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Management of Crush-Related Injuries after Disasters

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Disasters can rarely be anticipated, much less prevented. After both natural disasters (e.g., earthquakes, hurricanes, tornadoes, and landslides) and man-made catastrophes (e.g., wars, mining accidents, and terrorist attacks), injuries to vital organs can cause instant death. Late mortality is generally attributable to rhabdomyolysis resulting in the crush syndrome, which is the most frequent cause of death after earthquakes, apart from trauma.[1,2] Crush-related acute renal failure is one of the few life-threatening complications of crush injuries that can be reversed.

The crush syndrome affects many organs. Problems in addition to acute renal failure include sepsis, the acute respiratory distress syndrome, disseminated intravascular coagulation, bleeding, hypovolemic shock, cardiac failure, arrhythmias, electrolyte disturbances, and psychological trauma.[3-5] Therefore, knowing about and instituting appropriate treatment are important not only for nephrologists and trauma specialists but also for internists, cardiologists, psychiatrists, surgeons, anesthesiologists, intensivists, and generalists, all of whom may be confronted with patients with crush injuries before nephrologists become involved.

General disaster-response algorithms provide operational plans for the disaster area, transportation and admission to hospitals, the deployment of health personnel, and instructions for triage as well as early surgical and medical treatment.[6-8] However, conceptual information about later stages of rescue activity, most often related to life-threatening crush injuries with concomitant renal insult, is lacking. In this article, we consider lifesaving aspects of medical care that can be related to both global and local coordination of renal rescue, on the basis of our experiences during several mass disasters.

DISASTERS AND THE CRUSH SYNDROME

DISASTERS — A WORLDWIDE PROBLEM

Many earthquake-prone areas lie in densely populated regions such as California, the Mediterranean, the Middle East, and Southeast Asia. Both Istanbul, Turkey, and Tehran, Iran — each with more than 10 million inhabitants — are situated close to a fault. The predicted risk of major earthquakes in those areas is extremely high — in Istanbul, for example, a mean (±SD) of 32±12 percent in the next 5 years and of 62±15 percent in the next 25 years.[9] Similarly, there is a 62 percent probability that an earthquake with a magnitude above 6.7 will strike the San Francisco Bay area before 2031.[10] An increasing frequency of other types of disasters in densely populated areas of the world (e.g., the recent tsunami in Southeast Asia and hurricanes Katrina and Rita in the United States), as well as the possibility of damage by war, suggests that mass catastrophes may affect ever more people. Therefore, devising concepts and plans for rescue activities arguably should prevent repeated errors and render care more effective.

RECENT HISTORY OF THE CRUSH SYNDROME

Although acute renal failure owing to crush injury after war wounds and motor vehicle accidents was described early in the 20th century, Bywaters and Beall highlighted the syndrome in detail after the Battle of London, during World War II.[11] The first catastrophe of epidemic dimensions, however, occurred in the aftermath of a natural disaster — the Armenian earthquake in 1988.[12] Since then, at least eight other mass disasters have occurred that have involved numerous casualties or the need for dialysis, or both, as a result of crush injuries (Table 1).[13-26] Detailed reports of these catastrophes are often lacking, because adequate documentation has been quite difficult, if not impossible, to obtain.

Clear documentation is occasionally available, as in a report following the sudden collapse of an eight-story building, in which 80 percent of the entrapped victims died instantly from direct trauma, 10 percent survived with minor injuries, and the remaining 10 percent were badly injured, with the crush syndrome developing in 7 of 10.[27,28] If these percentages are extrapolated to mass disasters wherein thousands of buildings may collapse, dramatic numbers of crush-related casualties can occur, although many variables (e.g., the severity, type, and timing of the disaster; geologic features; the population density; the quality of the buildings; the effectiveness of rescue activities; the time victims spend under the rubble; and the affected region's health care infrastructure) determine the ultimate number of and outcome among the victims.[4,29-31] The best preventive option for decreasing casualties in the event of a disaster is the construction of high-quality buildings; in some cases, affixing the furniture to the walls may also be helpful.[4] In the absence of such measures, the incidence of disaster-related crush injuries often remains high.[21,31]

THE CONCEPT OF RENAL DISASTER

In December 1988, an earthquake with a magnitude of 6.9 on the Richter scale killed more than 25,000 people in Armenia.[17] In the aftermath, the occurrence of nearly 600 cases of acute renal failure[15] created a second catastrophe, subsequently called a "renal disaster."[32] At least 225 victims required dialysis,[17] but despite the availability of more than 36 tons of dialysis supplies, 100 dialysis machines, and volunteer personnel from many countries,[17,33] the response was ineffective, because no organized international support structure with appropriate training and deployment strategies was available at that time.[17] The poorly organized relief effort with its influx of rescuers and material only worsened the chaos, creating a secondary disaster and interfering with global rescue activities.[32] In this article, we describe management and medical strategies for preventing

