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Floods and Tsunamis

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Floods and tsunamis cause few severe injuries, but those injuries can overwhelm local areas, depending on the magnitude of the disaster. Most injuries are extremity fractures, lacerations, and sprains. Because of the mechanism of soft tissue and bone injuries, infection is a significant risk. Aspiration pneumonias are also associated with tsunamis. Appropriate precautionary interventions prevent communicable disease outbreaks. Psychosocial health issues must be considered.

The events of the past year and a half have rewritten the history of destructive natural disasters. On December 26, 2004, a massive earthquake and subsequent tsunami in the Indian Ocean killed more than 200,000 people; on August 29, 2005, the most destructive hurricane in United States history devastated New Orleans and the Gulf Coast; and on October 8, 2005, a large earthquake in the Kashmir area of Pakistan killed more than 50,000 people. Disaster and disaster preparedness are on everyone's mind and television. Several publications, written before these recent events (including the destructive hurricanes that punished Florida in 2004), provide excellent reviews of disaster preparedness and management [1–4]. A more recent review provides an historical summary of disaster preparedness, describing the National Disaster Medical System (NDMS) and President Carter's creation of the Federal Emergency Management Agency (FEMA) in 1979 [5].

History, Epidemiology, and Basic Science

Floods are the most common natural disasters that affect developed and developing countries [6]. Mortality statistics are usually readily available, as

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opposed to more specific information on injuries and illnesses that is essential for clinicians to optimally prepare for these events [6]. Mortality alone is not a sensitive indicator of health risk [7]. This article reviews the available data and extrapolates from recent experiences.

According to the OFDA/CRED International Disaster Database [8], the tsunami of December 26 was undoubtedly the most lethal natural disaster that occurred in 2004 (Table 1). Among the top disasters of 2004, determined by the number of resulting deaths, floods were the most common, and as shown in Box 1, occurred most frequently.

Clearly, people living in developing countries are more vulnerable to floods, and flood size and populations at risk are variable. What is being seen today seems to be what Dr. Noji [9] predicted 10 years ago: “The future seems to be even more frightening. Increasing population density in flood plains, along vulnerable coastal areas, and near dangerous faults… point to the probability of catastrophic natural disasters.”

According to the National Oceanographic and Atmospheric Administration (NOAA), “In most years, flooding causes more deaths and damage than any other hydro- meteorological phenomena. In many years it is common for three-quarters of all federally declared disaster declarations to be due, at least in part, to flooding” [10]. Table 2 shows the United States fatalities from floods in recent years.

In 2004, deaths were reported from flash, river, and urban/small-stream floods. The 0- to 9- and 20- to 29-year-old age groups had the most deaths at 14 each, of which 62% were men. In recent years, 50% or more of all flood-related deaths have occurred in automobiles.

Approximately 8000 people died in 1900 when a large hurricane hit Galveston, Tex. In 1928, 1836 people died from another hurricane around Lake Okeechobee in Florida. Most of these deaths were believed to be caused by the large storm surge associated with powerful hurricanes. Deaths from

Table 1
Top disasters by deaths in 2004

Rank	Disaster	Month	Country	Number of deaths
1	December 26 Tsunami	December	12 countries	226,408
2	Hurricane Jeanne	September	Haiti	2,754
3	Flood	May/June	Haiti	2,665
4	Typhoon Winnie	November	Phillipines	1,619
5	Flood	June/August	India	900
6	Flood	June/August	Bangladesh	730
7	Flood	May/June	Dominican Republic	688
8	Dengue epidemic	January/April	Indonesia	658
9	Earthquake	February	Morocco	628
10	Meningitis epidemic	January/March	Burkina Faso	527
11	Cyclone Galifo	March	Madagascar	363

Data from EM-DAT: THE OFDA/CRED International Disaster Database. Available at: www.em-dat.net. Université Catholique de Louvain; Brussels, Belgium.

Box 1. Most frequent natural disasters of 2004

1. Floods: 128 occurrences
2. Wind storms: 121 occurrences
3. Epidemic: 35 occurrences
4. Earthquake: 30 occurrences

Data from EM-DAT: The OFDA/CRED International Disaster Database. Available at: www.em-dat.net. Université Catholique de Louvain; Brussels, Belgium.

Hurricane Katrina are estimated to be more than 1300, making 2005 the third deadliest year in United States history for flood deaths, and by far the worst in recent years. The storm surge, produced by the high winds and vacuum effect of low-pressure systems, can produce dramatically high seas. These large storm surges that are so destructive and fatal are believed to account for an estimated 90% of deaths before a warning and evacuation system is implemented [11]. According to NOAA, the storm surge "is unquestionably the most dangerous part of a hurricane," acting "like a giant bulldozer sweeping everything in its path" [10]. The slope of the continental shelf can influence the effects of the storm surge's coastal inundation, and a normal high tide can add to the raised water level. The storm surge of category 5 Hurricane Camille that pounded the Gulf Coast in 1969 measured 25 feet.

