Earthquake Disasters – Lessons to be Learned

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Earthquakes are a frequent phenomenon varying in force and extent of damage. Every year millions of earthquake events are documented at numerous seismographic centers around the world. The site of earthquakes is quite predictable due to the plate theory developed during the second half of the nineteenth century [1].

Since the earliest documentation of earthquake casualties [2], some 15 million people have lost their lives in these catastrophic events. One author calculated that the average toll per year is around 8,000 fatalities and 26,000 injuries! [3] This figure amounts to 37% of all natural disaster deaths in the world [4]. The twentieth century saw some 1.5 million deaths due to earthquakes, nearly one-third in China alone [5]. Significantly, nine countries suffered more than 80% of all fatalities China, Japan, Italy, Peru, Turkey, the countries of the former Soviet Union, Chile and Pakistan [6]. Table 1 depicts the major earthquakes with the most casualties in the last 20 years of the twentieth century.

Historically, Israel has experienced multiple earthquakes, some of them strong enough to cause large-scale disasters. The Syrian-African fault along the Jordan and Dead Sea valleys was the center of most quakes in this region. Future events of large magnitude are expected. The ancient cities of Jaffa, Jerusalem, Hebron, Nablus, Ramleh, Safed, Beit She'an, Gaza, Jericho and Tiberias have all been hit, some with extensive damage, at least once in the last 1,000 years. The last major earthquake in Israel occurred in July 1927. The epicenter was north of the Dead Sea, along the Syrian-African Rift valley. More than 3,000 people were killed and some 1,000 homes were destroyed. Areas near Lod-Ramleh were also affected. The extent of the disaster is huge considering the sparse population in those areas in the beginning of the twentieth century [1].

Table 1. The great earthquakes in the last 20 years [5]

Year	Country	No. of fatalities
1999	Turkey	17,000
1998	Afghanistan	6,000
1995	Japan	5,400
1993	India	10,000
1992	Turkey	500
1990	Philippines	2,000
1990	Iran	40,000
1988	Armenia	25,000
1985	Mexico	10,000
1980	Italy	1,300

Factors affecting the extent of damages and injuries

Local magnitude (Richter scale)

The greater the magnitude of the earthquake, the greater the potential for casualties and damage at a certain location given the same conditions (population, building construction, etc.).

Distance from the epicenter

The closer the epicenter of the earthquake to more densely populated areas, the greater the number of casualties.

Character of the infrastructure

The character of the ground at the site in the area and surrounding the epicenter of the earthquake contributes to the overall damage. A good example is the Mexico City quake of 1985: greater damage was sustained in those areas of the city built on the type of ground that amplified the vibrations, even at a distance of up to 400 km away from the epicenter, than other populated areas built on ground that absorbed the vibrations though situated closer to the epicenter [1].

Type of buildings and quality of construction

"...where there are no buildings, there is no damage..." [1]. A building built without strict specifications to withstand earthquakes with certain magnitudes will suffer extensive damage even during a moderate magnitude earthquake [7]. Thus, the height of the structure, the building material used, and other parameters will influence its ability to withstand the quake vibrations. An evaluation of the death rate among casualties during the 1992 earthquake in Turkey showed that about 92% of all fatalities occurred inside the buildings compared to only 8% outside [8].

The combination of the above four parameters dictated the extent of the damage in the Los Angeles, California, earthquake of 1994 (Richter scale magnitude 6.7), with 72 fatalities and 11,800 injured [9]. A similar earthquake with a similar magnitude occurred in Armenia in 1988; however, the consequences were quite different, with nearly 55,000 deaths [1]. In the 1995 earthquake in the area of Kobe, Japan, with a Richter scale of 7.2, approximately 5,500 people were killed and 41,000 injured [10]. Clearly, the magnitude of the quake is not the most significant factor determining the number of casualties.

Engineering experts will attribute the damage to the factors mentioned above. However, other factors dramatically affect the extent of the human toll.

