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# Prehospital management of earthquake crush injuries: A collective review

**Fikri M. Abu-Zidan[1]*, Kamal Idris[2], Arif Alper Cevik[3]**

*[1]The Research Office and [3]Department of Internal Medicine, College of Medicine and Health Sciences, United Arab Emirates University, [2]Department of Critical Care and the Intensive Care Unit, Burjeel Royal Hospital, Al-Ain, United Arab Emirates*
**Corresponding author*



**Abstract:**

Earthquakes are natural disasters which can destroy the rural and urban infrastructure causing a high toll of injuries and death without advanced notice. We aim to review the prehospital medical management of earthquake crush injuries in the field. PubMed was searched using general terms including rhabdomyolysis, crush injury, and earthquake in English language without time restriction. Selected articles were critically evaluated by three experts in disaster medicine, emergency medicine, and critical care. The medical response to earthquakes includes: (1) search and rescue; (2) triage and initial stabilization; (3) definitive care; and (4) evacuation. Long-term, continuous pressure on muscles causes crush injury. Ischemia–reperfusion injury following the relieving of muscle compression may cause metabolic changes and rhabdomyolysis depending on the time of extrication. Sodium and water enter the cell causing cell swelling and hypovolemia, while potassium and myoglobin are released into the circulation. This may cause sudden cardiac arrest, acute extremity compartment syndrome, and acute kidney injury. Recognizing these conditions and treating them timely and properly in the field will save many patients. Majority of emergency physicians who have worked in the field of the recent Kahramanmaraş 2023, Turkey, earthquakes, have acknowledged their lack of knowledge and experience in managing earthquake crush injuries. We hope that this collective review will cover the essential knowledge needed for properly managing seriously crushed injured patients in the earthquake field.

**Keywords:**

Acute kidney injury, crush syndrome, disaster, earthquake, injury, management, mass casualty, medical response, rhabdomyolysis, trauma

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**ORCID:**
*FMA: 0000-0003-0143-8568*
*KI: 0000-0003-4190-6581*
*AAC: 0000-0001-6691-6298*

**Address for correspondence:**
Prof. Fikri M. Abu-Zidan, College of Medicine and Health Sciences, United Arab Emirates University, Al-Ain, United Arab Emirates.
E-mail: fabuzidan@uaeu.ac.ae

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## Introduction

Earthquakes are among the most unpredictable and catastrophic natural disasters which may cause mass casualties, severe destruction of the urban and rural infrastructures, and high mortality without any advanced notice.[1,2] The principles of medical management of earthquakes are like other disasters whether natural or man-made. This includes the four *PMRR* stages which are preparedness, mitigation, response, and recovery.[3-5] These should be modified according to the nature of the disaster, the number of victims, and the type and severity of injuries.

Preparedness for earthquakes includes developing well-structured buildings that can resist the earthquake shakes, and a resilient community that can cope up with disasters and return to its normal function as soon as possible. As an example, Ikegaya *et al.*, from Japan, reported the establishment of a hospital-based



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reverse-osmosis purification system that can supply ultrapure water covering 85% of daily hospital water consumption needs as preparedness for renal dialysis in managing future earthquake-related crush syndromes.[6] Mitigation is reducing the earthquake effects immediately after it occurs by evacuating inhabitants from the earthquake area to avoid the risk of the aftershocks which may cause the collapse of incompletely damaged buildings, and providing them with the *five survival essentials*, which are shelter, food and water, energy resources, communication facilities, and hope.[7] Response includes having a command center to control and manage the disaster. The medical response is an important part of disaster management which has four components: (1) search and rescue; (2) triage and initial stabilization; (3) definitive care; and (4) evacuation; and finally, recovery is the action made to make the community return to its normal function.[8] Major destruction involving the health-care facilities, transportation routes, and medical supplies that occur by earthquakes can have long-term negative impact on the health-care system.[9] The successful management of disasters should have all these components.

The recent two consecutive Kahramanmaraş 2023 earthquakes that occurred on February 6, 2023, in the south of Turkey demonstrated the importance of all these stages. These earthquakes had 9 h between them with a severity of 7.8 and 7.6 Richter, and an effect of 500 km in diameter. They caused the death of more than 57 thousand victims and damaged more than 230 thousand buildings. The disaster zone was in an area of high poverty with old buildings and high number of Syrian refugees living in crowded houses which increased its number of deaths.[10-12] The members of the Disaster Committee of the Emergency Medicine Association of Turkey summarized the observations given by doctors who participated in the medical response of this disaster. These observations include: (1) the snowy cold winter with ice on the roads delayed the transportation of the medical response teams, (2) there was shortage of medical equipment supply, (3) the deployment of health-care providers to the earthquake area was unplanned and uncoordinated, and finally, (4) majority of health-care providers acknowledged their lack of knowledge and experience in treating earthquake injured patients.[13]

The striking point of lack of knowledge is supported by similar observations from other disasters. Basic knowledge about the pathophysiology and mechanisms of earthquake-related crush injuries and how to treat them, both in the field and in the hospital, is of utmost importance, and usually lacking for those involved in earthquake rescue.[1,14,15]

Death on the field can be due to direct trauma to the head, spine, chest, major vessels, suffocation under the rubble, or acute metabolic changes resulting from relieving a crushed limb.[16] Delayed death can be due to sepsis or renal failure following the crush syndrome. Long-term, continuous pressure on a muscle group causes a *crush injury* with extensive necrosis of that muscles, with or without associated neurological problems.[8] *Crush syndrome* is a type of crush injury which has high mortality and is characterized by systemic complications after extrication of the patient.[9] It is the second-leading cause of death after earthquake trauma.[17] Out of 957 Kahramanmaraş earthquake victims, 7.7% had crush injury and 2.1% had compartment syndrome.[18] Historically, Professor Antonino D'Antona, an Italian surgeon and Director of Surgery at the University of Naples, Italy, was most likely the first person to describe the association between rhabdomyolysis and kidney injury following the Messina earthquake, Italy, 1909. He took care of 197 earthquake-injured patients, seven were in shock, and two died of uremia.[19] At the same time, it was described by *Franz von Colmers*, a German surgeon, who came in a relief expedition to treat patients in the Messina earthquake.[20,21] In 1941, Bywaters described four cases of crush syndrome which was not mentioned before in the English literature. He demonstrated the degenerative changes in the proximal convoluted tubules of the kidneys and the pigment casts in the distal part of the nephron.[22]