Table 1. Statistics Related to Major Earthquakes in the Past 18 Years.*

Location and Year	Death	Crush Syndrome	Dialysis
		overall number of crush victims	
Spitak, Armenia, 1988[15-17]	25,000	600	225–385
Northern Iran, 1990[18]	>40,000	?	156
Kobe, Japan, 1995[19,20]	5,000	372	123
Marmara region, Turkey, 1999[21]	>17,000	639	477
Chi-Chi, Taiwan, 1999[22]	2,405	52	32
Gujarat, India, 2001[23]	20,023	35	33
Boumerdes, Algeria, 2003[24]	2,266	20?	15?
Bam, Iran, 2003[25]	26,000	124	96
Kashmir, Pakistan, 2005[26]†	>80,000	118	65
Total	>217,000	>1900	>1200

* Data are from Vanholder et al.[13] and the U.S. government.[14]
† The latest data as of December 11, 2005, are given and are limited to the major reference centers of Islamabad and Abottabad; data were provided by Drs. Asrar Hussain and Sameeh Khan, our Pakistani contact who handled the statistical follow-up.

the renal problems related to such disasters, which are based on the approach taken by the Renal Disaster Relief Task Force of the International Society of Nephrology[34,35] (information on the Renal Disaster Relief Task Force can be obtained from the secretariat of the coordinating center at chantal.bergen@ugent.be). This approach was tested in the 1999 earthquake in the Marmara region, Turkey, in which 639 victims had acute renal failure[13]; in the 2003 earthquake in Bam, Iran[25,36]; and in the 2005 earthquake in Kashmir, Pakistan (Table 1).[26]

CHARACTERISTICS OF THE CRUSH SYNDROME

Medical professionals living in disaster-prone regions should learn about the pathophysiology, complications, and treatment of crush-related acute renal failure. Impaired kidney perfusion and intratubular obstruction by myoglobin and uric acid contribute to the pathogenesis. Early fluid resuscitation (within the first six hours, preferably before the victim is extricated) is essential.[28] The preferred fluid is isotonic saline, given at a rate of 1 liter per hour (10 to 15 ml per kilogram of body weight per hour), while the victim is under the rubble, followed by hypotonic saline soon after rescue. Adding 50 mEq of sodium bicarbonate to each second or third liter of hypotonic saline (usually a total of 200 to 300 mEq the first day) will maintain urinary pH above 6.5 and prevent intratubular deposition of myoglobin and uric acid.[28] If urinary flow exceeds 20 ml per hour, 50 ml of 20 percent mannitol (1 to 2 g per kilogram per day [total, 120 g],[37] given at a rate of 5 g per hour) may be added to each liter of infusate. The addition of mannitol also decreases compartmental pressure.[28,38]

Once a patient with the crush syndrome has been hospitalized, urinary output should ideally exceed 300 ml per hour. Such a goal may require the intravenous infusion of up to 12 liters of fluid per day (4 to 6 liters of which will contain bicarbonate). The volume administered is generally much greater than the urinary output; the difference between intake and output is due to the accumulation of fluid in the damaged muscles, which may exceed 4 liters. This protocol should be continued until clinical or biochemical evidence of myoglobinuria disappears (usually by day 3).

However, the urinary response may differ from patient to patient, and fluid administration should be individualized according to the patient's clinical course[28,39] or central venous pressure measurements, with the latter approach considered optimal. If the patient cannot be monitored closely because of chaotic disaster conditions, less than 6 liters of a mannitol–alkaline solution should be infused per day to avoid volume overload.[40] Patients with insufficient urinary output should be monitored closely, so that hypervolemia can be prevented or, if necessary, dialysis initiated.

Electrolyte abnormalities are frequent in patients with crush-related acute renal failure (Table 2),[41] with fatal hyperkalemia being the most important. Because many victims may die from hyperkalemia before reaching the hospital, empirical administration of potassium-containing solutions in the field should be strictly avoided.[42] Serum potassium levels should be measured at least three or four times daily, especially in the first days after a patient is admitted and in patients with severe trauma, who are at higher risk for hyperkalemia than are patients with less severe injuries.[42] Hypocalcemia should be treated only if it is symptomatic, because early intramuscular accumulation of calcium is followed by hypercalcemia at later stages.[40]

This complicated course may necessitate dialysis, which is a vital procedure in patients with crush injuries. Nephrologists and intensivists should be ready to initiate dialysis for standard indications (Table 2) and prophylactically in patients at increased risk for hyperkalemia.[40] For logistic reasons, it is important to be able to gauge how long dialysis will be needed; the average is 13 to 18 days.[43-45] Twice- and even thrice-daily dialysis may be needed. Dialysis can be discontinued only after kidney function has recovered, as suggested by a normalization of urinary volume in a patient with improving serum biochemical values in the absence of fluid overload.