Timing of the event

There are hardly any signs to warn inhabitants of an imminent earthquake [11]. In fact, the time of day that the quake strikes has a crucial effect on the casualty toll [12]. An earthquake that occurs in the middle of the night when people are sleeping will cause a greater number of injuries than at midday. Daylight and alertness afford people the opportunity to react within seconds, to run away from buildings or find refuge in more secure areas of buildings.

Another component affecting the rate of injury is the day of the week and the season of the year. These factors will affect the distribution of people inside or outside buildings. For example, in mid-winter most people remain indoors even at midday, thereby increasing the risk of injury. In high summer, and especially at midday during summer vacations, many will spend time in open areas, thus reducing the risk of injury.

Time to rescue and treatment

Survival is directly related to the length of time from the occurrence of the quake until the time of extrication from under the rubble. In the 1990 earthquake in the Philippines, 99% of all victims who were extricated alive during the first 48 hours survived [13]. Schultz et al. [14] compared three earthquakes in populated areas: the 1976 earthquake in China, the 1980 quake in Italy, and the 1988 quake in Armenia. They found that 85–95% of all surviving extricated casualties were pulled from the rubble within 24 hours. They also found that in the earthquakes of Turkey and China, victims trapped for 2 to 6 days under the rubble had only a 50% survival rate. The authors quote Safar who stated that 25–50% of all earthquake fatalities during the Italian earthquake could have been saved had they received medical treatment immediately. Pretto and colleagues [15] arrived at the same conclusion when analyzing the medical care provided by rescue units during the quakes in Costa Rica in 1991 and Armenia in 1988.

Reaction of the local population

If the local population is educated on measures to minimize injury, the number of casualties and the severity of injuries can be reduced substantially. In the Philippine earthquake, some 70% of all casualties were located inside buildings during the earthquake [13]

Distribution of casualties

Ratio between dead and injured

One of the crucial considerations is the number of fatalities among the total number of victims. A University of Massachusetts study [8] examined this ratio in various earthquakes with a Richter scale magnitude of between 6.5 and 7.4. The ratio was found to be 1:3 dead to injured. In the 1976 earthquake in Nicaragua 22,778 of 76,504 casualties died [16]. However, some major earthquakes resulted in a different proportion: a more catastrophic outcome is usually due to a faulty urban infrastructure, while in other incidents the casualty toll is extensive but the injury severity is not, i.e., a large number of lightly injured individuals and smaller numbers of fatalities. During the 1995 Kobe earthquake, “only” 527 fatalities were counted among 6,107 casualties, resulting in a 8.6% fatality rate. The casualties comprised 372 crush injury victims of whom 50 (13.4%) succumbed to their injury, and 2,346 with other traumatic injuries of whom 128 (5.5%) died. Some kind of disease occurred in 3,389, resulting in 349 deaths (10.3%) [10].

During the 1988 earthquake in Armenia many towns and villages were devastated. The fatality rate was 80.9% in the town of Spetak, which was completely destroyed, and 30.7% in the town of Gormy [8]. In Spetak, the combination of delayed arrival by rescue and medical units together with severe infrastructure problems and sub-optimal building standards resulted in an unusually high casualty rate. Most of the buildings in the vicinity of the earthquake collapsed. These events are true "mass casualty events" or "medical disasters," straining emergency medical services and hospital-based facilities and often overwhelming them. This situation inevitably causes some areas to receive less medical and rescue unit attention and in some cases none at all, for an extended period. Obviously, this has a major impact on the survival of those who are seriously injured or trapped alive under rubble. Severe weather conditions that impede the rescue teams also affect the victim toll.

Types of injuries and their distribution

Trauma victims are the focus of interest in natural disasters around the world. In reality, other types of victims are of no less importance. Post-traumatic stress disorders, heart problems, respiratory diseases and many other medical conditions are aggravated by earthquakes. Infectious diseases and outbreaks of epidemics in conjunction with the earthquake also affect the health and welfare of the public. Finally, psychological stress among the medical teams is another issue.