Prolonged crushing injuries of the chest and abdomen usually cause death at the field. Accordingly, the majority of those who arrive to hospitals have limb crush injuries.[23] Hereby, we aim to review the prehospital medical management of earthquake crush injuries in the field which will be useful for those health-care providers working in the earthquake field so as to improve the patients' care.

## Methods

PubMed was searched on March 3, 2023, and repeated on September 2, 2023, by the senior author (FAZ), using a combination of general terms including rhabdomyolysis, crush injury, and earthquake in English language without time restriction so as to have a wide range search. Titles were browsed, and then, the abstracts of relevant articles were read. Articles related to earthquake crush injuries were selected as judged by FAZ and then downloaded through the National Medical Library of the United Arab Emirates University.[24] This was meant to be a narrative collective review and not a systematic or a scooping review. Accordingly, there was no protocol used for search or data analysis. Articles were requested through the National Medical Library from other resources if they were not available. The articles were classified into three main categories and divided between three experts in the areas of (1) emergency medicine AAC to cover the prehospital care of crush injuries, (2) disaster medicine and acute care surgery (FAZ) to cover the disaster medicine and surgical management of crush injuries, (3) and critical care (KI) to cover the critical care section. Each of the three experts critically read their allocated literature and drafted their sections. Extra relevant references were retrieved from the reference lists of the studied articles. Finally, the senior author (FAZ) critically read the written material, restructured it, and repeatedly edited it. When needed, the reported categorical analysis was redone using Fisher's exact test or Pearson's Chi-square test as appropriate through the Simple Interactive Statistical Analysis program.[25] Illustrations, to simplify the text, were drawn by the authors or retrieved from open-access sources as needed. Due to the extent of the topic and differences in the management resources of the prehospital and hospital settings, and after discussion with the Editors-in-Chief of the Turkish Journal of Emergency Medicine, it was deemed appropriate to divide this topic into two reviews: the current one addressing the prehospital management of earthquake crush injuries, and a near future one addressing the surgical and critical management of crush syndrome. We think that these two separate reviews will be useful for those who treat crushed injured patients both in the field and in the hospitals.

## Epidemiology

Although more than million earthquakes occur every year, less than forty are annually reported [Figure 1].[26] Major earthquakes may injure up to 8% of the population at risk.[9] Majority of deaths occur within the first 3 h following an earthquake.[27] More than 80% of earthquake-related deaths occur in nine countries (Chile, China, Iran, Italy, Japan, Pakistan, Peru, Russia, and Turkey).[8] Figure 2 shows the most 11 deadliest earthquakes in human history, two of them occurred in Antakya, Turkey, where more than a quarter of a million died. These earthquakes occurred in a belt extending from Turkey in the west up to Japan and the Philippines in the east. In the year 1556, more than 800 thousand deaths occurred in Shaanxi, China.[28] Around 20% of deaths can be prevented with proper early medical response.[29] After earthquakes, those with limited mobility, such as the elderly, those with paralysis, amputees, those on ventilators, and those in wheelchairs and walkers, are more prone to become trapped under debris and develop crush injuries.[30] The burden of medical care occurs in the first few days following the earthquake, mainly in the first 24 h. Those injured patients who were hospitalized within the first 24 h had significantly more severe crush injuries, and complications.[31,32]

## Biomechanism of Earthquake Injuries

The effects of earthquakes on humans depend on 5 factors: (1) the structure design of the buildings; (2) the strength of the earthquake which is measured by Richter magnitude; (3) the associated factors which may include aftershocks, landslides, tsunamis, fires, release of nuclear materials, and destruction of dams; (4) the patients' demography and comorbidities; and finally, (5) the climate and environment where the earthquake occurred.[8] Ding *et al*. compared the severity of injuries of the Wenchuan earthquake 2008, China, which measured 8 on the Richter scale, and the Nepal earthquake 2015 which measured 8.1 on the Richter scale.[33] Although the severity of these two earthquakes was the same, the climates and environments were completely different.[33] The buildings in the Wenchuan earthquake were made mainly from brick-concrete compared with mud or stones in the Nepal earthquake. The authors studied 465 patients from the Wenchuan earthquake and 71 patients from the Nepal earthquake. Wenchuan earthquake had significantly more crush injuries (11.2% compared with 2.8%, $P = 0.03$) while Nepal earthquake had more fall injuries (18.3% compared with 2.8%, $P < 0.0001$). Similarly, van der Tol *et al*. compared the crush-related acute kidney injury (AKI) patients of Kashmir earthquake 2005 ($n = 88$) with Marmara 1999 earthquake ($n = 596$). Both earthquakes had the same severity of 7.6 and 7.4 Richter scale consecutively. Marmara patients had significantly more AKI (13.6 per 1000 victims compared with 1.3 per 1000 victims; $P < 0.001$), significantly more fasciotomies (52% compared with 26%, $P < 0.001$), amputations (16% compared with 3%, $P < 0.001$), and renal dialysis (80% compared with 63%, $P = 0.0003$). These differences were attributed to the buildings' structure, available medical care, and transportation times.[34]