LOGISTICS AND COORDINATION IN RENAL DISASTERS

Advance logistic planning is usually not necessary for everyday practice but is vital for providing effective support in the event of a catastrophe[20,46] (Fig. 1A), in which chaos, damage to hospitals, and a shortage of manpower prevail. Global logistic coordination (Fig. 2) from countries or areas removed from a disaster is probably the most effective solution, even if difficult to implement. As shown in Figure 2, such global support should

Table 2. Major Steps in Treating Patients with the Crush Syndrome after a Disaster and Consecutive Steps for Effective Coordination of Local Relief Efforts after Renal Disasters.

Major steps in treating patients with the crush syndrome
Consider the importance of early fluid administration in the field.
Initiate an infusion of isotonic saline at the earliest convenience, followed by hypotonic saline–alkaline solution.
In patients with adequate urinary flow, add mannitol to the solution.
Avoid empirical administration of potassium-containing fluids.
Closely monitor each patient's fluid intake and urinary output after admission.
Administer up to 6 to 12 liters of appropriate fluids per day.
Remember that in patients with the compartment syndrome and other causes of fluid loss, urinary output may be substantially lower than the amount of administered fluid.
Define the amount of fluid to be administered on the basis of the clinical course or central venous pressure measurements.
Correct electrolyte abnormalities.
Hyperkalemia is often fatal and should be corrected vigorously.
Hypocalcemia should be corrected only if it causes symptoms.
Remember that virtually any other electrolyte disturbance (hyperphosphatemia, hypercalcemia, hypernatremia, hyponatremia, and even hypokalemia) may occur as well and should be treated.
Consider dialysis as a lifesaving procedure.
Begin dialysis when indicated by the presence of any of the following: oliguria or anuria, volume overload, or biochemical abnormalities such as severe uremia, hyperkalemia, and acidemia.
Consider the initiation of prophylactic dialysis in patients at high risk for hyperkalemia.
In order to estimate logistic needs, remember that the average duration of dialysis will be 13 to 18 days.
Consider continuing dialysis support until patients' kidney function has recovered.
Consecutive steps for effective coordination of local relief efforts
Assess the severity of the renal disaster.
Estimate the total number of victims, including the number who are or will need to be hospitalized, the number with the crush syndrome, and the number with or at risk for acute renal failure.
Determine the status of local health care facilities and transportation possibilities.
Determine the functional status of local hospitals.
Evacuate patients with the crush syndrome from the disaster area.
Administer potassium binders such as sodium polystyrene sulfonate to patients before they are transported.
Determine the timing of anticipated hospitalizations and consumption of medical supplies.
Discharge victims with mild injuries.
Remember that most admissions for the crush syndrome occur during the first week after the disaster and may eventually represent 25 percent of overall hospitalizations.
Use medical equipment economically.
Prepare schedules for medical and paramedical personnel.
Prepare advance global strategies for the allocation of personnel in disaster-prone areas.
Assign more experienced personnel during the first days after a disaster; regulate work hours to reduce stress and avoid burnout of personnel.
Remember that for practical or emotional reasons, local personnel may not work as efficiently as usual and may not be able to come to work owing to disaster-related events.
Estimate the need for renal replacement therapy.
Prepare a plan to handle the dialysis program in the event of a disaster.
Refer patients with chronic renal failure who require dialysis to outpatient units and temporarily reduce either frequency or duration of dialysis.
Define the most appropriate method of dialysis for patients with the crush syndrome.
Deliver medical supplies and personnel.
Avoid organizing random support campaigns.
Try to ensure the availability of 8 to 10 sets of dialysis equipment, 4 to 5 units of blood and blood products, at least 5 liters of crystalloids, and 15 g of sodium polystyrene sulfonate (or equivalent) for each potential patient with the crush syndrome.

Table 3. Requirements for Dialysis and Blood and Blood-Product Transfusions in 639 Patients with the Crush Syndrome after the Marmara Earthquake.*

Variable	Value
Dialysis	
No. of patients undergoing dialysis	477
No. of hemodialysis sessions	5137
No. of hemodialysis sessions per patient undergoing hemodialysis	11.2±8.0
No. of hemodialysis sessions per patient†	8.2±8.4
Transfusion	
No. of blood transfusions	2981
No. of fresh-frozen plasma transfusions	2837
No. of human albumin transfusions	2594
No. of blood transfusions per patient receiving transfusions	8.3±10.7
No. of blood transfusions per patient‡	4.6±9.0
No. of fresh-frozen plasma transfusions per patient receiving transfusions	13.6±19.8
No. of fresh-frozen plasma transfusions per patient‡	4.4±12.9
No. of human albumin transfusions per patient receiving transfusions	8.8±9.1
No. of human albumin transfusions per patient‡	4.0±7.5

* Data are from Sever et al.[43,72] Plus–minus values are means ±SD.
† The number is for the entire population (both patients who underwent hemodialysis and those who did not), for logistic reasons.
‡ The number is for the entire population (both patients who received transfusions and those who did not), for logistic reasons.

be incorporated into the local initiatives that are described below.