Most of the trauma victims suffer multiple system injuries. The main causes of death are shown in Table 2. The Colombia earthquake victims in 1979 were described by Gueri [17] as follows: lower extremity 39%, torso (chest and abdomen) 14.8%, combined injuries 14.3%, face 12.1%, head 8.9%, upper extremity 4.9%, others 6%. Evaluating the victim toll of the 1994 earthquake in California, Teeter [18] noted that the majority of patients seeking medical attention were suffering from upper respiratory tract infections. In addition, less frequent but still present medical conditions include: headaches 10%, emotional stress 9%, muscle aches 9%, hypertension 8%, intestinal disorders 7%, and others. Women suffered stress disorders at three times the rate of males. The highest rate of psychological stress was observed in men and women between the ages of 30 and 50. Although physical injuries are the main concern in the early aftermath of the quake, in recent years it became clear that other medical conditions are not less important and sometimes result in major health problems over time.

Leor et al. [19] speculate that during the earthquake and its aftermath, the incidence of myocardial events increases. Knoler [20] observed a clear increase of 71% in cardiac mortality in 1994 compared to 1992 and 1993 in his analysis of the cause of 20,000 deaths in Los Angeles during that 3 year period. The gender ratio

Table 2. Main causes of death in earthquake victims

Injury	Victims
Asphyxia	50%
Crush injuries	12%
Burns and inhalation injuries	12%
Direct injuries	8%
Head injuries	3%
Hypovolemic shock	2%
Torso (chest and abdomen)	2%

was found to be nearly identical, 48.3% vs. 50%, among victims of the Chile earthquake.

However, the body site of injury seems to differ between men and women. Facial injuries were 2.5 times less common among female victims. Neurologic injuries were found six times more often in males. On the other hand, women had a sixfold higher rate of lower extremity injuries [21]. There is still no good explanation for these differences. The distribution of injuries among survivors of the Armenian earthquake in 1988 was reported [22] as follows: 24.9% superficial trauma, 12.1% fractures of the lower extremities, 11% crush injuries, 8.6% brain concussion, 8% back and spine injuries, 6.6% head injuries, 5.5% upper extremity injuries, and 25% other injuries.

Psychological reactions during earthquakes

There are essentially two types of psychological stress reactions during large natural disasters: the first concerns the victim population and the second the rescue teams. Psychological reactions can surface in the form of myocardial infarction-type chest pain, increase in blood pressure, panic reactions, etc. Katsouyanni et al. [23] showed a substantial increase in cardiac-related events and other stress disorders following the 1986 earthquake in Greece. Ursano and co-workers [24] point out that medical and rescue personnel are prone to short and long-term post-traumatic stress disorders when involved in the care of mass numbers of death and injuries. Up to 9% of rescue and medical personnel providing care for earthquake disaster victims develop signs and symptoms of a similar severity to those of the victims themselves [24–26].

Risk factors contributing to post-traumatic stress disorder symptoms include the duration and intensity of the exposure and the existence of physical injury. Other factors that play a role include threat to the life of the provider, the existence of social support, gender of the rescue personnel, level of education, previous psychiatric disorders, and exposure to corpses (especially children). Evaluation of the Israeli rescue team in the 1999 earthquake in Turkey revealed incidences of mental stress, loss of appetite, mild depression and other signs of post-traumatic stress disorders. This occurred despite the fact that more than 70% of the staff had experience from other disaster zones around the world [27].

Medical preparedness for earthquake disasters

Several steps can be identified when analyzing medical preparedness for earthquakes: a) creation of a national plan for reduction of casualties and damage; b) development of specific plans for medical forces at different levels in the pre-hospital and hospital phases; and c) training and preparation of medical teams (including equipment, team selection, protocols, and mode of operation).

Reduction of damage and injuries

The best action plan in medicine is preventive medicine. Since we cannot prevent earthquakes, a way must be found to reduce injuries and minimize damage. This can be achieved by implementing strict building standards according to the type of building, its use, the building site, and the geologic and seismologic risk. Special attention should be given to the stability of hospitals and their ability to continue functioning after an earthquake [1,28,29].

