 6 h, repeat the dose every 6 h [226]. However, consider that diuretic use should not postpone the initiation of dialysis, if required [30].

Dopamine: Low dose dopamine has been considered to reduce the risk of AKI by improving renal blood flow. Prospective controlled trials and careful meta-analyses have shown, however, that dopamine neither reduces mortality, nor promotes recovery of kidney function [117, 119, 227], and 'renal dose' dopamine may even worsen renal perfusion, as reflected by increased renal resistive indices in patients with established AKI [228]. Therefore, do not use dopamine for prevention of crush-related AKI.

Other agents: In experimental studies several other agents such as nitric oxide synthase inhibitors or nitric oxide scavengers [229], pentoxifylline [230], glutathione [231], aminosteroids [232, 233], deferoxamine [234, 235], superoxide dismutase, vitamin C and E [236] and acetaminophen [237] have been suggested to prevent rhabdomyolysis-induced AKI. However, their efficacy has not been proven in clinical trials; therefore, do not use these agents in the prevention of crush-related AKI.

Section V.2: Conservative treatment of crush-related AKI during oliguric phase

V.2.A: When deciding on the type of therapeutic approach always consider the urinary volume, which is often oliguric initially, but evolves into polyuria at a later stage.

V.2.B: While the patient is oliguric:

V.2.B.1: Avoid, eliminate or treat the factors that interfere with recovery of kidney function; i.e. nephrotoxic agents, urinary tract obstruction, urinary or systemic infections, hypotension, hypertension, heart failure, gastrointestinal bleeding and anemia.

V.2.B.2: Monitor volume and electrolyte homeostasis to treat all abnormalities as soon as possible by determining serum potassium at least twice daily; and, fluid intake and losses, serum sodium, phosphate and calcium levels at least once daily.

V.2.B.3: Measure blood gas parameters at least once daily. If serum pH decreases below 7.1, start bicarbonate. If in spite of this, pH continues to decrease, increase the amount of administered bicarbonate. Use bicarbonate only temporarily until dialysis becomes available.

V.2.B.4: Maintain appropriate nutritional status with balanced protein, carbohydrate and lipid intake to prevent catabolism and favor wound healing.

V.2.B.5: Continuously evaluate for medical and surgical complications and treat them appropriately.

Rationale

V.2.A: *When deciding on the type of therapeutic approach always consider the urinary volume, which is often oliguric initially, but evolves into polyuria at a later stage.*

AKI following crush is usually, but not consistently, characterized by an initial oliguric period, which ranges from 7 to 21 days [23, 70]. In general, oliguric AKI is associated with a poor prognosis [238, 239]. In the Marmara earthquake, 61% of the crush victims were oliguric at admission to the hospital; these cases had a higher mortality and dialysis need compared to nonoliguric cases [23] in parallel with observations in AKI in general [109, 240, 241]. However, in an observational study of patients who required dialysis, a higher urine volume was independently associated with higher in-hospital mortality [242]. A possible explanation for this isolated discordant finding may be delayed initiation of dialysis or underestimation of the severity of AKI in patients with nonoliguric AKI.

During the early oliguric phase, patients are subject to more severe uremia and fluid-electrolyte disturbances, and their therapeutic approach differs substantially from that during the subsequent polyuric period.

The duration of oliguria depends upon the length and severity of the initial ischemia, the recurrence of ischemia, and the association of nephrotoxic insults. Some patients recover within days, while others require dialysis for weeks. Since most of the life-threatening complications occur during the oliguric period, monitor crush cases very closely during the first 2 weeks. Once patients survive this phase, most will eventually recover kidney function and be discharged. In addition to conservative treatment (described below) initiate dialysis and use it as intensively as necessary (see Section V.3.B, page i33).

V.2.B: *Consider the following issues while the patient is oliguric:*

V.2.B.1: *Avoid, eliminate or treat the factors that interfere with recovery of kidney function; i.e. nephrotoxic agents, urinary tract obstruction, urinary or systemic infections, hypotension, hypertension, heart failure, gastrointestinal bleeding and anemia.*

Avoid or discontinue any potentially nephrotoxic agents (e.g. aminoglycosides, NSAIDs and radiocontrast agents) to optimize recovery of tubular cell injury [243–245]. If unavoidable, adjust drug dosages according to renal function, and monitor serum levels (e.g. of aminoglycosides) to minimize additional nephrotoxicity [213, 246]. Similarly, monitor and treat other co-existing conditions that may interfere with recovery of renal function, e.g. urinary tract obstruction, urinary and/or systemic infections, hypotension, hypertension, heart failure, gastrointestinal bleeding and anemia (see Section VI, page i36).

V.2.B.2: *Monitor volume and electrolyte homeostasis to treat all abnormalities as soon as possible by determining serum potassium at least twice daily; and, fluid intake and losses, serum sodium, phosphate and calcium levels at least once daily.*

Fluid and electrolyte management are among the mainstays of treatment of patients with established AKI.

Fluid balance: Assess the fluid status every day. A variety of measures to evaluate hydration in a patient with AKI are available; however, not all the methods are applicable to every patient and situation; so, first of all, make a clinical judgment to determine the fluid status [109]. Intense thirst, salt craving, orthostatic syncope, non-fluent speech, and muscle cramps often are symptoms of extracellular fluid loss; hence, check hemodynamic data (vital signs, input and output, and daily body weight) to exclude dehydration. Also consider clinical signs of volume overload (edema, distention of jugular veins, increased liver span, hepato-jugular reflux) in oliguric victims who may have received inappropriate fluid administration in chaotic disaster conditions.

Although central venous pressure (CVP) estimations may be used to assess volume status, absolute numeric values usually are not helpful [109]. Only serial CVP determinations may be useful, but then still to a limited extent.

Serum sodium levels can give a rough idea about volume status as well; *hyponatremia* suggests relative excessive free water accumulation, while *hypernatremia* suggests inadequate free water replacement.

In patients in whom fluid shifts to the muscular compartment no longer exist, and, based on experience in AKI not related to crush syndrome, fluid balance can be maintained by adding 400–500 mL above urinary output plus other losses of the previous day [30].

Potassium: When possible, measure serum potassium levels at least twice daily, especially in patients who are catabolic due to co-morbidities such as infection, gastrointestinal bleeding or surgery. If potassium rises above 6.5 mmol/L, if it is increasing quickly even if concentration remains below this threshold, or if clinical signs of hyperkalemia are present (see Section III.2.C; page i20), initiate urgent antihyperkalemic treatment, hemodialysis being the most effective approach (Table 8, page i22). However, life-threatening hyperkalemia can develop even in patients already treated by dialysis necessitating the use of additional measures or the application of several dialysis sessions in 1 day [247]. In the case of rapid rebound hyperkalemia, consider unidentified causes, such as ongoing compartment syndrome, large hematomas, extensive hypercatabolism, acidosis, or potassium-retaining drugs.

Take the following preventive measures to avoid hyperkalemia in this phase [12, 151].

- Avoid potassium-containing infusions.
- Prescribe a high-carbohydrate, low-potassium diet. Potassium-rich foods include, but are not limited to, potatoes, bananas, oranges, tomatoes, broccoli, kohlrabi, pumpkin, Brussels sprouts, zucchini, strawberries, dried apricots, dried grapes, mushrooms, chocolate, spinach, kidney beans and fruit juice [248]. Kayexalate prevents intestinal absorption of dietary potassium; each gram of this resin removes approximately 1 mmol of potassium ion even if there is no food intake (see also Section II.2.D, page i21) [249]. Preferably use sodium kayexalate and discourage calcium kayexalate in crush victims because of the risk for calcium sequestration in the affected muscles and its release at a later stage causing hypercalcemia.

Phosphorus. Phosphate reabsorption from the gut can be reduced by phosphate binders; however, calcium-containing agents carry the risk of precipitation of Ca X P complex in the soft tissues. Therefore, prescribe oral aluminum hydroxide (300–600 mg, 3 times/day with meals) or other non-calcium containing phosphate binders to prevent the absorption of phosphorus from the diet. Protein restriction can limit hyperphosphatemia, but increases the risk of malnutrition in catabolic patients. Consider increasing the frequency of dialysis or prolonging the sessions if hyperphosphatemia is severe.

Calcium. Hypocalcemia is common in crush patients and can lead to tetany, seizures and aggravation of the cardiotoxic effects of hyperkalemia [162, 250]. However, avoid treatment of asymptomatic hypocalcemia because of the risk of calcium precipitation in injured muscles [50, 174] further enhancing cell damage [251].

On the other hand, monitor and treat symptomatic hypocalcemia as described previously (see Section III.2.H, page i23).

V.2.B.3: *Measure blood gas parameters at least once daily. If serum pH decreases below 7.1, start bicarbonate. If in spite of this, pH continues to decrease, increase the amount of administered bicarbonate. Use bicarbonate only temporarily until dialysis becomes available.*

A high anion gap metabolic acidosis is common in rhabdomyolysis-induced AKI [9] (see Section III.2.H, page i23) and sometimes is worsened by respiratory acidosis [124]. Administer parenteral alkaline solutions when serum pH drops to below 7.1, and then only as a temporary rescue until dialysis becomes available. Sodium bicarbonate administration carries many drawbacks, such as hypernatremia, volume overload, overshoot alkalosis, tissue hypoxia, and paradoxical intracellular acidosis [12, 122]. Moreover, rapid correction of acidosis by alkaline solutions carries the risk of decreasing ionized serum calcium, resulting in tetany.

In case of severe and persistent acidosis, combine parenteral bicarbonate and dialysis.

V.2.B.4: *Maintain appropriate nutritional status with balanced protein, carbohydrate and lipid intake to prevent catabolism and favor wound healing.*

Adequate nutrition is essential for the maintenance of body mass and immunocompetence, wound healing and prevention of hypercatabolism [252–254]. Poor nutritional status, hypoalbuminemia and hypocholesterolemia are associated with increased mortality in patients with AKI [255, 256].

Severe catabolism, which is suggested by an increase of BUN >30 mg/dL/day, of serum potassium by >2 mmol/L/day, or a loss of >1 kg body weight on two consecutive days without any other obvious reason, is a bad prognostic indicator [257] and is frequent in general trauma cases and crush victims [258]. The main reasons for increased catabolism in trauma cases are: (a) the severity of trauma, (b) major surgical interventions, (c) complications such as infection, and (d) inflammation [23, 254].

In order to decrease the extent of catabolism, proper nutrition is mandatory. KDIGO AKI guideline suggests 20–30 kcal/kg/day for all noncatabolic AKI patients [109]. Higher (30–45 kcal/kg/day) caloric load has been suggested for trauma victims of mass disasters, because of their highly catabolic status [254]. To provide these calories, prescribe 3–5 (maximum 7) g/kg/day of carbohydrates and 0.8–1.2 (maximum 1.5) g/kg/day of lipid [259, 260].

The most important nutrient in AKI is high biologic value protein. Give at least 1–1.5 g/kg/day to patients on renal replacement therapy (RRT); increase the protein intake by 0.2 g/kg/day to compensate for protein and amino acid losses, when high-flux filters and/or continuous RRT modalities, including PD, are used. On the other hand, avoid administration of too much protein because very high protein intake may contribute to acidosis and azotemia, and increase dialysis dose requirements [109]. Nutritional support should provide a maximum of 1.7 g amino acids/kg/day. For AKI patients who are not highly catabolic and not on RRT, lower protein intakes rich in essential amino acids (up to 0.8–1.0 g/kg/day) will suffice, if they are used for only short periods [259, 260]. Avoid restriction of protein intake with the aim of preventing or delaying initiation of RRT [109].

Oral feeding is preferred because it helps to maintain intestinal integrity, and prevents intestinal atrophy and bacterial and endotoxin translocation through the intestinal wall. Furthermore, oral feeding reduces the risk of stress ulcers or bleeding, but may be difficult in patients with impaired gastrointestinal motility or decreased absorption secondary to bowel edema [261]. In AKI patients in general, enteral feeding (tube feeding) initiated within 24 h, has been shown to be safe and effective if oral feeding is impossible [262, 263]. Due to dialysis-induced losses, supply water-soluble vitamins in dosages of: folic acid (1 mg/day), pyridoxine (10–20 mg/day) and vitamin C (30–60 mg/day). Supplementation of fat-soluble vitamins is usually not necessary [259].

Administer specific oral or parenteral solutions containing glucose, fat and amino acids to the patients who cannot ingest enough protein and calories via the traditional routes.