Pan *et al*. studied the impact of the damaged buildings' structure and the victims' location on the severity and type of sustained injuries. This included the height of the building, the severity of its damage, and the injuries of the patients. Three hundred and nine subjects of the Meinong, Taiwan, 2016 earthquake which measured 6.4 on the Richter scale were studied, of whom 37.2% died, 38.2% were injured, and 24.6% were not injured. Residents who lived in high floors had the odds of 2.9 of dying and those who lived in crushed buildings had the odds of 18.2 of dying compared with others. Eighty percent of the residents who were in collapsed buildings had crush injuries.[35] Those who are crushed under the rubble in earthquakes and die will have more torso injuries, while those who arrive at hospitals will have more extremity injuries and fractures. These fractures will frequently involve more limbs and more bones, will be more in the lower limbs [Figure 3],

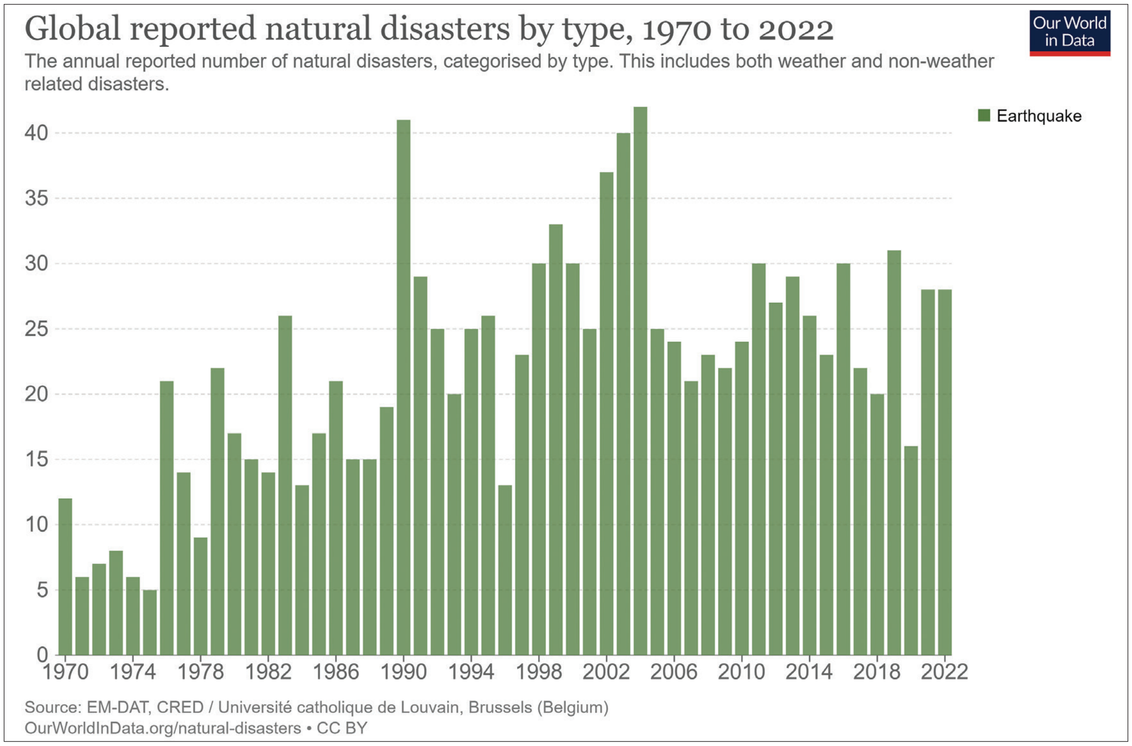


**Figure 1:** The annual global reported earthquakes during the period of 1970–2022. Reproduced from Our World in Data, Source: EM-DAT, CRED/Université catholique de Louvain, Brussels (Belgium). Licensed under the terms of the Creative Commons Attribution 4.0 International License (CC BY) (http://creativecommons.org/licenses/by/4.0/), which permits reproduction in any medium or format, as long as appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made. https://ourworldindata.org/grapher/natural-disasters-by-type?country=~Earthquake (Accessed on 2023 Sep 01)