Operational plan

Noji [5] states that the effectiveness of the emergency medical services is revealed in the first 24 hours after the incident. For the individual victim the first steps are administration of life-supporting first aid and advanced trauma life support. These include minor surgical procedures to obtain airway and control bleeding at the field level. All further substantial treatment is provided at the hospital level (if it exists). However, after the initial medical care for traumatic injuries, primary medical care and epidemic prevention become the paramount issue.

Darlene [30] describes the methods undertaken by the emergency and rescue units in Los Angeles. All firefighters trained as medics are deployed in the field for initial first-aid care. Only about 10% of casualties will receive this type of care, while most people with minor injuries will arrive at hospitals on their own. In most places around the world, experience shows that the telecommunication system collapses and it is impossible to call for help. Cellular phone service is also unreliable in an emergency and only radio communication systems function. In the United States, the NDMS (National Disaster Medical Service) mobilizes volunteer medical teams, and hospitals begin discharging non-urgent patients in order to make room for mass casualty situations. Schultz et al. [14] suggest four main stages of the medical response: a) the first hour after the earthquake – self-care, buddy care and first aid at the site of the disaster; b) the initial 1–12 hours – the deployment of first-aid stations within the disaster area in the community; c) 12–72 hours – deployment of casualty clearing centers according to the most seriously hit urban sites; and d) evacuation to nearby hospitals, if functioning, or distant medical centers by land or air.

Initial casualty management at the site

The first principle in emergency medicine is short reaction time [14]. The earlier the critically injured victim receives medical care, the better the chances of survival [14,30]. The management of a disaster the size of a major earthquake should include rapid deployment of medical and rescue personnel. Initially, the teams should utilize the systems at the site of the incident (if functional). Subsequently, or if there are no such teams, statewide or nationwide support is necessary. If this is unavailable, foreign support is also an option.

The time to definitive treatment is closely related to the time of extrication. Early extrication is crucial for survival [7,31]. Only life-saving procedures should be performed in the field. It is worth mentioning that the Israeli army victims from the crush injury incidents at Tyre and Sidon received early fluid resuscitation following life-saving procedures (airway, breathing, hemorrhage control). In certain cases, this was provided even when the victims were still trapped under rubble. Kidney damage was thus minimized [32].

Casualty care at the local community first-aid station

During the second phase, the main effort is concentrated on deployment of casualty triage stations within the community. At these sites basic triage is performed including both ambulatory and non-ambulatory cases [14]. Further triage is performed according to severity of injury and the need for urgent hospital care. Casualties that can benefit from basic medical care at these stations, with no imminent danger of complications, should not be transferred immediately to hospitals, which are overwhelmed with victims in need of urgent life-saving medical care.

The less seriously injured can be transferred to makeshift treatment centers such as undamaged community centers, schools and outpatient clinics. In this way hospitals are relieved of some of the masses of injured people and can work in a more orderly fashion [14].

In the 1994 earthquake in California, special train cars were used as mobile clinics, treating some 1,100 minor casualties (respiratory distress, anxiety responses and minor injuries). Military medical units and National Guard units (in the USA) can also provide this type of medical care and more.

Casualty clearing stations

Schultz et al. [14] advocate deployment of medical centers as close as possible to the disaster site, such as field hospitals, and even suggest that they be spread 10 miles apart. Of course, this depends on the magnitude of the casualty toll and the ability to use existing medical/hospital facilities. They contend that casualties should be evacuated by air (helicopters), ground ambulances or any other available means of transportation to the various medical facilities in the disaster area.

Hospital use during earthquakes

Hospital availability during earthquake disasters is of paramount importance. The ability of the hospital to continue functioning depends on the magnitude of the quake and the construction standards. In the 1964 Alaska earthquake (Richter scale 8.4) medical facilities were severely damaged. In the 1988 earthquake in Armenia, the city of Leninakan was devastated and all four general hospitals were severely damaged and had to shut down. In one hospital, the entire staff and patients were killed or injured. In the San Fernando, California, earthquake of 1971 (Richter 6.4), two hospitals collapsed, resulting in the deaths of 47 people, one newly built hospital partially collapsed and three others were severely damaged [28]. As a result of this disaster, the government issued new safety laws in 1972 and in 1982. Under current building standards, hospitals should withstand even major earthquakes [29].