ASSESSMENT OF SEVERITY

Several reports about the incidence of disaster-related crush syndrome have been published. After the earthquake in Tangshan, China (death toll, 242,769), 2 to 5 percent of all those injured had the crush syndrome.[48] After the Kobe earthquake, this syndrome was observed in 13.8 percent of hospitalized patients, and acute renal failure developed in half these patients.[20]

The Marmara earthquake, which occurred in a region with mostly concrete buildings, injured 43,953 persons. Among the 5302 who were hospitalized, renal failure related to the crush syndrome occurred in 639 (12 percent), 477 of whom received dialysis (9 percent).[21] As many as 23 percent of persons injured in the Armenian earthquake were reported to have acute renal failure, on the basis of data from global hospital admissions.[49] Thus, overall, up to 25 percent of hospitalized victims of disasters appear to be at risk for acute renal failure.

The magnitude of these figures necessitates ongoing estimation of the number of hospitalized victims over the entire affected area during a disaster, which allows estimation of the potential number of patients with acute renal failure. Likewise, the day-to-day evolution of the number of patients with acute renal failure itself should be followed scrupulously, in order to predict supply needs.

Specific conditions may influence the risk of the crush syndrome. In the Gujarat earthquake, the low incidence of crush injuries was attributed to the limited rescue possibilities.[50] In addition, the fact that the disaster occurred during the day, when many people were out and about, may have increased the number of people who died instantaneously from head or thorax trauma and decreased the number who might have sustained nonfatal muscle-crush injuries had they been at home. The circumstances following the recent Kashmir earthquake were almost identical.[26] The collapse of the low adobe buildings prevalent in the area of the Bam earthquake resulted in many deaths by suffocation, but fewer crush-related injuries.[51] The unexpectedly low incidence — only one case — of acute renal failure owing to the crush syndrome after the September 11, 2001, terrorist attack in New York City, in spite of more than 3000 deaths, was explained by the rapid collapse of the buildings, resulting in very few injured survivors.[52] No cases of acute renal failure were reported after the Southeast Asian tsunami in 2004, most likely because all victims who were crushed subsequently drowned.

STATUS OF LOCAL HEALTH FACILITIES AND TRANSPORTATION POSSIBILITIES

Usually, hospitals in the area of a disaster either are heavily damaged or must be evacuated because of the possibility of collapse from aftershocks in the case of an earthquake.[53] Therefore, one of the most important missions of renal-disaster coordination is determining the status of local hospitals and organizing the transportation of patients to health care facilities in the unaffected areas.

Because resources and personnel are limited, triage is vital in the wake of a disaster. In mass disasters, early treatment in the field should be focused on seriously injured persons who require immediate care[54] but who are judged to have at