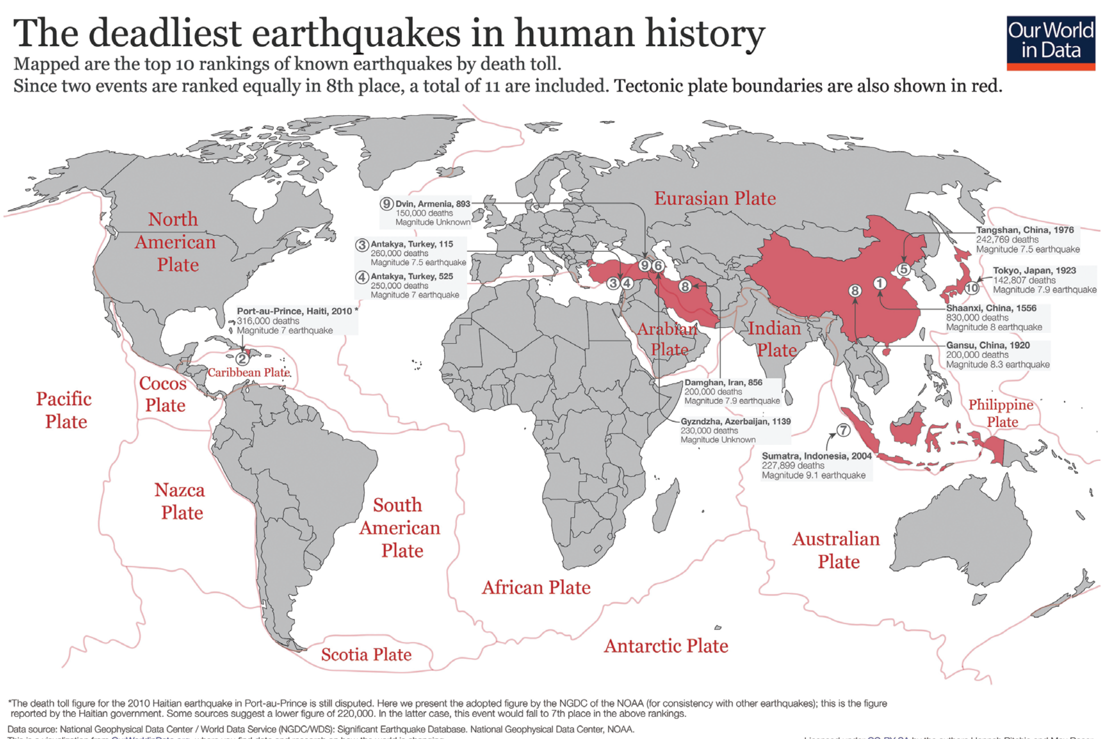


**Figure 2:** The top 10 rankings of deadliest earthquakes in human history. Note that it is resembling a belt extending from Turkey in the west up to Japan and the Philippines in the East. Reproduced from Ritchie H. Our World in Data. What were the world's deadliest earthquakes? October 5, 2018. Licensed under the terms of the Creative Commons Attribution Share-Alike license by the authors Ritchie H and Roser M which allows re-distribution and re-use of a licensed work on the conditions that the creator is appropriately credited and that any derivative work is made available under "the same, similar or a compatible license." https://ourworldindata.org/the-worlds-deadliest-earthquakes (Accessed on 2023 Sep 01)

**Figure 3:** An earthquake-injured patient who was transferred from the field of the Kahramanmaraş earthquakes to Ankara, Turkey, where he/she was treated at the Bilkent City Hospital. Note the large area of necrotic skin at the lateral side and front of the left knee where skin lies directly on bones. Also note the swelling of the left leg and the necrosis of the back of the right leg. Hospitalized crush injuries of earthquakes usually affect the lower limbs bilaterally. Reproduced from Ulusoy *et al*. Analysis of wound types and wound care methods after the 2023 Kahramanmaraş earthquake. Jt Dis Relat Surg 2023;34:488-96, which is an open-access article under the terms of the Creative Commons Attribution-Noncommercial License, which permits use, distribution, and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes (http://creativecommons.org/licenses/by-nc/4.0/)

mainly the fibula and tibia, and frequently will be comminuted compared with fractures encountered in daily routine trauma.[36,37]

Entrapment of victims and environmental conditions are important factors. Victims can be trapped for days under the rubble. Survival will then depend on their injuries and their needs for water and food.[9] Earthquake-injured patients may have confined space which makes the rescue more difficult. They may have dehydration, hypothermia, ambient hyperthermia, metabolic abnormalities, airway dust impaction, untreated closed-head injury, hypovolemia, dehydration/starvation, and cardiac arrhythmias. Blood loss may be repeatable or persist during extrication, and hemorrhage control options can be limited.[38]

## Pathophysiology of the Crush Syndrome

Many of the victims waiting to be rescued under the rubble are potential candidates for crush syndrome. Crush syndrome is a systemic complication following the relieving of muscle compression after an enough period for lactic acid, myoglobin, potassium, and other possible toxins to accumulate within the compressed tissue. The time required for this accumulation is around 1 h but can be less.[38] This ischemia–reperfusion injury leads to a situation where some materials accumulate within the crushed muscle while others are released into the circulation affecting other organs.[14,15,39] Rhabdomyolysis is the breakdown and release of muscular tissue (myoglobin) in the bloodstream resulting in renal impairment and subsequently buildup of toxic compounds in the blood [Figure 4].

Some materials change their concentration gradient from extracellular to intracellular compartments including sodium, water, and calcium which enter the cell, while others such as potassium and myoglobin are released into the extracellular compartment. The raised intracellular calcium causes muscular contractions that consume the cellular adenosine triphosphate (ATP) stores. ATP deficiency causes mitochondrial damage along with the release of enzymes such as proteases and phospholipases. These enzymes combined with oxidative stress damage the phospholipids of the cell membrane which leads to muscle cell lysis. Accordingly, the toxic metabolites which were accumulating in the cells are released to the extracellular compartment.[39,40] These substances will damage the capillaries leading to increased capillary leakage and third spacing of fluids. The increased fluid within muscle compartments that are surrounded by fascia such as the leg, thigh, and gluteal region will increase the pressure within these compartments [Figure 4]. This initially overcomes the small vessel pressure which occludes them and further depletes the energy sources of the cells such as ATP and glycogen. The decreased circulation will subsequently cause a reduction in oxygen saturation leading to anaerobic metabolism and accumulation of lactic acid. Major damage occurs when circulation is re-established by removing the crushing objects and extrication of the crushed limbs. Reperfusion will carry toxic materials, myoglobin, and high extracellular potassium to the systemic circulation which may cause cardiac arrhythmias and arrest. Furthermore, hypocalcemia will increase the effects of hyperkalemia on the heart.[15] During reperfusion, inflammation occurs which activates leukocytes that attack the tissues of the injured limb releasing further toxins to the rest of the body including myoglobulin. Myoglobulin and uric acid can directly damage the kidney by forming casts within the renal tubules leading to their obstruction.[9,41]

Crush injury patients are at high risk of shock within a few hours of presentation. This can be a hypovolemic shock from external, intra-abdominal, pelvic, or intrathoracic bleeding; distributive shock caused by extravasation of fluid to the third space; spinal shock caused by spinal injury; or cardiac shock caused by the toxic metabolites and hyperkalemia during the reperfusion of the crushed extremities. It is important to recognize the type of shock to properly manage it. Hypotension increases the risk of AKI and traumatic brain injury.