Due to patient overload, chaos and limited health care personnel, patients may not be followed closely enough in disaster circumstances. Furthermore, many crush patients are immobilized due to compartment syndrome and other injuries to the pelvis and lower extremities, surgical interventions, and presence of drains and/or catheters. These patients need help for reaching food, medications and above all drinking water. Therefore, provide necessary water and nutrients at regular intervals at the bedside of unaccompanied immobilized patients.

V.2.B.5: *Continuously evaluate for medical and surgical complications and treat them appropriately.*

Patients with crush syndrome-related AKI develop several surgical and medical complications, especially during the oliguric period. Treat these complications appropriately to improve final outcome (see Section VI, page i36).

Chaos usually results in incomplete filling out of complex patient files, which may cause inadequate follow-up and data documentation. Charts, prepared by the RDRTF have proven to be useful in the follow-up and treatment of disaster victims. Table 11 provides an example of such a chart. This chart aims to facilitate the follow-up of crush syndrome cases in overloaded hospitals during mass disasters. Other charts made available by the RDRTF are shown in the Appendix (page i49).

Section V.3: Dialysis treatment of crush-related AKI

V.3.A: Dialysis is life-saving. Make every effort to dialyze disaster crush victims when changes in fluid, electrolyte and acid–base balance develop.

V.3.B: Individualize dialysis dose; aim at correcting life-threatening complications of uremia when deciding on frequency and intensity of dialysis.

V.3.C: For the timely initiation of dialysis, monitor victims closely for development of indications for dialysis, specifically hyperkalemia, hypervolemia and severe uremic toxicity.

V.3.D: Although continuous renal replacement therapy (CRRT) or peritoneal dialysis (PD) can be used depending on availability and patient needs, prefer intermittent hemodialysis (IHD) as the first choice of renal replacement therapy.

V.3.E: In patients with bleeding diathesis, perform hemodialysis without anticoagulation or use PD.

V.3.F: When discontinuing dialysis support, monitor the patient closely for any clinical or laboratory deterioration that may require reinstitution of dialysis.

Rationale

V.3.A: *Dialysis is life-saving. Make every effort to dialyze disaster crush victims when changes in fluid, electrolyte and acid-base balance develop.*

Renal replacement therapy is essential for the survival of crush syndrome victims with AKI to prevent or treat frequent life-threatening changes in fluid, electrolyte and acid-base balance [247, 264, 265].

Important logistic considerations that impact dialysis delivery in disasters include:

- Capacity of local dialysis centers may be diminished or insufficient [64, 265–267],

Table 11. Chart distributed by the Renal Disaster Relief Task Force (RDRTF) of the International Society of Nephrology for clinical follow-up of crush syndrome victims.

Patient Name:... Gender:................. Age:...................... Date of admission:...															
Date	B.P.	Temp.	Intake	Urine volume	Hct	WBC	Plt.	CK	Crea.	BUN	Na	K	Alb.	HD (yes/no)	OTHER

Abbreviations: B.P., blood pressure; Temp., body temperature; Intake, oral and parenteral fluid intake; Hct, hematocrit; WBC, white blood cells; Plt., platelets; CK, creatine phosphokinase; Crea., serum creatinine; BUN, blood urea nitrogen; Na, serum sodium; K, serum potassium; Alb., serum albumin; HD, hemodialysis.

- General infrastructure for delivery of water and electricity may be damaged [28, 268, 269],
- Local dialysis personnel and their families may be affected [27, 28].

Therefore, in disaster-prone regions, disaster response scenarios should be prepared in advance to address these logistic problems (see Section VIII; page i42) [42].

V.3.B: *Individualize dialysis dose; aim at correcting life-threatening complications of uremia when deciding on frequency and intensity of dialysis.*

Controversy remains about the optimal intensity (frequency and dose) of dialysis in patients with AKI. Target serum levels of urea and creatinine as indicators of dialysis dose are arbitrary, because they are influenced by several extrarenal factors such as ethnicity, age, gender, nutrition, liver disease, sepsis, muscle injury, drugs, etc. Thus, parameters other than small-solute clearance, such as fluid balance, acid–base status, electrolyte disturbances and nutritional state must be considered when prescribing dialysis.

Intensive daily dialysis, instead of alternate day treatment, may provide better control of uremia, prevent intradialytic hypotension and improve mortality [270–273]. However, in some studies of AKI, intensive renal replacement did not improve renal or patient outcomes over less intensive therapy [274, 275], although severity of illness and comorbidities were likely confounding factors. Measurement of delivered dose of dialysis in each session may be useful in prescribing the dose of next dialysis [109].

Given the likely limited availability of dialysis in most disaster situations, optimize dose or frequency of therapy considering not only electrolyte, acid–base and fluid balance, but also local logistic circumstances.

V.3.C: *For the timely initiation of dialysis, monitor victims closely for development of indications for dialysis, specifically hyperkalemia, hypervolemia and severe uremic toxicity.*

Although early initiation of dialysis may intuitively seem beneficial, the literature is inconclusive as to optimal indications for and timing of initiation of RRT in patients with AKI [276]. Traditional indications for RRT, developed for patients with end-stage renal disease, may not be valid in the context of AKI. Most studies on initiation of RRT in AKI are observational and include subjects with diverse causes of AKI observed at varying dialysis prescriptions, making it difficult to draw generalizable conclusions [109]. Furthermore, crush-related AKI differs from AKI due to other etiologies because of the accompanying hypercatabolic state, and rapid development and high incidence of life-threatening problems (i.e. severe hyperkalemia, acidosis, pulmonary edema and uremic complications). There are no studies specifically addressing the effects of early versus late initiation of dialysis in crush-related AKI cases. A study of 100 adults with general trauma-associated AKI characterized subjects as ‘early’ or ‘late’ starters, based upon whether the BUN was less than or more than 60 mg/dL prior to CRRT initiation. Survival rate was significantly increased among early starters compared to late starters, suggesting a benefit for initiation of CRRT at lower BUN concentrations in trauma victims [277].

Therefore, consider more liberal indications for start of dialysis in crush syndrome patients, in anticipation of potential complications. Absolute indications for dialysis include [12, 109, 278, 279]:

1. Serum potassium $\geq$6.5 mmol/L or rapidly rising serum potassium not responding to other measures,
2. Acidosis: blood pH $\leq$7.1,
3. BUN level $\geq$100 mg/dL (30 mmol/L) or serum creatinine $\geq$8 mg/dL (700 μmol/L),
4. Uremic symptoms such as volume overload, pericarditis, bleeding or an otherwise unexplained altered mental status,
5. Continued oliguria or anuria in spite of adequate fluid resuscitation.

V.3.D: *Although continuous renal replacement therapy (CRRT) or peritoneal dialysis (PD) can be used depending on availability and patient needs, prefer intermittent hemodialysis (IHD) as the first choice of renal replacement therapy.*

All forms of renal replacement therapy (IHD, CRRT and PD) can be considered for the treatment of crush syndrome victims with AKI.

Several RCTs and meta-analyses have compared CRRT to IHD in AKI patients. The most inclusive meta-analysis was performed by the Cochrane Collaboration, which analyzed 15 RCTs in 1550 AKI patients. It concluded that outcomes were similar in critically ill AKI patients treated with CRRT and IHD for hospital mortality, ICU mortality, length of hospitalization and renal recovery in survivors [280]. Similar results were obtained in other meta-analyses as well [278, 281].

Advantages and drawbacks of the three modalities are summarized in Table 12.

The advantages of IHD specific to mass disasters include efficient clearance of small molecules such as potassium and urea, utilization of the same machine for several patients per day, and minimization or avoidance of anticoagulation, making it the treatment of choice.

If PD is the only option, rapid exchanges may be required to allow more efficient potassium removal; frequent exchanges with high-glucose solutions may be applied to maximize ultrafiltration. On the other hand, PD may be useful in small children, when performed by an experienced medical team.

The ‘REDY’ (REcirculating DialYsis) sorbent dialysis system allows dialysate regeneration, requires very small volumes of city water and for that reason has been used in mass disasters [202]. However, insufficient uremic solute removal and high cost generally limit its use.

In conclusion, no form of RRT is ideal for all patients with AKI. Prescribe dialysis on the basis of the individual and potentially changing needs of the victims. Consider the available expertise, resources and logistic conditions as an important determinant of the ultimate choice besides the individual patient characteristics. Consider that, in general, in the chaos of a mass disaster, dialysis treatments should be as efficient and as simple as possible.

Table 12. Potential advantages and drawbacks of various renal replacement therapies in disaster trauma victims [5, 24, 64, 109, 159, 169, 278, 282, 283]

Dialysis Modality	Advantages	Drawbacks	Comments
IHD	- High clearance rate of low molecular weight solutes. - Possibility to dialyze without anticoagulation. - Possibility to treat several patients per day at the same position.	- Need for experienced personnel and technical assistance. - Some fluid is needed as a priming volume; if unavailable, this might aggravate hypotension in already hypotensive or hypotension prone victims during dialysis. - Increased risk of disequilibrium syndrome.	- The most practical RRT modality in disaster conditions.
CRRT	- Better control of fluid status. - Gradual removal of solutes, decreasing the risk of disequilibrium syndrome. - Giving opportunity to administer more calories. - CAVH has the advantage of no need for pumps and electricity. Only minimal equipment is needed.	- Need for continuous heparinization in patients often suffering from or susceptible to bleeding. - Low removal capacity for small solutes like potassium. - Treatment restricted to only one patient per machine per day. - Bulky if fluid bags are to be transported to the disaster area.	- RCTs showing survival advantage over IHD are lacking (see text). - More labor intensive and expensive than IHD and PD. - CAVH may be feasible only in very few cases, because many patients are hypotensive, and also, achieving intra-arterial access may be difficult in disaster conditions.
PD	- No need for vascular access. - Simpler technique and less hemodynamic instability. - No need for water and electricity.	- Low clearance of small molecules (i.e. potassium). - Difficulty in maintaining sterile technique. - Difficult application if the patient cannot lie down, suffers from abdominal wall infection, intestinal obstruction, large abdominal hernia, pronounced obesity, and/or aortic aneurysm. - Bulky if fluid bags are to be transported to the disaster area.	- Difficult to perform in patients with thoracic, pulmonary and abdominal trauma. - Can be used as a temporary rescue when IHD is not available. - Patients should be closely monitored for hyperkalemia.

Abbreviations: IHD, intermittent hemodialysis; CRRT, continuous renal replacement therapy; PD, peritoneal dialysis; RRT, renal replacement therapy; RCT, randomized controlled trial; CAVH, continuous arterio-venous hemofiltration.

V.3.E: *In patients with bleeding diathesis, perform hemodialysis without anticoagulation or use PD.*

Catheterization for vascular access is needed for IHD or CRRT, but this may cause bleeding complications such as hemothorax, pericardial tamponade or mediastinal hemorrhage, especially in patients with coagulation disturbances. Small portable ultrasound devices are useful during the insertion of central catheters, and decrease the risk of complications; however, they may not always be available in disaster conditions.

Anticoagulation, needed for IHD and CRRT, may increase the risk of bleeding [284]; thus, in the patients with hemorrhagic diathesis, either apply hemodialysis without anticoagulation or perform PD. Although citrate anticoagulation could be considered especially in high risk patients [285–287], this necessitates technical experience and is prone to life-threatening metabolic complications such as hypocalcemia, metabolic alkalosis and citrate intoxication [278]. The risk of these complications increases in chaotic disaster conditions. Consequently, do not use regional citrate anticoagulation in this clinical setting.

Refer to KDIGO AKI guideline for an in-depth discussion of this subject [109].

V.3.F: *When discontinuing dialysis support, monitor the patient closely for any clinical or laboratory deterioration that may require reinstitution of dialysis.*

Most patients requiring RRT will recover enough kidney function to discontinue dialysis. The mean duration of dialysis support in AKI in general is around 12–13 days [274]. This duration is similar to the dialysis duration in overall rhabdomyolysis-related AKI patients (mean 14.6 days) [288] and in the crush cases of mass disasters (i.e. in the Marmara earthquake mean 13.4 days) [159].

There are no clear algorithms for when to stop dialysis in patients with AKI. Assessment of kidney function for this purpose is not easy and prone to bias depending on the dialysis modality used. In IHD, the fluctuations of solute levels prevent achieving a steady state and should be taken into account for renal clearance calculations. Native kidney function can only be assessed during the interdialytic period by evaluating urine volume, urinary excretion of creatinine, and changes in serum creatinine or BUN levels, which are difficult to determine in disaster conditions. Also, one must realize that changes in BUN and creatinine levels can be modified by nonrenal factors, such as volume status and catabolic rate.