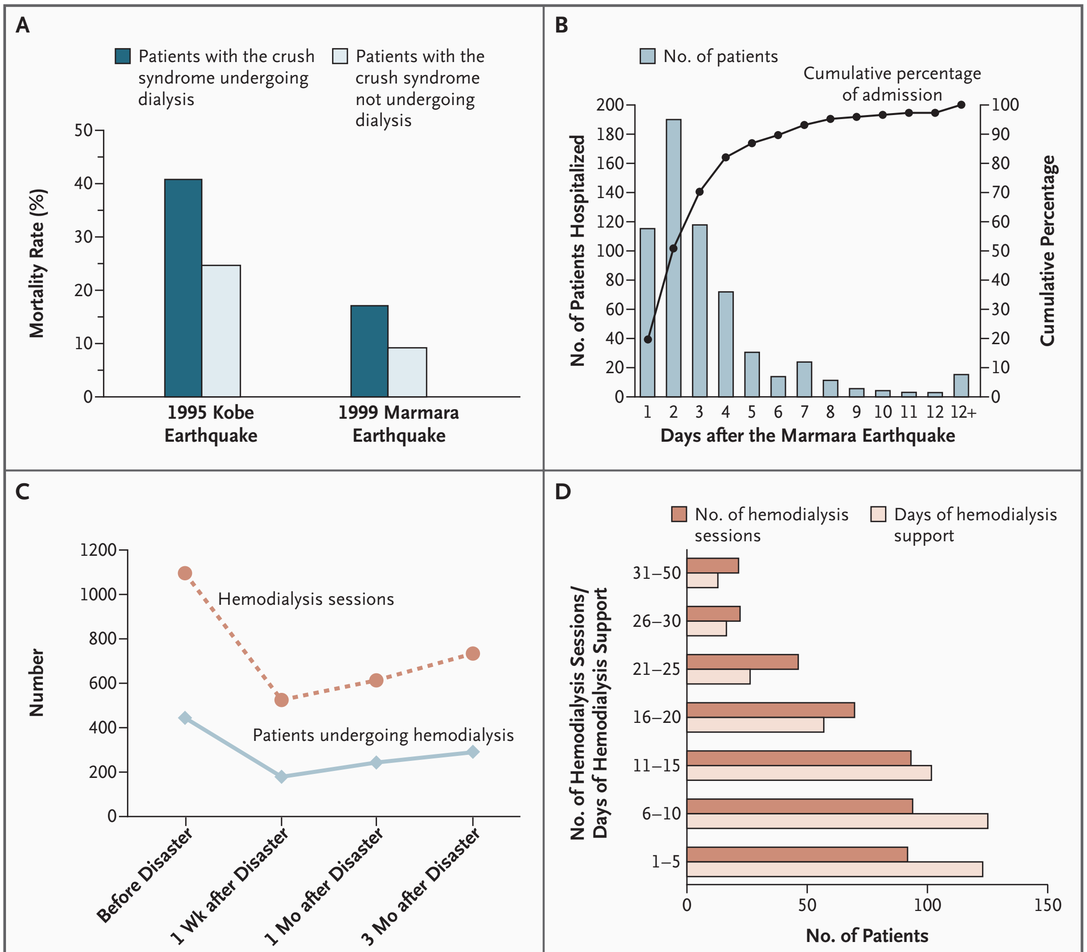

Figure 1. Mortality Rates among Patients with the Crush Syndrome after the Marmara Region, Turkey, and Kobe, Japan, Earthquakes (Panel A); Incidence of Renal Problems among Patients Hospitalized in Reference Hospitals after the Marmara Earthquake (Panel B); Number of Hemodialysis Sessions and Patients Undergoing Maintenance Hemodialysis in Eight Centers in the Damaged Area before, One Week after, and One and Three Months after the Marmara Earthquake (Panel C); and the Number of Patients with the Crush Syndrome, According to the Number of Hemodialysis Sessions or Days of Dialysis after the Marmara Earthquake (Panel D).

In Panel A, data on the Kobe earthquake are from Oda et al.[20] In Panel B, by the end of the first week after the earthquake, more than 90 percent of all patients injured in the disaster had been admitted, according to data from Sever et al.[21] Data shown in Panel C are from Sever et al.[47] Data shown in Panel D are from Sever et al.[43]

least a 50 percent chance of survival.[7] Triage should separate these people from those who are mildly injured, those who are hard to treat, and those who are already dead.

After a disaster, rapid transport systems should be devised, if feasible, to evacuate injured persons from the epicenter. Peripheral triage areas should be set up in a spoke-and-wheel pattern, with the spoke being the disaster area and the periphery of the wheel being the nearest undamaged areas that have access to fluids, electricity, and other resources required for medical care. Transport is often a major obstacle, as illustrated in the recent Kashmir earthquake, which occurred in a remote mountain area with few roads and an overwhelming lack of helicopters. This situation resulted in a feeble influx of patients with the crush syndrome and disproportionate mortality. Transport problems after a disaster can often be solved by collaboration between military and civilian groups[55] — for example, military boats and helicopters were used in the Marmara earthquake[21] and military planes were used to transfer patients injured in the Bam earthquake to remote major cities.