## Rhabdomyolysis and Metabolic Changes

There are three pillars for the diagnosis of rhabdomyolysis: (1) a crushed swollen limb, (2)

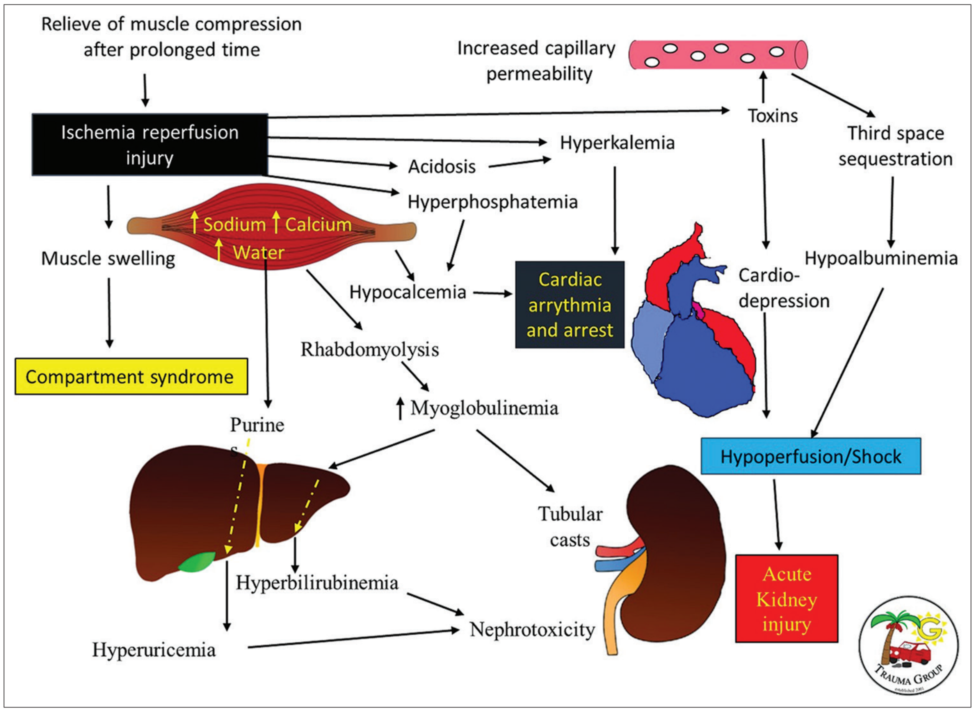


**Figure 4:** The pathophysiology and mechanisms of the crush syndrome, rhabdomyolysis, and acute kidney injuries *(Illustrated by Professor Fikri Abu-Zidan and Professor Arif Alper Cevik, College of Medicine and Health Sciences, United Arab Emirates University)*

discoloration of urine (reddish to brownish) which mimics hematuria, and finally, (3) elevation of creatinine phosphokinase (CPK) which is the most sensitive indicator of crush injury. Serum CPK peaks after 1 to 3 days of the injury and declines within 5 days. Crush injury rhabdomyolysis is usually defined as the rise of serum CPK higher than 5 times the upper normal limit (around 1000 U/L).[9,41]

Management of mass casualty earthquake incidents can be challenging in austere conditions, with limited trained manpower, destruction of medical infrastructure, and delayed transportation due to damaged roads.[1,39,42] Usually, laboratory investigations will not be available in the initial time after earthquakes. Clinicians will depend on the first two components to highly suspect the rhabdomyolysis. In the presence of highly equipped front-field hospitals or when patients are transferred to hospitals, other metabolic changes can be found. Urine analysis may demonstrate the presence of pigment granular casts. Serum analysis may demonstrate the presence of hyperkalemia, hyperphosphatemia, hypocalcemia, hyperuricemia, and high serum creatinine. Hyperkalemia may result in cardiac arrhythmias and may happen without an obvious finding of acute renal failure.[29]

Hypocalcemia may be present in early stages of rhabdomyolysis due to the deposition of calcium on necrotic muscle tissues. It is rarely symptomatic and should not be treated. Hyperphosphatemia is a result of the released inorganic phosphate from damaged muscles. Hyperuricemia is caused by the hepatic conversion of the purines released from injured muscle cells [Figure 4]. The release of phosphates and organic acids from damaged muscles leads to higher anion gap. Cell blood count should be performed in all suspected cases of rhabdomyolysis because an increased white blood cell count is an indicator of an inflammatory process. When disseminated vascular coagulation is suspected, the prothrombin time, activated partial thrombin time, the international normalized ratio, and fibrinogen should be tested and repeated as necessary. Hypoalbuminemia indicates severe capillary damage from rhabdomyolysis. Both albumin and erythrocytes can leak into the interstitial tissues. This can cause shock that is associated with acute reduction in the hematocrit in the absence of obvious hemorrhage or hemolysis [Figure 4].

## Acute Kidney Injury

AKI is a serious complication of the crush syndrome in the first few days following the injury. Its severity is associated with the amount of muscle damage and delayed fluid resuscitation.[43] Prompt and adequate fluid resuscitation appears to be the key to prevent renal failure after crush injury.[44] It occurs in more than one-third of those having crush syndrome.[40,45,46] Overall, 3%–5% of all earthquake-injured patients may develop

AKI, majority from crushed injuries although associated hypotension *per se* may cause it.[46,47] Out of 1827 injured patients of the Wenchuan 2008 earthquake, 8.2% had crush syndrome, of whom 42% had AKI. Of those who had AKI, 53.2% needed renal replacement therapy and 8.1% died.[46] Out of 476 injured patients of the Marmara earthquake, 1999, 18.3% had AKI. Sixty-eight percent of those who had AKI needed renal replacement therapy, and 11.8% of those who needed dialysis died.[48] Out of 5302 patients who were hospitalized following the Marmara 1999 earthquake, 12% had renal problems and 9% needed dialysis.[49] Many injured patients of earthquakes who survive the initial crush in the field may die later because of lack of dialysis facilities. The term of "*renal disaster*" was first introduced following the Armenian earthquake of 1988 to highlight this important point.[39]