Decreasing the frequency of IHD, for example from daily to every other day, represents a method of testing the ability of the patient's own kidney to take over [109]. During such interventions, monitor the patient's clinical status, urine volume and biochemical findings closely. In the case of any clinical or laboratory deterioration, do not hesitate to start dialysis again. If parameters remain stable between dialysis sessions, or continue to improve, and urine output begins to increase significantly, permanently stop dialysis.

Section V.4: Treatment of crush-related AKI during the polyuric phase

V.4.A: Avoid hypovolemia and maintain electrolyte balance in the recovery phase of crush-related AKI, as it is usually characterized by polyuria.

V.4.B: Once renal function begins to improve, taper volume of administered fluids gradually, while continuing to monitor clinical and laboratory parameters closely.

Rationale

V.4.A: *Avoid hypovolemia and maintain electrolyte balance in the recovery phase of crush-related AKI, as it is usually characterized by polyuria.*

Oliguria of acute renal failure is often followed by polyuria, which usually starts within 1–3 weeks after the primary event [23].

Management depends on the amount of water and electrolytes excreted daily. There are no rigid rules for therapy. In order to avoid dehydration and consequent renal hypoperfusion, administer appropriate amounts of fluid, which is 400 mL of fluid in excess of urinary volume and other losses of the previous day. Unless the patient is anabolic, catabolic or fluid overloaded, the absence of changes in body weight indicate that the appropriate amount of fluid is being administered. In case of fluid overload, reduce fluid replacement below urinary losses (usually to 2/3 of previous day's urine volume). Evaluate volume overload or depletion from biochemical examinations and clinical findings indicative of hydration status. Changes in body weight are crucial to follow up.

Polyuria carries the risk of losing excessive amounts of electrolytes; even hypokalemia has been described in cases with traumatic rhabdomyolysis due to excessive loss of potassium via the urine [122]. However, in some cases, there remains a risk of hyperkalemia even in the polyuric phase, due to the persistent inability of the kidneys to handle potassium. Therefore, measure serum electrolytes daily to allow their appropriate replacement. If possible, match these data to daily urinary volume and electrolyte content [151].

V.4.B: *Once renal function begins to improve, taper volume of administered fluids gradually, while continuing to monitor clinical and laboratory parameters closely.*

To avoid maintenance of polyuria, gradually taper the volume of administered fluid under close clinical and laboratory monitoring once blood chemistry normalizes. Administer 400–500 mL on top of 2/3 of all fluid losses the previous day, which will result in a gradual decrease of polyuria [151]. In case of rigid fluid restriction, and if tubular function has not yet completely recovered, persistent polyuria carries the risk of dehydration and reappearance of kidney dysfunction. In this case, increase the amount of administered fluid again to the previous level. After volume restoration, make another attempt to limit fluids; but this time restrict volume less extensively than the previous time to avoid recurrence of dehydration. A decrease in urinary output together with normal clinical and biochemical findings indicates that tubular function has been restored. Then discharge the patient, with a follow-up blood test as an outpatient in 3–4 days.

Section V.5: Long-term follow-up

V.5.A. Evaluate crush syndrome victims at least yearly after discharge to detect late renal and systemic adverse effects.

Rationale

V.5.A. *Evaluate crush syndrome victims at least yearly after discharge to detect late renal and systemic adverse effects.*

The long-term outcomes of AKI have not been well characterized. In many studies, patients with AKI subsequently suffered from chronic kidney disease [289, 290]. Elderly individuals and those with previous chronic kidney disease are at significantly increased risk for progression to end stage renal disease (ESRD), suggesting that episodes of AKI may accelerate progression of renal disease [291]. Even in the best of circumstances – meaning survival during hospitalization and recovery of kidney function sufficient to stop dialysis for a month – there is almost a 10% chance of requiring chronic dialysis in the next few years [292]. These reports highlight the magnitude of the problem of AKI as a cause of ESRD.

Apart from the risk of ESRD, many single and multicenter analyses suggest that AKI is independently associated with increased long-term mortality despite renal recovery [293–296], highlighting it as a major health problem.

Specifically, the long-term prognosis of patients with crush-related AKI is unknown. Full recovery can be expected in the vast majority of crush cases in the short term [9, 70, 211, 264], but there is no study investigating the ultimate outcome. It has been reported that prognosis of overall post-traumatic acute tubular necrosis is usually favorable [297]. However, this may not be applicable to crush cases. Rare cases of permanent renal lesions such as interstitial nephritis and crescentic glomerulonephritis have been described after rhabdomyolysis-induced AKI [124]; but their link with the primary event is not clear.

In an analysis conducted 2–4 years after the Armenian earthquake, among the overall 35 000 individuals who had experienced the disaster, a significant increase in cardiac deaths was noted within the first 6 months after the catastrophe. Loss of one or more family members and loss of property associated to an increased risk [298]. Since many crush cases are characterized by these losses, they should be closely monitored for long-term cardiovascular morbidity as well.

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Section VI: Diagnosis, prevention and treatment of medical complications during the clinical course of crush-related AKI

Section VI.1: Diagnosis, prevention and treatment of medical complications during the clinical course of crush-related AKI

VI.1.A: Anticipate and prevent complications of crush-related AKI to optimize interventions and improve outcomes.

VI.1.B: Investigate and treat infections early and appropriately.

VI.1.C: Remove intravascular catheters as soon as possible to avoid the risk of bacteremia and sepsis.

VI.1.D: Differentiate peripheral neuropathy caused by compartment syndrome from spinal cord injury to determine appropriate therapy.

VI.1.E: Provide psychologic support, and have a relative, a member of personnel or a third-party in the close vicinity of crush victims, especially those with suicidal ideation.

Rationale

VI.1.A: *Anticipate and prevent complications of crush-related AKI to optimize interventions and improve outcomes.*

The clinical course of crush syndrome-related AKI is complicated by many surgical and medical problems (Table 13) [23].

Irrespective of the cause of AKI, and specifically in that due to crush injury, extra-renal complications (infections or pulmonary, cardiovascular, hematological, gastrointestinal, neurological and psychiatric problems) (Table 13) aggravate the course of the disease and increase morbidity and mortality [256, 257, 299, 300].

In addition to daily careful evaluation, if possible, perform laboratory assessments [daily complete blood cell count and urinalysis; twice weekly cultures of various body fluids (i.e. urine, wound exudate, drainage fluids)] and imaging investigations (at least once weekly chest X-ray) for early diagnosis and treatment of potential clinical complications.

VI.1.B: *Investigate and treat infections early and appropriately.*

Sepsis, wound infection, pneumonia, empyema, urinary tract infection and tetanus occur frequently in disaster victims due to contaminated wounds, suboptimal care of trauma and surgical wounds, urinary or vascular catheterization, intubation, and immunodeficiency (Table 14) [314–316].

Table 13. A summary of complications in various systems during the clinical course of crush-related AKI

System	Complication(s)	Etiology
Cardiovascular	Myocardial infarction, congestive heart failure, hypertension	Disaster-related stress, interruption of antihypertensive and anti-ischemic medications, volume overload [115, 125, 126, 301–304]
Hematological	Anemia, leukocytosis, thrombocytopenia	Traumatic bleeding, hemodilution in oliguric / anuric victims, rhabdomyolysis, infections, DIC [123, 124, 305]
Pulmonary	Bronchitis, pneumonia, asthma	Suboptimal living conditions, stress, dust inhalation during entrapment, aspiration, volume overload [90, 306, 307]
Gastrointestinal	Bleeding, peptic ulcer	Stress, drugs which increase gastric acidity or disrupt gastric epithelial integrity, hemorrhagic diathesis due to DIC or uremia [12, 306, 307]
Neurological	Peripheral neuropathy, paresis, paralysis	Stretching, immobilization and compression of peripheral nerves by increased compartmental pressure; spinal injury [308]
Psychiatric	Depression, delirium, posttraumatic stress disorder	Disaster-related stress, loss of family member or property [306, 309]
Metabolic	Impaired glycemic control	Stress, irregular nutrition, emergence of surgical or medical complications, problems in regular treatment [307, 310–313]

Abbreviation: DIC: disseminated intravascular coagulation.

Table 14. Predisposing factor(s) and prevention of infections in crush syndrome victims

Type of infection	Predisposing factor(s)	Prevention
Sepsis	Immunosuppression, malnutrition, indwelling catheters, bacteremia	Meticulous catheter care, removal of catheters at the earliest convenience, blood cultures in febrile patients, adequate nutrition
Wound	Foreign bodies in the wound, inadequate wound care in chaotic disaster conditions	Meticulous wound care, radical debridement of infected and necrotic tissues, antibiotic administration
Urinary tract	Urinary catheters, oliguria	Removal of catheters at the earliest convenience
Respiratory tract	Long entrapment, dust inhalation, pre-existing pulmonary disease	Periodic chest X-rays and monitoring oxygen saturation
Tetanus	Any open wound	Vaccination with tetanus toxoid (see Section III.1.E; page i18)

It may be difficult to diagnose systemic infections in crush patients, because fever and leukocytosis, key indicators of infection, may result from other factors like rhabdomyolysis, hematoma, or pulmonary emboli [317]. Furthermore, laboratories may not work efficiently in disaster conditions. Therefore, even if physical findings and laboratory results do not confirm an infection, maintain a high index of suspicion and consider their presence, since they contribute to mortality in 30% to 88% of patients with blunt and penetrating trauma [161, 317–319].

VI.1.C: *Remove intravascular catheters as soon as possible to avoid the risk of bacteremia and sepsis.*

Intravascular catheter-related infections are common in crush patients, and can progress to bacteremia or sepsis. The risk can be reduced by meticulous attention to aseptic technique during catheter insertion, exit site care, and early catheter removal.

If infection is suspected, remove the catheter, and culture its tip in addition to that of blood and exit site cultures. Consider that quantitative cultures are the most useful approach. If it is not safe to remove the catheter, obtain blood cultures from the line and a peripheral site and initiate empiric antibiotics pending culture results. For simplicity, use antibiotics requiring administration post-dialysis only (vancomycin, teicoplanin, cefazolin, ceftazidime, daptomycin) [320]. *S. aureus* and coagulase-negative staphylococci are the most frequently encountered pathogens in vascular access catheter-related bacteremia. If available, use vancomycin or teicoplanin for the empiric treatment of vascular catheter infections (see Table 10 for dosage in renal failure), especially if methicillin-resistant *S. aureus* is a current cause of infection in the hospital/location where the victim is treated. In patients on empirical vancomycin or teicoplanin in whom infection with methicillin-resistant *S. aureus* has been excluded, switch antibiotic treatment to cefazolin or daptomycin. Continued treatment with vancomycin in the absence of methicillin resistance substantially increases the risk of treatment failure [320]. Consider treating vancomycin-resistant Enterococci with daptomycin, administered after each dialysis session.

Gram-negative bacteria may be responsible for catheter-related bacteremia as well; the majority (95%) of them is sensitive to both aminoglycosides and third-generation cephalosporins. Although a single dose of aminoglycosides can be considered in view of their rapid bactericidal effect [320], third-generation cephalosporins are preferred because of the substantial risk of irreversible aminoglycoside ototoxicity, vestibulotoxicity and nephrotoxicity [321]. For antibiotics with substantial removal by the kidneys or dialysis, take into account renal function and dialysis adequacy when determining the dose and frequency of administration (Table 10).

VI.1.D: *Differentiate peripheral neuropathy caused by compartment syndrome from spinal cord injury to determine appropriate therapy.*

Peripheral nerve damage due to nerve stretching, immobilization and compression by increased compartmental pressure is the most frequent neurological complication in patients with crush syndrome [308, 322]. The usual clinical signs are flaccid paralysis and sensory loss, which occasionally can lead to the misdiagnosis of spinal cord injury. Since the treatment protocols are different, exclude spinal cord problems by checking the presence of urinary sphincter control and pain sensation during bladder catheterization [50, 308]. In the presence of peripheral nerve damage, physical therapy and rehabilitation are important therapeutic measures to conserve or improve limb function. Surgical nerve reconstruction, performed by specialized surgeons, may be possible at a later date. If spinal cord injury is diagnosed or suspected, immobilize and transfer the patients to a specialized treatment center as soon as possible.

VI.1.E: *Provide psychologic support, and have a relative, a member of personnel or a third-party in the close vicinity of crush victims, especially those with suicidal ideation.*

Psychiatric and psychological problems are very common in disaster victims [91, 323, 324]; consequently, if available, provide psychiatric or psychological support by trained personnel. Because of the high risk of suicide [325, 326], monitor all crush victims of mass disasters closely, especially those who have lost family members or property. If possible, arrange a relative, a member of personnel or a third-party to stay with them until this risk decreases or their psychological status improves.