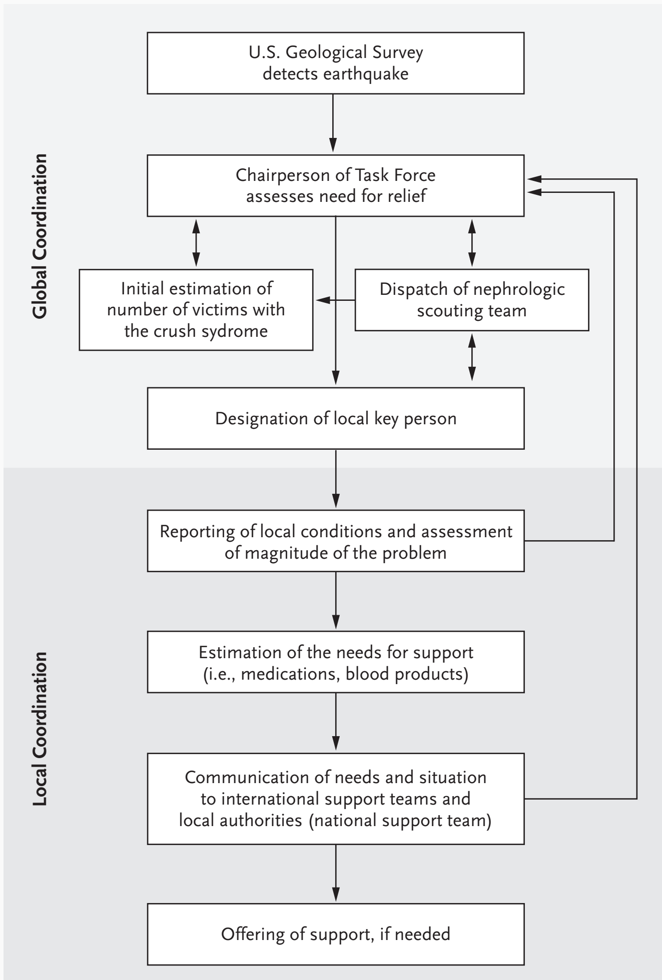

Figure 2. Algorithm for Global and Local Coordination of Renal-Disaster Relief Efforts.

The algorithm was developed by the Renal Disaster Relief Task Force of the International Society of Nephrology. Once an earthquake is detected, the need for an international relief intervention is assessed. If required, a scouting team is sent to the disaster region to evaluate the condition of the general health care infrastructure, the number of potential victims with the crush syndrome, and the need for dialysis support. This primary information is relayed back to the relief organization, which can rapidly mobilize additional teams and supplies as needed. If dialysis support is required, it can be deployed within three or four days. A key person from the affected country is identified who will be responsible for the local coordination efforts, which include estimating the need for support and relaying these needs to local authorities and, if necessary, international support teams.

People with crush injuries must be transferred to adequately equipped hospitals that have dialysis facilities and a trauma center. Patients should receive potassium binders such as sodium polystyrene sulfonate (Kayexalate) orally or rectally before they are transferred, since fatal hyperkalemia may otherwise occur during transport.

Because aftershocks may damage hospitals and dialysis centers that were initially operational after the first shock,[13] evacuation of the injured is mandatory for continuing and definitive treatment. Emergency field hospitals may be useful only for temporary treatment of acute complications of the crush syndrome. Patients with the crush syndrome may become difficult to transport later in their course owing to complications, and beds should be kept open in local hospitals for those who cannot be transported. Finally, patients who are treated locally in often inadequate conditions have a higher risk of death than those treated in appropriate surroundings.[56]

The installation of temporary dialysis units near the disaster area necessitates adequate water supplies, and such field units can handle only a few patients. The lack of a hospital infrastructure or the inability to place such units in existing hospitals is another potential drawback; thus, this option should be used only when there are no viable alternatives.

TIMING OF ANTICIPATED HOSPITALIZATIONS AND CONSUMPTION OF MEDICAL SUPPLIES

With appropriate means of evacuation, most injured patients are hospitalized within the first three days after a disaster[6,21,57-59] (Fig. 1B); for example, only 2.4 percent of victims were admitted six days after the Armenian earthquake.[16] The need to treat many patients with multiple needs combined with damage to hospital supplies inevitably results in a shortage of medical material at the site of a disaster. Hence, until effective external help is received, which usually takes one week, careful consumption of existing medical supplies is mandatory.

Even after additional supplies arrive, medical equipment should be used judiciously, because serious complications may not develop initially. Also, patients with undiagnosed renal injury may be dismissed early from local emergency care centers, only to be admitted subsequently with severe acute renal failure or electrolyte disturbances, as occurred in the Marmara, Bam, and Kashmir earthquakes. Patients with mild injuries who are hospitalized shortly after the disaster can be discharged and followed as outpatients.[6] They should not take up beds that may be required for the more seriously wounded, who often arrive later.

PREPAREDNESS OF MEDICAL AND PARAMEDICAL PERSONNEL

During the day on which the Kobe earthquake occurred, 42 to 69 percent of medical and administrative staff were unavailable because they themselves had been injured or had transportation difficulties.[2] In the immediate aftermath, even staff members who manage to reach the hospital are seldom able to work effectively, owing to shock, anxiety, and grief.[6,60] For example, after the earthquake in Loma Prieta, California, medical personnel at work felt that they were neglecting their families, whereas those who remained at home felt that they were neglecting their patients.[61] These drawbacks can be alleviated by careful preparation of on-call schedules. Furthermore, work schedules should be balanced to avoid burnout of personnel. The most experienced personnel should be scheduled to be on duty when the patients with the more complicated cases are expected,[21] usually during the first days after a disaster.