The effectiveness of these regulatory measures was proven during the 1989 San Francisco earthquake. All hospitals built after the new standards were introduced withstood the quake and continued functioning. Some older hospitals, built prior to the introduction of the new laws, were damaged. However, even during the 1994 earthquake, six medical facilities (12 buildings), suffered extensive structural damage and were forced to close down [28].

Training and exercise

The training of medical forces that provide emergency care to victims of national disasters like earthquakes can be divided into several categories: a) basic training of individual medical personnel who care for trauma victims (preference for training based on advanced trauma life support and pre-hospital trauma life-support – ATLS/PHTLS); b) training medical staff in professional work teams to function in emergency situations; c) training various medical organizations for readiness in the event of an earthquake; d) training the health system to respond, including preparation of decision-makers and command centers; e) training the entire health system as part of an overall strategy of emergency preparedness in the event of an earthquake; and finally, f) educating the public by various means including electronic media, which can improve the medical outcome of such events.

The structural integrity of hospitals in Israel

Along the Syrian-African fault, where the earthquake risk is highest, there are three major hospitals: the Sieff Medical Center in Safed, the Poriah Hospital in Tiberias, and the Yoseftal Hospital in Eilat. Many buildings in these hospital campuses were built prior to 1975, when the earthquake building standard was introduced, and before introduction of the seismic map of 1990 that greatly improved the stability of new medical facilities.

Rutenberg [28] claims that after a "minor" seismic incident (Richter 5.2) on 23 March 1984, tiles fell from the bathroom walls in the Dan Carmel Hotel in Haifa and medical equipment "moved" on the floor in the adjacent Carmel Hospital. It would be prudent to examine all medical facility buildings in the areas at risk for major earthquakes. This screening is essential to obtain advance indication of a region's ability to provide continuing medical care following an earthquake. Many installation systems are especially at risk. Oxygen supply systems, electricity, water, elevators, etc., can paralyze the normal functioning of a hospital. Needless to say, this could prove fatal to casualties or patients in the event of serious damage or failure. Equipment should be anchored, walls and foundations should be strengthened if possible, and strict building standards enforced.

Summary

Human beings do not have the ability to prevent earthquakes. However, we can take measures to minimize injuries and damage by using strict building codes and constructing infrastructures in areas of less risk. A great number of buildings in Israel, including some hospitals, will not withstand a major earthquake as they were built with inadequate standards.

Data collected during earthquakes show a significant rise in cardiac-related disease and stress-related medical problems in addition to conventional injuries. Public health issues are of increasing importance due to the collapse of sanitation facilities.

In addition to field clinics, field hospitals should be deployed in the vicinity of the stricken area. While planning the medical response for disasters such as earthquakes, one should take into account the availability of local medical personnel. Some or most of the local staff may be unable to function. A study from the Gulf War showed that even the threat of chemical attack resulted in less staff reporting to work [33]. During the 1999 earthquakes in Turkey, many of the hospital staff opted to care for their close families instead of reporting to work at the hospital. Regular training exercises in pre-hospital emergency medical services for the more common multiple casualty incidents should be bolstered with additional exercises in mass casualty incidents. The basic functions in these scenarios may be quite different. Although no exercise can mimic the real event, preplanning and drills are invaluable.

When an earthquake does occur, medical management includes local search and rescue teams together with emergency medical service teams if these can still function. Early deployment of local medical centers can alleviate the burden from local hospitals. Evacuation to distant medical centers is probably a major key for success.

Psychological problems are abundant in such incidences, affecting also rescue and medical teams. It becomes a major issue when there are large numbers of pediatric casualties and the operations continue for more than a few days.

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