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Section VII: Logistic Issues in the Treatment of Crush Syndrome Victims

Section VII.1: Logistic support for disaster relief

Section VII.2: General logistic planning of medical personnel and material

Section VII.3: Renal logistic planning of medical personnel and material

Section VII.1: Logistic support for disaster relief

VII.1.A: Assess the severity and extent of mass disasters early to organize effective logistic support.

VII.1.B: Estimate the number and incidence of crush victims as soon as possible to establish an effective rescue plan.

VII.1.C: Assess the status of local health care facilities to exclude any problem related to damage or lack of material.

VII.1.D: Evacuate crush victims from the disaster area to safer, remote and well-equipped facilities at the earliest convenience.

VII.1.E: Estimate the frequency and timing of hospitalizations to allow proper organization of health care.

VII.1.F: Evacuate corpses as soon as possible from the disaster area to avoid psychological problems and medical risks.

Rationale

VII.1.A: *Assess the severity and extent of mass disasters early to organize effective logistic support.*

The term *logistics* refers to 'the procurement, maintenance, distribution and replacement of personnel and material', so as to have 'the right thing, at the right place, at the right time'. Although usually not necessary in routine practice, logistical preparations are vital in anticipation of mass disasters, because of increased patient load, limited resources and considerable chaos even in countries experienced in disaster management [7, 41, 269, 306].

Disaster preparedness can reduce chaos, and prevent or minimize errors during disasters [327, 328].

For effective logistic support, the overall extent of problems should be evaluated as early as possible. The most important personnel in implementing logistic support are relief coordinators, who assess the dimensions of the problem immediately after a disaster, in order to:

1) Anticipate the number of victims,
2) Determine the capacity of local health facilities and transportation possibilities,
3) Foresee the timing of hospitalizations.

VII.1.B: *Estimate the number and incidence of crush victims as soon as possible to establish an effective rescue plan.*

Following earthquakes with an intensity >6.4 on the Richter scale, the ratio of deaths to injured victims is between 1:2.5 and 1:3, but may differ depending on local circumstances [35, 71, 211, 329, 330]. Similarly, the incidence of crush syndrome among injured victims varies between 2 and 20%, with the highest incidence in densely populated areas with multistory concrete buildings. Factors that reduce the number of crush victims relative to deaths or survivors following disasters are [1]:

- Limited rescue possibilities in proportion to the number of affected victims (e.g. the Gujarat, India earthquake in 2001 [331], the Kashmir, Pakistan earthquake in 2005 [43] and the Haiti earthquake in 2010 [132]),
- Sudden rapid collapse of buildings (e.g. the 9/11 New York terrorist attack) [332],
- Absence of multistory concrete buildings (e.g. Bam, Iran earthquake in 2003 [43]; Haiti earthquake in 2010 [132]),
- Daytime occurrence and moderated meteorological circumstances (e.g. the Kashmir, earthquake in 2005) [43].

For an effective rescue plan, estimate the number of eventual crush victims in advance considering the above factors, and by performing careful day-to-day follow-up in the entire area.

VII.1.C: *Assess the status of local health care facilities to exclude any problem related to damage or lack of material.*

Due to their complex clinical needs, crush victims cannot be treated in inadequately equipped field hospitals. Therefore, as a first measure, determine the status of local health facilities close to the epicenter to exclude any damage or lack of material jeopardizing their further use as a referral center [26].

VII.1.D: *Evacuate crush victims from the disaster area to safer, remote and well-equipped facilities at the earliest convenience.*

In case of considerable damage to the local infrastructure, evacuate crush victims from the area close to the epicenter at the earliest convenience, for the following reasons [333, 334]:

1. Hospitals in the disaster area are often heavily damaged or at risk of collapse from aftershocks,
2. Emergency field hospitals are most useful for temporary treatment of acute complications,
3. It may become difficult to transport crush victims later in their course because of secondary complications,
4. Space and facilities should be kept open in local hospitals for victims who cannot be transported,
5. Locally treated patients have a higher mortality risk compared to victims who are transported and treated in appropriate surroundings.

If possible, refer crush victims to experienced and well-equipped hospitals, with intensive care unit, dialysis and trauma facilities. Transport during mass disasters can be problematic, but can be facilitated in collaboration with local governmental and non-governmental organizations [335], by using boats, helicopters or planes [1, 45].

VII.1.E: *Estimate the frequency and timing of hospitalizations to allow proper organization of health care.*

With appropriate evacuation, most hospital admissions occur within the first 3 days of a disaster [7, 71, 90, 94, 336], when the high number of casualties can result in a shortage of hospital beds. Mildly injured victims, reaching the hospitals shortly after the disaster by their own means, may occupy hospital beds that would be needed for more seriously injured victims, who often arrive later [37, 337]. Therefore, triage mildly injured victims and discharge them as early as possible with verbal and written instructions to monitor their own condition for signs of rhabdomyolysis and crush syndrome and to return to the hospital if such signs appear.

VII.1.F: *Evacuate corpses as soon as possible from the disaster area to avoid psychological problems and medical risks.*

There is concern that unburied bodies in disasters may be a source of infection, although this is unlikely in isolated traumatic deaths [90, 329]. However, unevacuated bodies may transmit gastroenteritis or food poisoning to survivors if they contaminate streams, wells or other water sources. More than for this negligible risk, it is necessary to remove corpses, because they cause serious psychological problems. Those responsible should establish temporary morgues near the casualty-collection points, but in separate locations, which are well protected from public view. Access must be strictly limited [37]. It is useful to take photographs of the deceased victims for identification purposes.

Among the methods of evacuation, cremation is not a practical approach, because this practice does not comply with many religious beliefs, is demoralizing, and requires substantial quantities of fuel [90]. Mass burials are a more appropriate alternative, and were practiced in recent mega-disasters such as the 1999 Marmara (Turkey), 2003 Bam (Iran) and 2010 Haiti earthquakes.

Section VII.2: General logistic planning of medical personnel and material

VII.2.A: Avoid non-stop activity of medical personnel to prevent burnout. A supervisor should be assigned to evaluate for exhaustion and decide when personnel has to take a rest.

VII.2.B: Schedule the most experienced personnel during the first days of the disaster.

VII.2.C: Use existing medical supplies carefully until effective external support is received.

VII.2.D: Plan and extend calls for blood donation during the period when the largest amount of blood product administration is foreseen in order to avoid periods of excess alternating with periods of shortage.

Rationale

VII.2.A: *Avoid non-stop activity of medical personnel to prevent burnout. A supervisor should be assigned to evaluate for exhaustion and decide when personnel has to take a rest.*

If local medical personnel or their relatives are affected by the disaster, they may be unavailable for health care services. During the first day of the Kobe, Japan earthquake, 42–69% of medical and administrative staff were not available because they had been injured or had transportation difficulties [25]. Those available may be functioning inefficiently due to shock, anxiety and grief [37, 40]. Non-stop activity of the efficient personnel to compensate for missing or inefficient colleagues should be avoided to prevent burnout. On call schedules should be prepared carefully to prevent these drawbacks.

VII.2.B: *Schedule the most experienced personnel during the first days of the disaster.*

The most experienced personnel should be scheduled when the most complex cases are expected, which is during the first days after a disaster. Consider that mortality risk of the victims who are admitted within the first 3 days of the disaster is significantly higher [7]. Following the Marmara earthquake, the mortality rate was 18% in the victims who were admitted within the first 3 days, whereas this figure was 10% for those who had been admitted later on [71].

Assigning less-experienced personnel in the late period of disaster will minimize the risk of malpractice.

VII.2.C: *Use existing medical supplies carefully until effective external support is received.*

Treatment of large numbers of patients with multiple therapeutic needs combined with damage to medical supplies and facilities often results in a shortage of materials. Until effective external support is received, which usually takes 1 week, careful consumption of available medical supplies is mandatory [1, 306].

The day-to-day evolution of the number of AKI cases should be carefully monitored in order to predict supply needs. Unrestricted consumption of medical equipment after additional supplies have arrived remains unjustified as well, because supplies should be preserved for patients developing serious complications later on during the course of events.

VII.2.D: *Plan and extend calls for blood donation during the period when the largest amount of blood product administration is foreseen in order to avoid periods of excess alternating with periods of shortage.*

Crush victims need large quantities of blood and blood products during their treatment [115, 338]. The most important problem of blood products is their short half-life [1, 336]. In disaster circumstances, it may not be possible to store them effectively because blood banks are damaged, or reserves may become insufficient due to massive needs [339]. Therefore, calls for blood donation should be planned and spread over the entire period during which the need for blood products is foreseen, to maintain a steady supply to meet the needs. If this is not done, too many blood products may be collected early after a disaster, necessitating destruction of unused supplies, and contributing to subsequent shortage [340]. Although donations may be safe after small scale disasters in well-developed countries [341], the probability of classical medical complications associated with blood transfusions [113, 342] is especially high in chaotic mass disaster conditions [339, 343]. Attention should be paid to minimize such medical and logistic problems [344].

Section VII.3: Renal logistic planning of medical personnel and material

VII.3.A: Nephrology units in and around disaster-prone areas should develop their own detailed disaster preparedness plans to cope with sudden influxes of crush victims.

VII.3.B: The exact need for medical consumables to treat crush syndrome victims should be defined in advance to allow adequate stockpiling of supplies and the organization of acute help from outside the damaged area.

VII.3.C: Dialysis personnel should be redistributed from non-functioning to functioning units, as necessary.

VII.3.D: Relocation of chronic dialysis patients should be planned in advance.

Rationale

VII.3.A: *Nephrology units in and around disaster-prone areas should develop their own detailed disaster preparedness plans to cope with sudden influxes of crush victims.*

Disasters usually increase the need for dialysis, while at the same time, dialysis facilities may be damaged or destroyed, thus substantially increasing the workload of the remaining functioning units [27, 28, 345]. Therefore, every renal unit in and around disaster-prone areas should prepare its own detailed 'disaster plan' to cope with a sudden influx of patients [346]. This program should include:

- An adequate rotation of stock of drugs and consumables, to avoid shortages,
- A plan for mobilization of extra staff,
- Preparing information material for distribution to rescue teams and first-line health care services to increase awareness of crush syndrome and its management,
- A map of facilities where chronic dialysis patients can be relocated in the aftermath of a disaster.

Crush cases suffer from multiple complications that require fully equipped hospitals. Refer chronic dialysis patients who routinely undergo maintenance dialysis in those hospitals to nearby satellite outpatient units to conserve hospital resources for crush cases evacuated from the disaster area [347].

VII.3.B: *The exact need for medical consumables to treat crush syndrome victims should be defined in advance to allow adequate stockpiling of supplies and the organization of acute help from outside the damaged area.*

Anticipation of the medical needs of crush patients is critical in making national and international calls for support. This help is almost always necessary following mass disasters, because the quantity of medical supplies required may reach massive proportions [1, 115, 211]. The quantity for frequently consumed medical supplies (such as blood and blood products, dialysis material, crystalloids and kayexalate) needed for treatment of earthquake crush syndrome victims should be evaluated (Table 15).

In terms of supplies, extrapolating from Table 15 for the first 3 days of a disaster before initial support is organized, 15 000 L of crystalloids would be required per 1000 crush syndrome patients. In addition, at a usual dosage of 15 g/day, per patient, 45 kg of sodium polystyrene sulfonate (kayexalate) would be required for these victims. Considering the figures from the Marmara earthquake, the number of dialysis

Table 15. Amount of blood and blood products, dialysis items, crystalloids and kayexalate needed for earthquake crush syndrome victims

TRANSFUSION	N	DIALYSIS	N	OTHER	N
Mean no. blood trans./pt*	4.6±9.0	HD sessions/patient(hemodialyzed victims)	11.2±8.0	Crystalloids	5109±1711 mL/day
Mean no. FFP trans./pt*	4.4±12.9	HD sessions / patient (dialyzed + nondialyzed)	8.2±8.4	Kayexalate	15 g/victim/day
Mean no HA trans./pt*	4.0±7.5				

Transfusion and dialysis figures as well as volume of crystalloids are based on the experience of the Marmara earthquake; kayexalate is estimated from literature data [1, 115, 166].
*: Considering both transfused and non-transfused patients.
Abbreviations: Pt: patient; FFP: fresh frozen plasma, trans.: transfusions, HA: human albumin; HD: hemodialysis.

sets and blood/blood products required for 1000 crush patients would be 8250 and 13 000, respectively.