AKI can be defined as "*a 1.5-fold increase in serum creatinine or by 0.5 mg/dl or a decrease in glomerular filtration rate by 50%, and/or a reduction in urine output below 0.5 ml/kg/h for more than 6 h*."[42] Depending on the severity of AKI, it may present with oliguria, followed by polyuria after 1–3 weeks of the injury. Three mechanisms are involved in its occurrence: prerenal, intrarenal, or postrenal [Figure 4]. The *prerenal* mechanisms include severe hypovolemia because of deprivation of water while entrapped; bleeding from the injured organs in the chest, abdomen, or major vessels; cardiac depression; or ischemia–reperfusion injury after relieving the crushed region which causes capillary endothelial damage and third space fluid sequestration. The *renal* causes include the nephrotoxicity by the bilirubin or uric acid, deposits of tubular casts, or the deposits of calcium and phosphorus within the kidneys.[9,39,41] The *postrenal* obstruction can be caused by traumatic urethral injuries, mainly in pelvic fractures.

## Triage

Triage is the process of identifying and classifying victims by injury severity aiming to determine their clinical needs and match them with the most suitable health facility for transferals to provide adequate treatment. The presence of mass casualties, multiple and severe traumatic injuries, and lack of health-care providers necessities the need for a rapid triage.[16] This helps to maximize the efficiency of using resources to ensure that as many patients as possible are saved.[50,51] Triage decisions are challenging. They are often made within limited time using limited information in a chaotic disaster scene. Patients can be unintentionally under- or overtriaged.[51]

Physiological criteria, anatomical criteria, and mechanism of injury are used for triaging the patients in the field. The Prehospital Index, CRAMS (Circulation, Respiration, Abdomen/Thorax, Motor, and Speech), Revised Trauma Score, START (Simple Triage and Rapid Treatment), and Glasgow Coma Scale are some of the used triage systems.[50] Nonetheless, modified START is routinely employed and effective in numerous instances of disasters or mass casualty situations. It simply identifies victims who require immediate care, those who can tolerate delayed treatment, and those who are already dead or unsalvageable. Obviously, crush injury victims require immediate treatment. Appropriate timely treatment saves lives and reduces long-term complications of crush injury and crush syndrome. In earthquakes, survival of victims who are trapped under the rubble is low.[52] However, evacuated living victims having crush injuries can be treated effectively, and complications can be minimized. START triage system uses color coding for patients such as RED: immediate, YELLOW: delayed, GREEN: walking wounded, and BLACK: deceased. Crush injury patients should receive immediate care in the treatment area to prevent complications.[53,54] However, START triage categorization of victims is defined by various factors such being able to walk, having spontaneous breathing or not, respiratory rate, radial pulse, and mental status. Hence, in disaster situations, triage decisions cannot be given only by concentrating on the crush injury.

Patients usually go directly to the nearest hospital in their private cars if the hospital was not damaged. Accordingly, triage in front of the hospitals can be a useful solution so as to not be overburdened by minor-injured patients. Our own experience in treating war-injured patients during the Second Gulf War 1990 and triaging them at the entry of the hospital taught us that the most experienced surgeon should be performing the triage instead of being in the operating room. This will have proper leadership, organize the triage process, and save patients and resources. Kulakoğlu *et al*. described their local hospital experience in the 2023 Kahramanmaraş earthquake.[18] Their hospital was in the earthquake zone and was not damaged. The medical staff triaged 957 earthquake victims, 402 in the first day. Only 174 (18%) were admitted to the hospital including 140 to the ward and 34 to the intensive care unit. Emergency physicians working in the disaster zone of the Kahramanmaraş earthquake noted that relatives of victims brought a large number of dead-on-arrival patients to the emergency departments affecting the management of salvageable patients.[13]

## First Aid in the Field

It is an essential priority for physicians to ensure their personal safety and needs in the field. They should prepare themselves with essentials of living such as food, water, shelter, warming, and communication before traveling to the disaster zone; otherwise, they become themselves a burden. After 1 week of the Kahramanmaraş earthquakes, volunteer health-care providers struggled to secure their basic essential needs.[13] Furthermore, they should not directly assist in the extrication of people from collapsed structures but concentrate on the care and treatment of rescued victims while wearing proper protective equipment.[50,55]

The priorities of their medical tasks include: *First*, assessment of the site and the victims. *Second*, triage of the patients. *Third*, primary survey for immediate life-threatening injuries of individual patients. *Fourth*, perform achievable medical management in the field. *Fifth*, prompt transportation of the patient to the nearest "appropriate" medical facility.[38] Nevertheless, some of these goals may not be achieved due to logistic and practical limitations.[50]

Space around victims can be restricted under collapsed buildings with difficult access to the patients to properly supply medical care. Even before extrication, medical evaluation of an entrapped victim should be started as soon as contact with the patient is made.[29,50] Medical responders may use only verbal communication and clues to evaluate the victim's situation during extraction.[29] In field disaster medicine, management of earthquake victims, particularly those exposed to traumatic injuries, requires a different approach than those provided in healthcare facilities. Some victims may remain trapped in the rubble for long periods and may need immediate medical care. If fast and proper steps are taken during this critical time, the risk of serious complications such as AKI, compartment syndrome, rhabdomyolysis, and cardiac arrest can be significantly reduced.[38] Stopping bleeding, maintaining airway, supporting ventilation, administering intravenous fluids, and preventing hypothermia are basics of initial care of these victims.[29] It is invalid to assume that a trapped victim who can speak is adequately oxygenated.[29,56]