In disaster-prone areas, an overarching plan should be devised for medical personnel, since preparedness is the key element of any response. A list of physicians assigned to rescue activities in the field, in hospitals, and in logistic coordination should be devised and posted,[6] and these physicians should be trained to handle such situations. Since the crush syndrome may affect many organs and systems, physicians from various specialties should be trained to respond to each permutation. The treatment of particular systemic complications in disasters involving large numbers of patients with the crush syndrome may differ from the approach used in routine practice because of the severe logistic problems that characterize such disasters. For example, fasciotomy, the most frequently used surgical intervention in patients with the crush syndrome after a disaster, is often complicated by infection, sepsis, and even death.[3,62] Ideally, the decision to perform a fasciotomy should use an intracompartmental-pressure measurement above 35 mm Hg as the threshold. However, there is often a shortage of devices to measure intracompartmental pressure in disaster conditions. The absence of distal pulses indicates extremely high intracompartmental pressure and can be considered a simple bedside alternative threshold,[62,63] although patients with less severe injuries may retain distal pulses in spite of the presence of pathophysiologically relevant compression. Details of other key interventions in disaster conditions have been published elsewhere.[40,64-66]

FORECASTING THE NEED FOR RENAL-REPLACEMENT THERAPY

Disasters may increase the number of patients who require dialysis while simultaneously disabling dialysis units,[22,47,67] resulting in a dramatic increase in the workload of units that remain operational. Therefore, every unit in and around disaster-prone areas should prepare its own detailed “disaster dialysis program” to cope with a potential sudden influx of patients. Global planning should include distribution of comprehensive information about both acute and chronic renal failure to all health professionals.

Acute Renal Failure

In patients with crush-induced acute renal failure, all types of renal-replacement therapy, intermittent hemodialysis, continuous renal-replacement therapy, and peritoneal dialysis are valid therapeutic options, although each imposes specific logistic challenges.[13,15,32,43]

Intermittent hemodialysis allows the treatment of several patients per day with a single dialysis machine. Even short hemodialysis sessions (two to three hours daily) will avert life-threatening hyperkalemia. However, implementing this strategy requires technical support, experienced personnel, electricity, and water supplies, all of which are often affected by the disaster.

Continuous renal-replacement therapy allows the gradual removal of solutes and fluid. However, only one patient can be treated per machine, and experienced personnel, electricity, and enormous amounts of substitution fluid are needed. Continuous anticoagulation may provoke bleeding in patients who are seriously injured.

Peritoneal dialysis is technically simple, does not require electricity and tap-water supplies, and can be initiated rapidly. However, it is difficult to use in patients with abdominal or thoracic trauma, requires substantial quantities of sterilized dialysate, and may cause complications related to the nonhygienic field conditions in which it is supposed to be conducted. Both continuous renal-replacement therapy and peritoneal dialysis are less efficient in removing potassium than is intermittent hemodialysis.

During the Marmara earthquake, intermittent hemodialysis was the most frequently used form of dialysis and was applied in 462 patients, whereas only 34 and 8 patients, respectively, were treated with continuous renal-replacement therapy and peritoneal dialysis.[43] However, intermittent hemodialysis can be used only in countries with an adequate health care infrastructure. In regions without such facilities, victims with acute renal failure should be evacuated to nearby areas or countries as soon as possible.[13]

Chronic Renal Failure

Disaster-related problems also affect patients with chronic renal failure who live and undergo dialysis in the damaged area. Patients who undergo regular dialysis in fully equipped hospitals in the undamaged zone surrounding the disaster area should be referred to nearby satellite outpatient units so that hospital-based dialysis machines will be available for patients with complicated acute renal failure.

Within the first weeks after the Marmara earthquake, the number of patients undergoing regular dialysis for chronic renal failure and the number of hemodialysis sessions declined by almost 50 percent in the damaged area (Fig. 1C). Conceivably, many of these patients had moved to undamaged regions in order to continue treatment.[47]

In the case of disasters that can be predicted, such as severe hurricanes, the need to evacuate patients with a continuing need for dialysis should be anticipated and extra dialysis sessions or potassium binders should be administered before evacuation, if appropriate. The dialysis dose for such patients can safely be reduced for a limited time by decreasing the number or length of sessions.[47]

Personnel can also be redistributed from disabled units to other units that have remained functional. Authorities should give high priority to providing water and power to dialysis units, since the lack of dialysis facilities means certain death for patients who cannot be moved out of the affected area. Disaster-preparedness programs should also include a means to forewarn patients who require regular dialysis about impending disasters, since their understanding and compliance are of vital importance for medical, psychological, and logistic reasons.

DELIVERY OF MEDICAL SUPPLIES AND PERSONNEL

The medical supplies sent in response to a disaster are not always usable.[68-70] For instance, 90 percent of the drugs sent to Guatemala City, after the 1976 earthquake were unsorted and thus could not be used expeditiously.[70] Seventy percent of the 2500 tons of drugs sent to Armenia after the 1988 earthquake were expired, useless, unsorted, or damaged.[71] Destroying useless supplies consumes personpower and other resources and creates an additional ecologic threat.