In terms of medical professionals; an ideal assessment team should consist of two nephrologists (one for dialysis, one for medical issues), one dialysis nurse and one technician. Follow-up teams should contain 1–2 nephrologists, 3–5 nurses and 1 technician. However, the figures may differ along local needs. During the Marmara earthquake, 158 Turkish doctors (nephrologists, internists or general practitioners), and 387 hemodialysis nurses participated in the treatment of 477 dialyzed victims. In addition, 6 nephrologists, 35 hemodialysis nurses and 20 members of Médecins sans Frontières (MSF) from various countries participated in the intervention of the Renal Disaster Relief Task Force (RDRTF) [159, 348]. Of note, medical personnel were not only involved treating AKI and dialysis patients; local personnel continued to treat other renal problems and non-renal disease, whereas MSF members were active in many other non-renal programs as well as in diplomatic, informative, educational and logistic activities.

Circumstances and needs will differ depending on the disaster and its location [349, 350]. For example, in the Haiti earthquake due to the dimensions of the disaster, the number of victims, the duration of the intervention and the infrastructural damage, the RDRTF comprised 9 doctors, 11 nurses and 5 dialysis technicians for only 27 dialyzed AKI patients, whereas the MSF team at its maximum was composed of more than 100 rescue workers [132].

VII.3.C: *Dialysis personnel should be redistributed from non-functioning to functioning units, as necessary.*

While many dialysis units can become non-functional after disasters due to damage [28, 345, 351], the number of patients who are in need of dialysis increases considerably. This necessitates scheduling of extra dialysis shifts in still-functioning units. The local staff may be insufficient to deal with the increased patient load; therefore, the personnel of non-functioning dialysis units should be redistributed to the units that remain functional [1, 327]. External, local and international support should be sought early to help addressing this shortage.

VII.3.D: *Relocation of chronic dialysis patients should be planned in advance.*

Disasters strongly impact chronic dialysis patients, because they may have considerable difficulty accessing dialysis. In the immediate aftermath of Hurricane Katrina, more than 40% of dialysis patients missed at least one dialysis session and nearly 17% missed three or more sessions in the month after the storm, which resulted in higher rates of hospitalization [352, 353]. Almost all of the 2500 chronic dialysis patients from the affected area had to be moved to other dialysis centers throughout the United States [354]. To reduce chaos, for potentially predictable disasters such as hurricanes or volcano eruptions, the evacuation of chronic dialysis patients should be planned in advance; however, this is not possible for unpredictable disasters, such as earthquakes.

In all disaster-prone areas, local medical professionals should be aware of procedures and actions to relocate patients required during the period immediately preceding and following the disaster [355].

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Section VIII: Implementation of a Renal Disaster Relief Response Program

Section VIII.1: Preparations before the disaster
Section VIII.2: Measures to be taken in the aftermath of the disaster

Section VIII.1: Preparations before the disaster

VIII.1.A: Renal disaster relief strategies should include an advanced plan of measures to be taken following a disaster.

VIII.1.B: Renal disaster response teams should be composed of coordinators of operations, assessment team members, rescuers and medical personnel.

VIII.1.C: Mapping of local dialysis facilities and referral hospitals should be prepared in advance, so that an effective disaster response can be deployed immediately after the disaster.

VIII.1.D: Educational programs targeting the public, rescue teams, medical and (para-)medical personnel, as well as chronic dialysis patients, should be developed and implemented prior to the occurrence of any disaster.

VIII.1.E: Deployment of external and local medical and (para-)medical personnel, distribution of supplies and provision of dialysis services should be planned in advance.

VIII.1.F: A disaster response scenario should be prepared for collaboration with external rescue organizations.

Rationale

VIII.1.A: *Renal disaster relief strategies should include an advanced plan of measures to be taken following a disaster.*

Advance plans and preparations (as further described below) are vital to minimize chaos and provide the most effective care in a disaster situation [350, 355].

These preparations should include: composition of disaster response teams, organization of educational activities, planning of interventions and of collaboration with external bodies (Figure 6).

VIII.1.B: *Renal disaster response teams should be composed of coordinators of operations, assessment team members, rescuers and medical personnel.*

In order to decrease post-disaster chaos, renal disaster response teams should be composed in advance. Rescuers with different profiles and expertise should cooperate closely in one or more teams, composed of members from the local area and/or from outside the disaster area (mostly from abroad). Ideally, the teams should include [42]:

1. *Coordinators* [e.g. local key-person, disaster relief coordinators and the chairperson of the Renal Disaster Relief Task Force (RDRTF) or any other similar disaster relief organization to plan, organize and monitor the operations],
2. *Assessment team members* to visit the disaster field as soon as possible to determine the need for help on the spot,
3. *Rescuers and medical personnel* to directly and actively intervene at the disaster field, field hospitals, reference hospitals or in dialysis units.

Since most disasters occur unexpectedly, and qualified personnel in the disaster area may be unavailable for a variety of reasons, back-up personnel should be assigned for every function, especially for the coordinators.

VIII.1.C: *Mapping of local dialysis facilities and referral hospitals should be prepared in advance, so that an effective disaster response can be deployed immediately after the disaster.*

An inventory of the dialysis facilities and referral hospitals in areas at risk is of vital importance [355]. This should include the structural characteristics of buildings and the risk of damage after a disaster, in order to anticipate which units have the better chance to remain functional after a catastrophe (Table 16). Those units should be utilized as first-line referral sites from the disaster area, once it is established that they indeed are not damaged. The number of chronic dialysis patients, dialysis machines, medical/non-medical personnel in each unit and emergency contact information (name, address, phone, mobile phone, etc.) should be recorded for planning purposes.

This information should be made easily accessible and regularly updated in the emergency preparedness plans. An agreement should be made with the concerned hospitals, and confirmed after site visits subsequent to the disaster. These plans should be accessible on the internet, e.g. on the web page of national renal societies and local health authorities. Unfortunately these plans are not always accurate or up to date and may not be totally reliable, but may still be useful, when these drawbacks are taken into account.

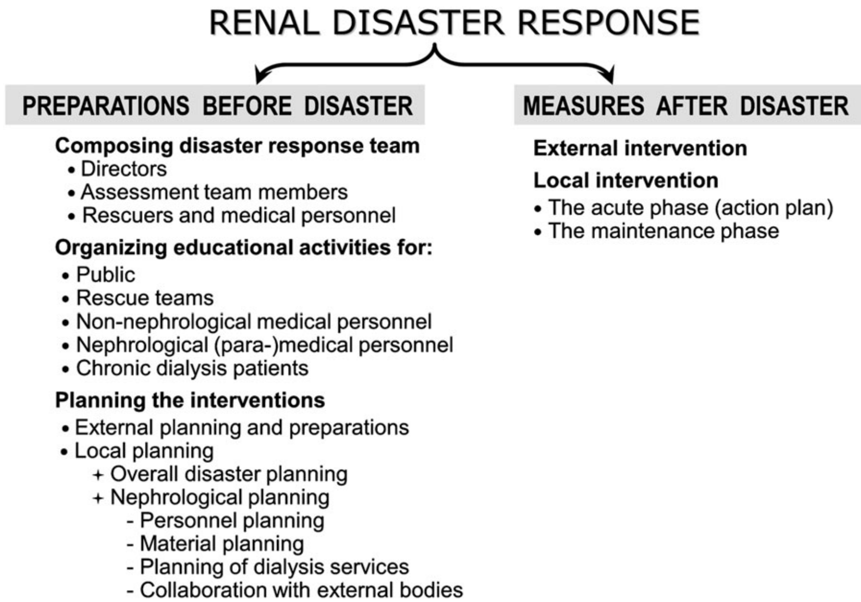

Figure 6. Major steps in renal disaster response (reproduced from [42] with permission).

Table 16. Checklist for information collection on dialysis units

• Name of the unit
• Private/public status
• Structural characteristics of the building
• Possibility for helicopter landing within a perimeter of 1 km
• Number of hemodialysis machines, type of the machines
• Normal staffing
• Number of hemodialysis nurses and their contact information, such as phone, mobile phone, and e-mail
• Number of nephrologists and their contact information
• Number of non-nephrologist doctors and their contact information
• Number of chronic patients dialyzed in the unit; their name and contact information
• Number of doctors available for health care service in the field or in other units
• Number of hemodialysis nurses and technicians available for health care service in the field or in other units
• Maximum number of patients who can be treated in that particular unit

VIII.1.D: *Educational programs targeting the public, rescue teams, medical and (para-)medical personnel as well as chronic dialysis patients, should be developed and implemented prior to the occurrence of any disaster.*

Disasters are inherently associated with chaos. Everyone who is expected to be affected or to intervene (Figure 6) should be educated in advance. Educational efforts should be directed to the following [42, 355].

Public: People living in disaster-prone regions should be trained on how to secure themselves, how to decrease the risk of injuries and related complications before, during and immediately after an earthquake [356–360], and how to contribute to the rescue of affected victims if they remain uninjured themselves [45, 74, 361].

Rescue teams: Optimal rescue teams include health care personnel; however, in mass disasters this is often impossible. Thus, non-medical rescue team members should be trained to recognize and treat the medical problems and complications associated with crushed limbs early during extrication [47].

Non-nephrological (para-)medical personnel: Crush syndrome is rarely encountered in daily practice, therefore not all medical personnel are familiar with its management [27]. To avoid errors, periodic pre-disaster educational programs should be organized to update information on treatment of crush syndrome casualties [42, 362].

Nephrological (para-)medical personnel: The care of AKI victims in disasters differs from that of AKI patients in regular clinical practice. Nephrologists and dialysis nurses should be trained in the management of crush-related AKI. Dialysis nurses should be trained in the appropriate measures to follow if a disaster occurs during a hemodialysis session [363].

Chronic dialysis patients: Hemodialysis patients should be trained how to react during a disaster, especially if the event happens during dialysis. They should be informed about the potential problems with which they may be confronted, and offered practical solutions to overcome them. Specifically they should be informed on how to disconnect themselves from a dialysis machine, in case medical personnel is not available or injured when a disaster occurs; and how to control their fluid, food and electrolyte intake in case their next dialysis session is delayed (Table 17) [28, 346]. Dialysis patients should also provide their contact information to the dialysis units. They should have a map of dialysis facilities and emergency numbers to call or web pages to consult for their continued care.

Chronic peritoneal dialysis patients should be educated on:

a) how to act in case of nonhygienic conditions,

b) specifically, how to make disconnection if automated peritoneal dialysis is being applied, and

c) quantity of medical material to be stored considering problems in delivery of dialysis solutions and other medications [364–366].

VIII.1.E: *Deployment of external and local medical and (para-)medical personnel, distribution of supplies and provision of dialysis services should be planned in advance.*

Consider that renal disaster relief response is a component of the general disaster relief process, and should be in coordination with overall command and control. Nephrological relief is only possible if rescue teams are embedded into larger (governmental and non-governmental) structures, both from medical and logistic point of view (please see appendix).

For an effective disaster response, external and local deployment of medical and (para-)medical personnel, and distribution of material and dialysis services should be planned.

1. External planning

To facilitate rapid intervention after a disaster from outside the disaster area, advance planning should cover [26, 205, 350, 367]:

- Enlisting volunteers for international response teams that include assessors, coordinators, adult and pediatric nephrologists, intensivists, dialysis nurses and technicians,
- Collaboration with other organizations (such as international and local nephrology societies),
- Assigning and developing relationship with local contact persons who can be reached in a disaster,
- Collaboration with non-governmental organizations with logistic experience in disaster conditions.

2. Local planning

A chief disaster relief coordinator should be responsible for overall nephrological planning before a disaster. A country should be divided into sectors, and sector coordinators should be assigned to act as primary coordinators in their own region or to provide support if a disaster occurs elsewhere in their region [42].

One of the most important responsibilities of nephrological disaster coordinators is planning of dialysis services for both acute and chronic patients:

a) If dialysis units and local infrastructure are not damaged, and if the dialysis personnel and the stocks of dialysis material are intact, the number of dialysis shifts may have to be increased to cope with extra dialysis sessions needed for crush victims.

b) If dialysis material, units and city infrastructure are intact, but the number of dialysis personnel is insufficient, support personnel should be recruited from other regional units or from abroad [1, 327].

c) If there is extensive damage to local infrastructure and dialysis units, the only option is transferring patients to other parts of the country or even abroad [327, 335, 368].