Renal failure is the most serious complication of crush syndrome.[57] Accordingly, medical responders should establish proper intravenous/intraosseous line, preferably large pore in any limb, to initiate fluid resuscitation. Before releasing the crushed limb, proper intravenous hydration with isotonic saline infusion at a rate of 1 to 1.5 L/h in adults and 10–20 mL/kg/h in children is essential.[29,38,50] Potassium-containing fluids, such as Ringer's lactate, should be avoided because of the risk of hyperkalemia in these patients.[17] Furthermore, medical responders should be careful about fluid volume during resuscitation. This will depend on the victim's age, comorbidities, body mass index, injury pattern, and time being under the rubble. The bolus infusion of isotonic saline can be harmful for victims who stayed for a long time under the rubble and became oliguric.[50] Point-of-care ultrasound (POCUS) is useful in the prehospital setting in managing mass causality patients.[58-60] POCUS is useful in defining the type of shock and in monitoring the need of fluids by measuring the diameter of the inferior vena cava.[61,62] Using a hand-held blood analyzer can be helpful to address initial acid-base and electrolyte abnormalities of victims.[63]

## Postextrication Management

The entrapped injured patients should be reevaluated immediately after the extrication. The time under the rubble till extrication must be documented. Delayed extrication of crushed limbs significantly increases the risk of limb amputation.[64] The mean extrication time of those hospitalized after the Kahramanmaraş 2023 earthquakes ranged between 36 and 58 h.[64,65] Patients may require a different approach than the ABCDE approach adopted by the ATLS. The *Massive bleeding*, Airway, Respiration, Circulation, Hypothermia (*MARCH)* approach can be occasionally more appropriate.[66] Bleeding is the main cause of early death in these patients. Massive bleeding should be immediately recognized and stopped. A tourniquet should be used only for life-threatening bleeding when direct pressure or hemostatic measures fail.[50] Tourniquets should be removed as soon as possible to reduce its ischemic effects. Following this, *airway* should be established and maintained while protecting the cervical spine because spinal cord injuries occur in around 4% of spinal fractures.[67] This is followed by *respiratory system* evaluation and support. Decompression of tension pneumothorax and properly designed occlusive dressing of open pneumothorax should be applied immediately. Some victims may require analgesics when broken ribs affect their respiratory function. Oxygen supply should be considered depending on other safety concerns.[50] This is followed by evaluating the *circulation* and acting to stabilize it with intravenous fluids or even cardiopulmonary resuscitation if needed. Pelvic stabilization with pelvic belts or bed sheets should be used when clinically suspected to be the cause of the shock. Finally, it is important to prevent *hypothermia*, especially in an austere cold environment. Body parts should be exposed only if needed. The patients should be covered with proper thermal protecting material as soon as possible. Hot packs are the most effective method for preventing and treating hypothermia.[29] This should be followed by secondary survey even if there are no apparent external injuries in order to diagnose and treat any injuries that were missed during the primary survey with proper planned follow-up for late signs of crush syndrome, such as decreased urine output, dark urine, and signs and symptoms of uremia.[50] We think that tertiary survey will be useful for earthquake victims after transportation when they arrive to hospitals.

## Acute Compartment Syndrome

The most injured body regions in earthquakes are extremities.[67] Crush syndrome may occur regardless of injury severity. Nevertheless, the large muscle mass of a crushed lower limb carries a higher risk of developing rhabdomyolysis and crush syndrome.[43,67] In one study, 42.5% of crush injury victims developed compartment syndrome.[68] Skin discoloration, pallor, mottling, ecchymosis, or edema should be carefully inspected. Gentle palpation can identify tenderness, sensation abnormalities, suspected fractures, the presence of arterial pulses in the upper and lower limbs, and the capillary refill time. While portable pulse oximetry devices can provide valuable data regarding pulse and oxygen saturation, a thorough clinical examination will suffice for addressing crush injuries.

Early diagnosis of compartment syndrome is essential for effective treatment of the crush syndrome. Its risk increases in fractured and crushed limbs.[69] Therefore, early suspicion is important for its diagnosis, which can be easily missed if not suspected. A crush injury of muscles which are surrounded by fascia results in edema, tissue swelling, and interstitial hemorrhage within the compartment. This increases the compartment pressure leading to further microcirculation collapse, ischemia, and irreversible nerve and muscle damage.[57] The normal compartment pressure is less than 10 mmHg. When it exceeds 20 mmHg, capillary blood flow will be impaired.[57,70] Added dehydration and hypotension can significantly impact the perfusion pressure and blood flow.[71]

When ischemic changes happen, classical signs and symptoms of compartment syndrome can be detected. These are Pain out of proportion (which is classical of ischemia), Pressure and Paresthesia feeling, Pulselessness, Paresis, and Pallor of the extremities (*the 6 Ps*). Severe pain is the main and most consistent symptom. Pulselessness is rarely found. It is a late sign showing irreversible ischemic damage when the major large vessels of the limb are occluded.[50,72] Pain exacerbated by passive stretching of the muscles is the most accurate sign of compartment syndrome followed by diminished sensation and paresthesia.[73]

The intra-compartmental pressures can be measured in two ways: either directly, by inserting a needle that is connected to a pressure monitor, or indirectly, by measuring an increase in limb circumference. When compartment syndrome is suspected, it is useful to measure the intra-compartmental pressures of all compartments of the affected extremity if it is feasible, using proper instruments, and if expertise in measuring it is available. Numerous measurements may be needed throughout time. This will aid the clinical findings, especially in unconscious patients.[57,74] This can be done by a handheld portable electronic machine connected to a needle which is inserted into the compartment, or alternatively by a simple nonexpensive manometer with a similar principle as measuring the central venous pressure [Figure 5]. Strict antiseptic precautions should be followed because infection of a crushed limb can be disastrous. This procedure is contraindicated in the presence of skin infection. The amount of saline which will be injected to the limb should be minimum without air so as not to falsely increase the pressure or affect the reading. The affected leg should be positioned at the heart level while the needle should enter the skin of the measured compartment at a perpendicular angle. This procedure is tedious and should not be taken lightly. It needs skill and expertise to be accurate. It is usually done by a trained emergency physician, orthopedic surgeon, or vascular surgeon. False high pressures can be recorded if the needle is very close to the fracture site. The difference between diastolic blood pressure and the compartmental pressure is termed the perfusion pressure. When it is less than 30 mmHg, it may indicate the presence of a compartment syndrome. Perfusion pressure has a high negative predictive value which can rule out and not rule in the diagnosis.[75]