Bringing personnel from elsewhere in the international community provides psychological support to local physicians and paramedics,[60] but such an influx may also have drawbacks. Unprepared and inexperienced foreign personnel may hamper relief efforts by tying up communications, transportation, resources, and housing.[16] Deployed support teams should be well trained and self-sustaining and should not increase the workload of local administrative bodies.[55]

Integrated collaborations between national and international organizations built on algorithms for a synergistic response are particularly effective. To avoid overlap, each organization should concentrate on different aspects of the problem (i.e., providing different types of health care personnel or different medical or nonmedical supplies and addressing different social problems). The optimal allocation of logistic tasks between local and international teams is difficult to define in advance. It depends on the severity and the location of the disaster, the local and international reserves, and the speed with which goods can be transported to the disaster area.

Anticipating the evolving medical needs of patients with the crush syndrome is a critical component in determining how much national and international help may be needed. The infrastructural needs of dialysis facilities, the amount of dialysis equipment, blood, and blood products needed, as well as the number of dialysis personnel required in the event of a disaster had not been analyzed before the Marmara earthquake. In that disaster, such calculations clearly showed that approximately 8 to 10 sets of dialysis equipment were needed per patient with the crush syndrome (Table 3 and Fig. 1D).[43]

Patients with the crush syndrome need numerous blood-product transfusions. The most important logistic problem is the efficient use of blood products, which is complicated by their short half-lives and improper storage.[59] Calls for blood donation should be carefully timed and gauged to cover the anticipated period of need. During the Marmara earthquake, patients with the crush syndrome received thousands of units of blood, fresh-frozen plasma, and human albumin (Table 3).[72]

The mean total volume of crystalloids administered to each patient with the crush syndrome during the day of admission exceeded 5 liters in the Marmara earthquake. Extrapolating this amount to the first three days of a disaster, before initial support can be organized, 15,000 liters of fluids would be required per 1000 patients with the crush syndrome. In the earthquake in Bingol, Turkey, the need for dialysis among patients with the crush syndrome was avoided by administering more than 20 liters of fluid per day to each patient.[73] The institution of such a policy during a disaster would necessitate the delivery of amounts close to 60,000 liters per 1000 injured persons (Fig. 3).

In addition, the requirement for substantial amounts of intestinal potassium binders should be foreseen. At a usual dose of 15 g per day per patient,[74] 45 kg of sodium polystyrene sulfonate would be required over a period of three days for every 1000 casualties.

Stockpiling equipment to be used in emergencies is a major concern. One option might be to construct specific warehouses in disaster-prone regions. Therapeutic agents should be entered into a computer database and classified, packaged, and labeled with information on the type, chemical structure, generic names, and production and expiration dates.[71] When these products approach their expiration date, they should be released to hospitals for routine use and replaced by new material. Any items required for disaster relief but not stored locally would need to be transported, generally from external, international resources. The possibility of a considerable lag time to organize transport and delayed clearance of imported items by customs and other local regulatory instances should be considered.

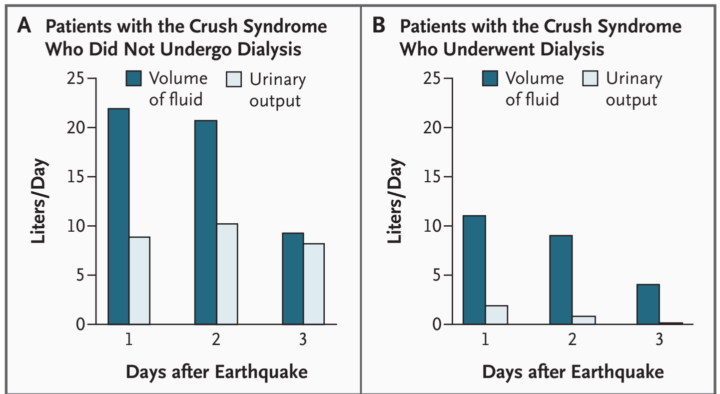

Figure 3. Amount of Fluid Administered and Urinary Response in Patients with the Crush Syndrome Who Did Not Undergo Dialysis (Panel A) and Patients with the Crush Syndrome Who Did Undergo Dialysis (Panel B) after the Bingol, Turkey, Earthquake.

Data are from Gunal et al.[73]

CONCLUSIONS

One of the most effective tools for decreasing the death toll after disasters is successful treatment of the crush syndrome and related acute renal failure. Unlike in daily medical practice, advance logistic planning and local as well as international coordination of medical interventions are vital for an effective response to a natural disaster. The same principles may be as valid in man-made disasters, because the initial period after these events is also characterized by chaos, a local shortage of medical supplies, and a lack of experienced health personnel.

Thus, preparation for disasters should include logistic plans for transferring the victims to the most appropriate health care facilities, effectively managing limited medical personnel and resources, and making realistic requests to obtain additional medical supplies and personnel.

Dr. Sever is the local coordinator, Dr. Vanholder is the chairman, and Dr. Lameire is the vice chairman of the Renal Disaster Relief Task Force of the International Society of Nephrology.

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