To overcome these problems, renal disaster relief planners should prepare a list of dialysis units in their country in advance, including their machine and personnel capacities, number of extra patients that can be taken on and emergency contact information. Local transportation possibilities should be explored and defined in advance. Local coordinators should keep themselves informed

Table 17. Problems arising in chronic hemodialysis patients and practical solutions that can be instructed to handle them [42, 355]

Problem		Solution to be instructed
Related to dialysis session	Attitude during disaster	- Disconnecting themselves from the dialysis machine and seeking protection.
	Attitude early after disaster	- Leaving the building as soon as possible, without removing dialysis needles.
Related to interdialytic period	Prevention of volume overload	- Restricting salt and fluid intake.
	Prevention of hypertension	- Continuing antihypertensive medication on a regular basis.
	Prevention of hyperkalemia	- Restricting potassium containing foods and use of kayexalate, which should have been stored before disaster.
	Missing of dialysis session(s)	- Remaining confident that omitting one or even two dialysis sessions can be tolerated. - Seeking alternative locations where it is possible to receive hemodialysis.

about all possibilities for transport of material and victims (timing of convoys, local flights, helicopter rotations, boat transport etc.) [39, 40, 43, 335].

In case of major transportation problems, the best compromise may be the installation of temporary dialysis units near the disaster area. This option should only be used when there are no valid alternatives, because such stand-alone units often lack adequate back-up facilities such as nearby intensive care units. In the Haiti earthquake, the RDRTF/ISN installed an almost *de novo* dialysis unit, importing machines and repairing the water system of a seriously damaged existing unit. The long-term sustainability of such an intervention remains to be proven [132].

Local logistic planning of nephrological personnel and supplies has been already described in Section VII.

VIII.1.F: *A disaster response scenario should be prepared for collaboration with external rescue organizations.*

Following mass disasters, external collaboration is essential for many reasons [39, 40, 205, 367]:

1. Shortage of dialysis hardware can be supplemented from outside,
2. Contributions of experienced coordinators and nephrologists are crucial to organize support since they are not affected by injury to their own family or property,
3. Experienced external personnel reduces the workload of local health care practitioners and services,
4. Personnel from other regions or countries provide emotional and psychological support to the local staff, who are at high risk of exhaustion and burnout.

Therefore, a plan for collaboration with external rescue organizations should be prepared in advance.

Section VIII.2: Measures to be taken in the aftermath of the disaster

VIII.2.A: The chairperson of the Renal Disaster Relief Task Force (RDRTF) and local authorities should be contacted as soon as possible.

VIII.2.B: Previously developed action plans should be implemented as early as possible, under the guidance of the formerly identified coordinator.

Rationale

VIII.2.A: *The chairperson of the Renal Disaster Relief Task Force (RDRTF) and local authorities should be contacted as soon as possible.*

Two levels of coordination should be considered in a renal disaster relief: 1. global coordination, 2. local coordination (Figure 7).

1. Global coordination: Coordinators of global rescue organizations [in case of a renal disaster the Renal Disaster Relief Task Force (RDRTF)] assess the need for relief and estimate the number of anticipated crush syndrome victims,

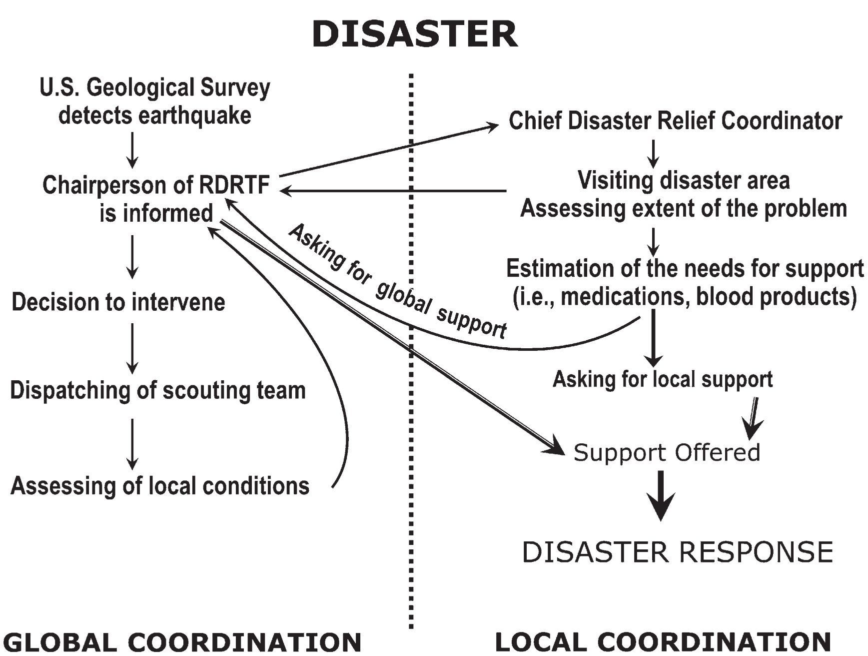

Figure 7. Principal steps in global and local coordination of renal-disaster relief efforts (see also Figure 8). (reproduced from [42] with permission).

based on international press resources (e.g. BBC-online) and telephone or e-mail communication with local contact persons. Other rescue organizations are often not aware of the opportunity of nephrological support or dialysis [55]. In that case communication with or participation in the Office for the Coordination of Humanitarian Affairs (OCHA) might be of help. There is certainly a need for efficient interagency communication. The full-time assignment of a liaison officer/technician to participate at the coordination meetings may be useful and save lives.

If necessary, the coordinator of the international organization assigns a local chief disaster relief coordinator, dispatches a nephrological assessment team and offers support (Figure 7) [26, 205].

2. Local coordination: The chief disaster relief coordinator visits the disaster field to assess the extent of damage and ask for national and international support, if the disaster cannot be coped with locally. He/she should contact with global coordinators as soon as possible to prevent any delays, misunderstandings or redundancies in international intervention.

VIII.2.B: *Previously developed action plans should be implemented as early as possible, under the guidance of the formerly identified coordinator.*

The previously developed disaster response plan comprises a series of actions aimed at an effective disaster response. Relief operations are initiated by the chief disaster relief coordinator unless this person is disabled or not reachable, in which case a step-by-step order of alternative assignment should be followed in selecting the next in-line substitute when needed (Figure 8) [42]. If a previously unreachable chief disaster relief coordinator makes contact subsequently, this eliminates the function of the substitute coordinator allowing for the resumption of relief activities at the previously defined level.

In the *acute phase,* which covers the first 3 days, the chief disaster relief coordinator should determine the extent of damage, preferably visit the most severely affected zones (Figures 7 and 8), to evaluate the infrastructure and the status of the medical facilities. The local coordinators should be contacted and briefed with instructions on how to optimize the supportive response (Figure 8) [42]. The results of this first assessment should be transmitted to national (governmental and non-governmental) and international organizations (in the case of renal rescue, mainly the RDRTF), which impact decisions on shipment of required medical supplies and personnel [26, 43, 205]. Unsolicited donations, if not based on specific and well-defined requests, should be discouraged [361]. They overburden the local distribution and logistic support system and contribute to the existing chaos [369]. For example, after the Haiti earthquake, the RDRTF received a donation of several thousands of liters of unsolicited peritoneal dialysis (PD) fluid, which were completely useless in that particular disaster. This donation obliged Médecins Sans Frontières (MSF) to transport, unpack, sort, store, and ultimately destroy tons of useless material. Therefore, material donations should be limited to what is requested, and should be coordinated with teams on the ground [132, 350, 370].

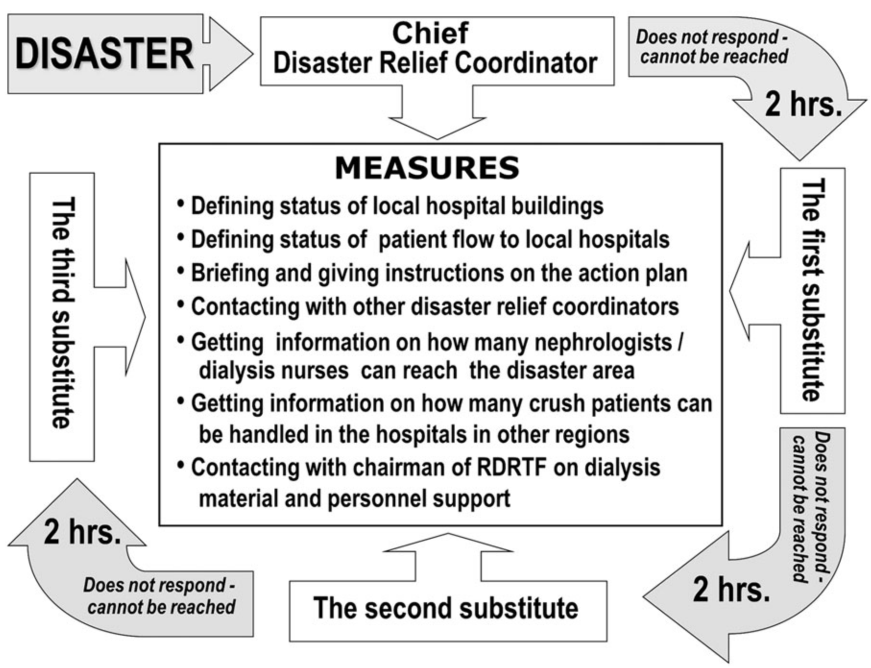

Figure 8. Major steps of renal rescue at the local level during the acute phase of a major disaster. Measures taken by the chief disaster relief coordinator are summarized. The substitutes should try to contact the chief disaster relief coordinator and each other even before the 2 hours limit shown, so that they know each other's status and availability as early as possible (reproduced from [42], with permission).
Abbreviations: RDRTF: Renal Disaster Relief Task Force; hrs: hours.

Table 18. Priority list of equipment and relief supplies

Consumables that can be carried as hand luggage	Consumables to be transported as cargo

• Dialysis catheters
• Point of care devices (e.g. I-stat^R)
• Airway devices
• Headlamps
• Printed sheets for recording laboratory values
• Urine dipsticks
• Emergency medications
  • Antiarrythmics
  • Antibiotics
  • Antihistaminics amp.
  • Antihypertensives (long and short acting)
  • Atropine sulphate amp.
  • Calcium gluconate amp.
  • Corticosteroids amp.
  • DDAVP amp.
  • Digoxin amp.
  • H2- receptor antagonists amp.
  • Haloperidol amp.
  • Heparin amp.
  • Insulin (regular and long acting)
  • Ketamine amp.
  • Sodium polystyrene sulphonate (Kayexalate)
  • Local anaesthetics
  • Magnesium sulfate amp.
  • Morphine sulphate amp.
  • Na nitroprusside amp.
  • NaCl (3% and 5%) amp.
  • $NaHCO_3$ (8.4%) amp.
  • Nitroglycerin amp.
  • Noradrenalin amp.
  • Potassium chloride amp.
  • Protamine sulphate amp.
  • Salbutamol/albuterol amp.
  • Short acting nitrates
  • Antibiotics suitable for once daily administration in dialysis unit (such as ceftriaxone, levofloxacin and vancomycin)
	• Hemodialysis materials
	  - Machines,
	  - Dialysis filters
	  - Arterial/venous lines, blood line systems (tubings)
	  - Needles
	  - Dialysate concentrates
	• IV fluids (crystalloids)
	• Defibrillator
	• Self-inflating bag
	• ECG machines
	• Respirators
	• Chlorhexidine 2% in 70% isopropyl alcohol
	• Disposable paper, surgical gowns and drapes
	• Disinfectants (peracetic acid)
	• Gauze
	• Masks
	• Sterile and nonsterile gloves
	• Syringes (2 cc and 10 cc)
	• Tape
	• Suture materials, scissors
	• Sterile saline and water for injection
	• Oxygen tubing (nasal cannulas, masks)
	• Water testing material (e.g. chlorine/chloramine strips)

Abbreviations: Amp.: ampules; IV: intravenous; ECG: electrocardiography; DDAVP: deamino-8-D-arginine vasopressin.

Priority should be given to equipment or relief supplies that allow the delivery of care to the largest number of victims and at the same time occupy as little of the available transport capacity as possible (Table 18).

Beginning immediately after the disaster, the chief coordinator should coordinate the patient flow to various hospitals and direct the casualties to appropriate destinations.

Mass disasters are chaotic, necessitating emergency rescue and medical interventions. In order to avoid panic and confusion during the acute phase, a brief algorithm should be developed and distributed describing global and specific tasks at the disaster field or field hospitals and tertiary care hospitals (Table 19).