In the event of major disasters, medical professionals frequently depend on their clinical findings, including severe pain exacerbated by passive stretching of the muscles, paresthesia and decreased sensation, firm consistency of the muscle bulk, and increased limb

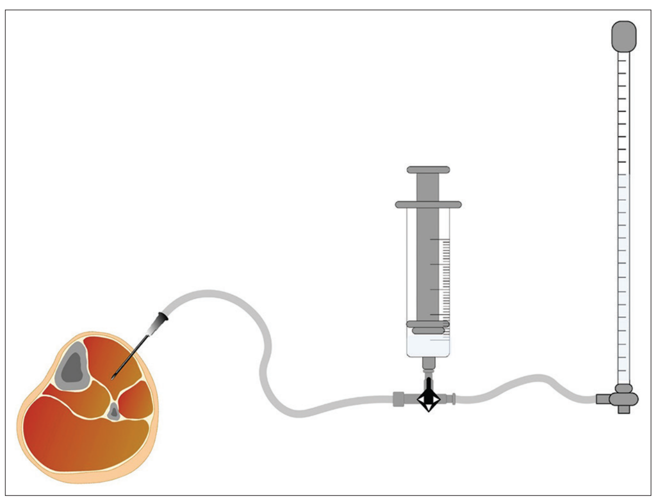

**Figure 5:** A simple method for measuring the intra-compartmental pressure in the prehospital setting, similar to measuring the central venous pressure, using a manometer, a syringe, tube connections, a stopcock, a needle, and saline *(Illustrated by Professor Arif Alper Cevik, Department of Internal Medicine, College of Medicine and Health Sciences, United Arab Emirates University)*

circumference compared with the normal limb of the patient.[76] The clinical findings have high specificity and low sensitivity.[75] We personally agree with Tillinghast and Gary[74] that repeated clinical examination by an experienced acute care physician is the best method for diagnosing extremity compartment syndrome in a conscious and cooperative patient during normal routine clinical practice. Nevertheless, we have personally learned the hard lessons during chaotic disaster situations, when there is an influx of patients,[77] that the physician may get distracted or not have the time to re-examine a patient having the risk of compartment syndrome. We think that clinical examination of a crushed limb by an experienced emergency physician is better than invasive procedures in the earthquake zone. Clinical examination takes shorter time, can be repeated easily, with less risk of infection. Decisions to make salvage fasciotomy or primary amputation in the field are preferred to be done by senior experienced surgeons because this has major implications on short-term survival and long-term disability.[64] The recommendations for the management of crush victims in mass disasters state that "Unless clearly indicated by physical findings or intra-compartmental pressure measurements, do not perform fasciotomies routinely to prevent compartment syndrome."[50] More details on the fasciotomy and indications for amputation will be elaborated in the second coming review.

## Transportation

Field hospitals can be useful only for temporary management of crush victims. These patients have special needs and should be transported to the nearest, suitable, well-equipped health facility outside the epicenter if those facilities are stable and unaffected by the disaster. Early transport is preferable because victims may show some additional complications in due course, and these complications may compromise the transport decisions.[50,78] Roads are usually affected. Accordingly, military boats and helicopters are the preferred ways of transfer.[78] Under certain circumstances, however, if roads are accessible, buses and even family vehicles can be utilized in addition to ground ambulances.[79,80] The role of air transport in reducing mortality and morbidity is significant.[79] Roadway transportation leading to the zone areas in the Kahramanmaraş 2023 earthquakes was disrupted due to these factors: (1) damage to the roads (2) ice covering the roads in a snowy February, and (3) relatives of patients using their private vehicles on roads. A transportation strategy was planned based on what is transported whether medical personnel, medical equipment, or patients. Roads, airways, and sea transportation were used in this strategy.[12]

The authors think that a national registry of all earthquake victims will be useful for those who make the transferal decisions so that they can follow up with the patients and know their complications and outcome. It is essential to close the learning loop of the health-care providers who helped in treating the earthquake crushed injured patients in the field so that they can learn from their own experiences. Understandably, patients' confidentiality should be protected. These data should be controlled and kept secure by a national committee. This can be an important source for research which can be used to identify areas of improvement on national and international levels.

## Conclusions

Earthquakes may cause major destruction of buildings resulting in a high toll of injury and death. Ischemia–reperfusion injury following relieving muscle compressions in the field may cause metabolic changes and rhabdomyolysis. Depending on the time of extrication, this may cause sudden cardiac arrest, acute compartment syndrome of the extremities, or AKI. We hope that this collective review covers the essential knowledge needed to recognize these complications so as to properly manage seriously crushed injured patients in the earthquake field.

**Author contributions statement**

All authors have contributed to the idea. Fikri Abu-Zidan supervised the project, did the literature search, retrieved the literature, critically read and wrote the disaster medicine and acute care surgical section of the article, drew Figure 4, organized the structure of the manuscript, and repeatedly edited the manuscript. Kamal Idris critically read and wrote the section on the pathophysiology of the crush syndrome, rhabdomyolysis, and acute kidney injury. Arif Cevik Alper critically read and wrote the section on the prehospital care of earthquake-injured patients, drew Figure 5, and assisted in drawing Figure 4. All authors approved the last version of the manuscript.

**Conflicts of interest**

None Declared.

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