In the maintenance phase, which includes the first month after a disaster, consider the following points.

- Visit the disaster area, hospitals and dialysis units periodically to determine ongoing needs.
- Arrange for needed material and personnel support from national and international resources.
- Provide follow-up of all crush patients. Record their need for dialysis, and also outcomes (recovery of renal function, discharge from hospital, deaths and complications). Inform the medical community periodically about the short term outcome of renal cases.
- Distribute tracking sheets for collecting medical data to reference hospitals treating crush victims in order to develop a database allowing the post hoc analysis of results and factors responsible for outcomes to help develop improved approaches in future interventions (see Appendix, page i56–i58) [42].

Table 19. Main points of focus and responsibilities for health care providers after a mass disaster (for detailed description of these tasks see Sections II and III; pages i7 and i17, respectively)

Location	Global Tasks	Specific Tasks
Disaster Field or Field Hospitals	Determination of personal status	- resolve own disaster-related problems and make a plan for the requirements of own family. - inform the coordinating authorities if unable to function in general relief.
	Intervention before extrication	- consider own safety when approaching damaged buildings - begin medical evaluation of entrapped victims as soon as contact is established. - start a 1000 mL/h infusion of isotonic saline even before extrication, if possible.
	Intervention during extrication	- reevaluate victims during the progress of extrication, if possible - continue isotonic saline administration at a rate of 1000 mL/h for the first 2 h, in adults. - adjust the rate of fluids not to exceed 500 mL/h. in adults, if extrication takes longer than 2 h.
	General approach to the victim after extrication	- remove the victim as quickly as possible from the site of structural collapse. - check vital signs and perform a 'primary survey'. - perform triage. - treat any life-threatening emergency. - perform a 'secondary survey'.
	Fluid administration and urinary volume monitoring after extrication	- continue (or initiate) isotonic saline at a rate of 1000 mL/h, in adults. - consider ambient conditions to determine fluid needs. - insert an indwelling bladder catheter to monitor urine output.
	Other measures to be taken after extrication	- treat problems other than crush injury, i.e. airway obstruction, respiratory distress, intractable pain. - diagnose and treat hyperkalemia as early as possible. - prepare the patient for transport to a hospital once stabilized.
Tertiary Care Hospitals	General approach to all victims	- perform triage to designate victims to the appropriate treatment zone - treat victims according to accepted trauma guidelines - evaluate and treat fluid problems; in hypovolemic victims, identify and treat the underlying cause(s) - correct hypothermia, if present - treat infections early and appropriately - keep records of patients
	Approach to crush patients	- check the type of administered fluid; stop potassium-containing solutions - determine serum potassium by any available means, as soon as possible - treat hyperkalemia immediately - insert a bladder catheter if necessary to monitor urine flow - in case of volume overload in oliguric victims, restrict fluids and initiate ultrafiltration - treat other emergencies, such as acidosis, alkalosis, infections, symptomatic hypocalcemia - prevent and treat AKI according to necessity; if indicated, dialyze early - avoid all nephrotoxic medications, if possible - dose medication depending on renal function and adequacy of dialysis

Abbreviations: AKI: acute kidney injury; h: hour.

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APPENDIX

I. Initial assessment and management of the trauma patients following earthquakes

II. Triage

III. Renal Disaster Relief Task Force (RDRTF) of the International Society of Nephrology (ISN)

IV. Médecins Sans Frontières (MSF) (Doctors Without Borders)

V. European Renal Best Practice (ERBP)

VI. Prospective data collection and assessment forms

I. Initial assessment and management of the trauma victims following earthquakes

Different protocols for different scenarios have been developed aimed at different professional sectors involved in trauma response [e.g. Advanced Trauma Life Support (ATLS®), Pre-Hospital Trauma Life Support] in order to limit preventable deaths and to lessen morbidity after trauma. These emphasize early recognition of life-threatening injuries and the selective allocation of resources.

Specific earthquake-related problems

Although the principles of initial assessment and management of trauma patients are universal, disruption of the medical infrastructure may force responders to adopt different approaches than those used in daily practice to treat injured patients.

At the disaster scene, the medical teams arriving on site have several priorities. These are in chronologic order:

- An overall assessment of the site and the victims to prevent further injury,
- The performance of a primary survey,
- Rapid transport to the nearest 'appropriate' medical facility, and
- The initiation of definite treatment either on site or during transport.

However, it may be practically impossible to accomplish some of these goals.

Specific problems of entrapped victims

Victims buried under rubble present specific problems; both assessment and treatment are constrained by the confined surroundings (Table 20) [46, 371, 372, 373].

Medical evaluation of the trapped victim should start as soon as contact is established. Verbal communication may be the only means of assessment at first. Physical contact allowing primary survey, not uncommonly, is impossible until immediately before or even only after extraction. It must be realized that even if the victim is fully conscious and cooperative, serious complications may be present.

Several issues may differentiate victims buried under rubble from victims injured in other circumstances:

- Airway and breathing problems are commonly caused by multiple mechanisms,
- These patients are often, if not always, dehydrated,
- Those with significant crush injury to the limbs are at risk in the acute phase, and subsequently, of life-threatening arrhythmias, and in the later phase of sepsis and kidney failure,
- These life-threatening conditions are potentially reversible and can be minimized by appropriate fluid resuscitation and proper treatment of the severed limbs,
- Spinal cord injuries are suggested by feeling of numbness or tingling in the extremities, but entrapment commonly does not allow for spinal immobilization until the patient has been extricated.

It is recommended to secure a large bore intravenous access as soon as possible to allow early infusion of fluids (see Section II, page i7).

Following extrication, the patient should be reevaluated and the extent of injuries defined before transport to a functional hospital for reassessment and treatment according to accepted trauma guidelines.

Table 20. Treatment and evaluation of the victim buried under rubble

Primary survey	Problems to be taken into account	Intervention
Airway	- Consider that airway may be compromised	- Maintain airway patency; protect cervical spine
Breathing	- Consider that ventilation may be impaired secondary to dust or noxious gas inhalation and/or direct trauma	- Protect the patient from dust by applying a dust mask - Limitation of available space may interfere with safe intubation - Supplying oxygen may be limited by safety constraints - Analgesia may aid breathing in patients with broken ribs
Circulation	- Exclude dehydration - Assume the presence of crush injury unless definitely excluded - If the victim has been trapped for a long time and is still alive, assume there is probably no major active bleeding	- Control external bleeding - Assess volume status and then administer as much fluid as possible considering medical circumstances and logistic possibilities
Disability	- Consider neurologic examination may leave relevant lesions unrecognized	- Install or maintain spine protection
Exposure	- Consider the possibility of hypothermia - Expose body parts only if deemed absolutely necessary for saving life	- Cover, if exposed, to avoid hypothermia

Abbreviation: IV: intravenous.

II. Triage

Triage of trauma victims is the process of rapid and accurate evaluation to determine the extent of their injuries, the appropriate level of medical care required and priorities in treatment if several patients are presenting simultaneously.

Trauma triage decisions are usually made within a limited time frame and are based on limited information. In mass disasters triage may help guide interventions that will save the highest number of lives in the long-term [373]. Various triage systems exist that rely either on physiologic or anatomic criteria or a combination of both [374].

Physiologic criteria include heart rate, blood pressure, capillary return, respiratory rate and effort, level of consciousness and temperature.

Anatomic criteria define the type and extent of injury of different areas in the body (head, neck, chest, abdomen, pelvis, extremities).

Mechanism of injury (blunt or penetrating), age and extreme environmental conditions can deeply affect the final outcome, and should also be considered in decision making [34]. Unfortunately, all these criteria have limitations that affect their validity in disaster circumstances even if used by the most experienced medical personnel [373].

Various triage systems exist such as: 'Prehospital index', 'CRAMS (Circulation, Respiration, Abdomen/Thorax, Motor, Speech)', 'Revised Trauma Score', 'START (Simple triage and rapid treatment)' [375] and 'GCS (Glasgow Coma Scale)' [376]. A full discussion of these systems is beyond the scope of this monograph. One of the most frequently applied and most accurate systems, modified START, is summarized in Figure 9.

The START approach identifies mildly injured patients who can be sent home or to shelters. The remaining cases are classified into three categories:

- Victims requiring immediate care,
- Victims in whom care might be delayed,
- Victims who are dead or dying (Figure 9) [36].

Victims assigned to immediate and delayed care should receive further evaluation and treatment. Those facing imminent death should be separated from other victims and kept comfortable. Mildly injured patients can be used as volunteers for helping other victims. The victims who were assigned to care should be periodically reevaluated, and if their condition changes they should undergo a new triage assessment. Once their condition is stabilized, patients should be transported either to newly established field hospitals or to functioning hospitals outside the disaster zone.

For medical and social reasons it is useful to place a wristband on victims, which includes information on clinical and demographic features both at the disaster field (i.e. time of rescue, address or location of rescue, diagnosis, administered therapy, contact information for the relatives), and at the hospital (i.e. location in the hospital, ultimate diagnosis, name of the attending doctor, drugs to be avoided).

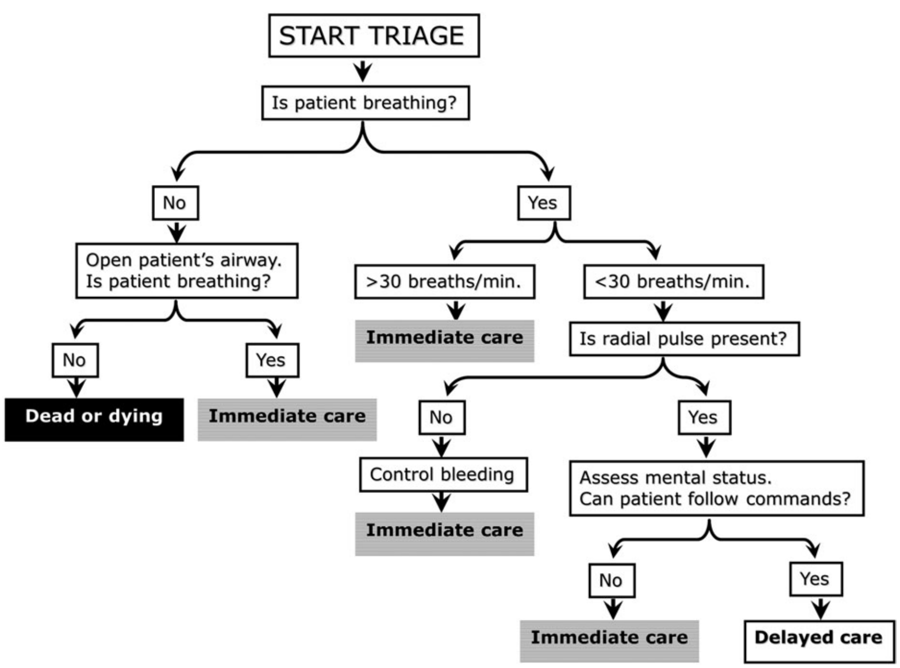

Figure 9. The Modified Simple Triage and Rapid Treatment (START) System. Victims who can walk are identified first and receive first-aid measures only. The remaining patients are classified according to the algorithm. Victims considered to need immediate care are assessed and treated before those whose care can be delayed. The algorithm should be used with caution in children younger than 8 years old (adapted from [36], with permission).

III. Renal Disaster Relief Task Force (RDRTF) of the International Society of Nephrology (ISN)

The Renal Disaster Relief Task Force (RDRTF) is an organization for humanitarian assistance created by the International Society of Nephrology (ISN). RDRTF missions always take place in coordination and with the logistic support of 'Médecins Sans Frontières' (MSF – Doctors Without Borders).

The Task Force consists of a worldwide network of experts in the management of patients with acute kidney injury (AKI) and crush injury. It sends volunteer nephrologists, intensivists, dialysis nurses and dialysis technicians to offer relief after earthquakes and other disasters by treating casualties with crush-related AKI, by coping with other problems involving renal failure patients in the aftermath of disasters, and by providing material and psychological support, and teaching [205, 368].

Volunteers must comply with a number of conditions (Table 21).

The local personnel of the affected country and international volunteers work together in order to organize the most effective disaster response and to save as many lives as possible (Table 22).

RDRTF has prepared charts to facilitate and standardize the collection of data regarding disaster victims. They are intended for:

- Clinical follow-up of crush syndrome patients (Table 11),
- The monitoring of the inflow of crush patients to various hospitals early after the disaster (see 'Prospective data collection and assessment forms – Form.1', page i56), and
- The collection of epidemiologic data on crush syndrome cases in chaotic conditions of overloaded hospitals (see 'Prospective data collection and assessment forms – Form.2', pages i57–i58).

Information on the Renal Disaster Relief Task Force can be obtained from the secretariat of the coordinating center at: rdrtf@ugent.be or at the web page: *http://www.isn-online.org/isn/society/about/isn_20011.html.*

Table 21. Conditions with which renal rescue volunteers should comply

Compulsory
- A valid international passport
- Being a nephrologist, nephrological nurse, dialysis technician or intensivist
- Vaccinated against tetanus, diphtheria, hepatitis A and B, polio and yellow fever
- Ready to work under stressful and emotional conditions
- Ready to work under the rules and habits of the coordinating NGO (MSF, in the case of renal rescue)
- Ready to respect the local medical personnel and victims of the affected area and their culture
- Ready to work in team and to respect the team leader
- Having organizational skills

Desired
- Experience with dialysis
- Experience with disasters
- Vaccination against typhoid fever, rabies, meningococcal meningitis
- Knowledge of foreign languages (including local languages of earthquake-prone areas like Urdu, Pharsi)
- Permission from the employer to participate

Abbreviations: NGO: non-governmental organization; MSF: Médecins Sans Frontières.

Table 22. The members of the renal disaster relief response team and their duties

	The personnel	Duties
The local (national) level	Chief disaster relief coordinator	- Develops disaster preparedness programs, organizes advance educational courses. - Prepares clear algorithms to minimize therapeutic errors in chaotic conditions - Develops logistic plans for managing medical material, personnel and dialysis services. - Prepares action plans (or disaster response scenarios).
	Local coordinators	- Serve as primary coordinator in their particular region. - Support the chief coordinator and serve as his/her substitute.
	Nephrologists	- Perform activities which are similar to their daily routine; however they are assumed to treat more complicated cases than under usual conditions.
	Logistic support team[a]	- Provides medical material and restores damaged local infrastructure - Supports other team members for their practical and logistic needs.
	Hemodialysis nurses	- Provide dialysis service to both chronic and a large number of AKI patients.
	Technicians	- Solve technical problems with local infrastructure.
The external (international) level	Chairman of the RDRTF	- Develops and assembles advance response plans, educational material, volunteer lists, material stocks. - Collaborates with governmental and non-governmental organizations to intervene rapidly. - Offers organizational advice, medical material and personnel support, as needed.
	Members of the assessment team[b]	- First representatives of the Task Force to go to the disaster area - Inform the RDRTF chairman about the local conditions and the need for help.
	Coordinators[c,d]	- Cooperate with the local authorities and colleagues in logistic management - Offer medical care, if needed.
	Logistic support team[a]	- Helps local logistic support team. - Supports other team members for their practical and logistic needs.
	Follow up teams[c]	- Are usually composed of doctors, nurses and technicians. - Their assignment overlaps with that of the assessment team or previous or next follow-up teams. - They support local medical personnel.

[a]Logistic support team consists of logisticians, translators and drivers
[b]Assessment team ideally is composed of at least two members with nephrological experience (at least one nurse and one intensivist/nephrologist); returns back home if it has nothing more to do, which may be 2 to 3 days after arrival.
[c]Usually assigned for a 10 - 22 days period, including travel.
[d]International coordinators may be nephrologists or intensivists, if possible, experienced in disaster circumstances
Abbreviations: AKI: Acute kidney injury; RDRTF: Renal Disaster Relief Task Force

IV. Médecins Sans Frontières (MSF) (Doctors Without Borders)

MSF is an international, independent medical humanitarian organization, specialized in emergency aid to people affected by armed conflict, endemics and epidemics, exclusion from healthcare, and natural or man-made disasters. It has an associative structure, where operational decisions are made, largely independently, by the five operational centers (Amsterdam, Barcelona, Brussels, Geneva and Paris). Common policies on core issues are coordinated by the International Council, in which each of the sections (national offices, in 2009 a total of 19 sections) is represented.

In 2008 over 26 000, mostly local, doctors, nurses, and other medical professionals, logistical experts, water and sanitation engineers and administrators provided medical aid in approximately 80 countries. Nearly 2000 of these are expatriate positions in the field. Private donors provide almost 80% of the organization's funding, while governmental and corporate donations provide the rest, giving MSF an annual budget of approximately USD 650 million (2008 figure).

MSF was awarded the 1999 Nobel Peace Prize in recognition of its members' continuous effort to provide medical care in acute crises, as well as raising international awareness of potential humanitarian disasters. For further information, please see *www.msf.org.*

MSF field missions

MSF has field missions in close to 80 countries, mainly but not exclusively, in developing countries. The missions provide health care support in the broad sense of healthcare, including prevention, water and sanitation, nutrition, mental health etc.

Before a field mission is established in a country, an MSF team visits the area to determine the nature of the humanitarian emergency, the level of safety in the area and what type of aid is needed. Medical aid is the main objective of most missions, although some missions help in such areas as water purification and nutrition.

A field mission team usually consists of a small number of coordinators to head each component of a field mission (medical, logistics, administrative), and a 'head of mission', accountable to the headquarters (HQ). The head of mission oversees and integrates the different activities and deals with the media, national governments and other humanitarian organizations.

Medical volunteers include physicians, surgeons, nurses, and various other specialists. The conditions with which MSF volunteers should comply is provided in Table 23. In addition to operating the medical and nutrition components of the field mission, these volunteers are sometimes in charge of a group of local medical staff and provide training for them.

Table 23. Conditions with which MSF volunteers should comply

Compulsory
- Professionally qualified and licensed to practice (MSF cannot work with undergraduates)
- Languages: French and/or English

Desired
- The members of the nephrology intervention accept to work under the coordination of the medical coordinator and the emergency coordinator of MSF (respecting MSF rules regarding security, communications, medical focus).

The members accept to respect the 'Charter of MSF', below.

MSF's Charter

Médecins Sans Frontières (MSF) is a private international association. The association is made up mainly of doctors and health sector workers and is also open to all other professions which might help in achieving its aims. All of its members agree to honor the following principles:

- Médecins Sans Frontières provides assistance to populations in distress, to victims of natural or man-made disasters and to victims of armed conflict. They do so irrespective of race, religion, creed or political convictions.
- Médecins Sans Frontières observes neutrality and impartiality in the name of universal medical ethics and the right to humanitarian assistance and claims full and unhindered freedom in the exercise of its functions.
- Members undertake to respect their professional code of ethics and to maintain complete independence from all political, economic or religious powers.
- As volunteers and members understand the risks and dangers of the missions they carry out, they make no claim for themselves or their assigns for any form of compensation other than that which the association might be able to afford them.

MSF emergency interventions in case of natural disasters

When a natural disaster occurs, the initially available information is analyzed to decide if support can be relevant. Most often the decision is taken to carry out a needs assessment. This can be done by staff from the mission in the country where the disaster takes place, and especially in larger scale emergencies with staff sent by the emergency unit from the Headquarters. Based on the initial information and the context, it can be decided to carry out a needs assessment to decide on an eventual intervention. Most often however, the initial team will be large enough to enable the team to combine needs assessment with a first intervention to respond to immediate needs. A full assessment team (eventually combined with first intervention team) consists of an emergency coordinator, medical staff with different backgrounds (i.e. general practitioner, surgeon, operation theatre nurse), logistics, water and sanitation experts, and psychologists. In this team the 'assessors' from the RDRTF can be integrated. The decision to intervene, the objectives and the scope of the intervention is normally based on the findings of the assessment team, completed with information from other sources, and is taken formally in a 'project committee meeting' at headquarters, where an initial budget will be allocated.

V. European Renal Best Practice (ERBP)

The European Renal Association – European Dialysis and Transplantation Association (ERA–EDTA) Council has nominated an advisory board to discuss and define the future of European nephrology recommendations and guidance. This board met the first time in January 2008. Due to a substantial change in philosophy, it was decided to change the name of the initiative from European Best Practice Guidelines (EBPG) to European Renal Best Practice (ERBP). ERBP's main purpose is to increase the visibility and implementation of European nephrology recommendations and guidance and to enhance the quality of European and worldwide nephrology practice.

ERBP generates guidelines, recommendations, position statements and other guidance documents depending on the needs of the nephrological community and the available evidence [6, 320, 377–388]. More information can be obtained at: http://www.era-edta.org/page-8-38-0-38-erbpeuropeanrenalbestpractice.html.

VI. Prospective data collection and assessment forms

Another form of this series was shown in Table 11 of this text

Form 1. *Renal Disaster Relief Task Force of the ISN - Flow Chart for the registration of Crush Syndrome Cases.* This chart aims to facilitate the follow-up of the overall number of crush syndrome cases in chaotic conditions. It is meant for use by coordinators only, to inform both international coordination centers as well as local authorities. Since chaotic conditions usually result in loss of patient records, it is recommended to update this chart daily and transmit the data twice/thrice weekly to the coordination center(s).

Renal Disaster Relief Task Force of the ISN – *Flow Chart for the registration of Crush Syndrome Cases.*

Date	Name of the Hospital	Number of Crush Cases						
		Still in need of dialysis support	Dialyzed before, but no more in need of dialysis now	No need for dialysis so far	Recovered from AKI	Discharged from the hospital	Dead	Total

Definitions:
Still needs dialysis support: Patient who needs dialysis at least once weekly.
Dialyzed before, but does not need dialysis now: Patients not dialyzed since >7 days.
Recovered from AKI: Patient with serum creatinine level below 2 mg/dl who did not need dialysis support for the last >7 days.

Form 2. *Renal Disaster Relief Task Force of the ISN – Crush Syndrome Patient Questionnaire*. This chart intends to collect epidemiologic data on crush syndrome cases in chaotic conditions, to avoid the usual loss of medical records; hence it is recommended to fill out these queries at the earliest convenience. This may also help to identify patients with the crush syndrome.

Renal Disaster Relief Task Force – CRUSH SYNDROME PATIENT QUESTIONNAIRE – Page I* (Hospital:....................)

Case No	DEMOGRAPHY								TRAUMA			
	Name	Age	Gender	Chronic illness before disaster	City of origin	City where treated	Date of admission	Time under rubble (hr)	Extremity trauma	Abdominal trauma	Thoracic trauma	Other
1												
2												
3												

*In reality this chart actually includes 10 rows, which occupy one page, and each row is dedicated to one patient; however, for space concerns only 3 rows are shown.

Renal Disaster Relief Task Force - CRUSH SYNDROME PATIENT QUESTIONNAIRE – Page II*

Case No	ADMISSION FINDINGS													RIFLE CRITERIA				
	Blood Pressure	First 24 hr urine vol.	First urine color	CK	BUN	Crea.	K	Hb	WBC	Plt	Ca	P	Uric Acid	**R**= Risk of renal dysfunction	**I** = Injury to the kidney	**F** = Failure of kidney function	**L** = Loss of kidney function	**E** = End-stage kidney disease
1																		
2																		
3																		

*In reality this chart actually includes 10 rows, which occupy one page, and each row is dedicated to one patient; however, for space concerns only 3 rows are shown.
Abbreviations: CK: creatine phosphokinase; BUN: blood urea nitrogen; Crea.: serum creatinine; K: serum potassium; Hb: hemoglobin; WBC: white blood cells; Plt.: platelets; Ca: serum calcium; P: serum phosphorus.

Renal Disaster Relief Task Force - CRUSH SYNDROME PATIENT QUESTIONNAIRE – Page III*

Case No	Surgical Interventions at admission		Medical Interventions at admission		Surgical interventions during the clinical course		Medical interventions during the clinical course	
	Fasciotomy/Amputation	Other	Antibiotics	Other	Fasciotomy/Amputation	Other	Antibiotics	Other
1								
2								
3								

*In reality this chart actually includes 10 rows, which occupy one page, and each row is dedicated to one patient; however, for space concerns only 3 rows are shown.

Renal Disaster Relief Task Force – CRUSH SYNDROME PATIENT QUESTIONNAIRE – Page IV*

Case No	DIALYSIS			TRANSFUSIONS			COMPLICATIONS	OUTCOME Discharge/death	Date of discharge (death)
	Type / No. Days on Dialysis	Date of start of dialysis	Date of end of dialysis	No. Blood Transf.	No. FFP Transf.	No. Hum. Alb. Trans.			
1									
2									
3									

*In reality this chart actually includes 10 rows, which occupy one page, and each row is dedicated to one patient; however, for space concerns only 3 rows are shown.
Abbreviations: Transf.: transfusions; FFP: fresh frozen plasma; Hum. Alb.: human albumin.

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