In the United States, as much as 90% of the damage from natural disasters (excluding droughts) is caused by floods, costing $3.7 billion annually between 1988 and 1997. Between 1940 and 1999 an average of 110 deaths per year occurred in the United States, mostly from flash floods. A flash flood is defined as flooding that occurs within 6 hours of the inciting event, such as a heavy rainfall or a levee or dam failure. Flooding occurs in known floodplains. "Conversion of land from fields and woodlands to roads and parking lots" has resulted in "loss of ability to absorb water and has increased run off" leading to increased flood risk in some areas [12].

Table 2
United States fatalities from floods in recent years

Year	Flooding deaths	Flood deaths in automobiles
2004	82	45
2003	99	47
2002	50	31
2001	66	31
2000	41	20
1999	77	40
1998	136	86

Data from NOAA, National Weather Service Available at: http://www.nws.noaa.gov.

The power of water, especially moving water, is astounding. For example, "Two feet of water will carry away most automobiles…The lateral force of a foot of water moving at 10 mph is about 500 pounds on the average car. And every foot of water displaces about 1,500 pounds of car weight. So two feet at 10 mph will float virtually every car" [12].

In recent years, Continental Europe has experienced increased flooding. The 2002 flooding was caused by record rainfall combined with record warm months resulting in glacier melting. Dams could not withstand the surges of water pressure. According to the World Health Organization (WHO), flooding is the most common natural disaster in Europe [13]. "The number of deaths associated with flooding is closely related to the life-threatening characteristics of the flood (rapidly rising water, deep flood waters, objects carried by the rapidly flowing water) and by the behavior of the victims" [13], such as being in automobiles. Injuries are likely to occur during the aftermath or cleanup stage, particularly sprains and strains, lacerations, and contusions. As in the United States, vulnerable groups include the elderly, the very young, and individuals who have disabilities. Unfortunately, a "comprehensive surveillance of morbidity following floods is limited" [14].

Injuries and illnesses related to floods

What morbidity information exists? In 1992, Alson and colleagues [15] reported on the experience of an NDMS Special Operations Response Team after Hurricane Andrew. The team, consisting of one surgeon, three emergency department physicians, one physician assistant, four registered nurses, one psychologist, one pharmacist, 19 emergency medicine technicians/paramedics, six support personnel, and one public health preventive medicine specialist, saw 1203 adult and 336 pediatric patients. Only five injuries were directly caused by the hurricane; 285 injuries were sustained during the cleanup. Most of the care was routine and provided to those whose source of care was destroyed or not accessible. Supplies of tetanus antitoxin, antibiotics, and insulin were depleted in 24 hours. Many visits were to obtain prescription refills. Of the patients seen, 54 were pregnant, 13 were in active labor, and 10 had obstetric complications, such as suspected ectopic pregnancy or placenta previa. Twenty cases of simple corneal abrasions or corneal foreign bodies were seen, with one penetrating globe injury. In descending order, the most common procedures were: cardiac monitoring, intravenous therapy, laceration repair, abscess drainage, extremity splinting, abrasion debridement, and foreign body removal. Major lessons learned were that the unit must be self-sustaining for 72 hours, and communications, supplies, and record keeping are vital functions.

D'Amore and Harin [16] reported their experiences with an Air Force Expeditionary Medical Support Unit (EMEDS) that deployed to Houston, Tex, in 2001 when Tropical Storm Allison deposited 40 inches of rain on the city between June 6th and 10th. "The city's medical infrastructure bore the brunt of the storm's damage". Nine of the city's hospitals were closed or severely limited in services. The EMEDS +25 deployed from Wilford Hall with an 87-person staff. It had 10 ED beds, 2 OR tables, 3 ICU beds, 14 inpatient beds; and digital radiology, dental, and laboratory capabilities. It worked in coordination with a FEMA-operated Disaster Medical Assistance Team (DMAT). The DMAT performed most of the primary and referral care, while the EMEDS functioned as the hospital. One thousand thirty-six cases were seen over 11 days. Five hundred seven were "general medicine" and 232 were "trauma." There were 16 operation room cases: 4 I/Ds, 3 ORIFs, 2 closed fracture reductions, 2 laceration repairs, 2 hernias, 1 DPL/ex-lap for multiple trauma with mesenteric tear, 1 peri-rectal abscess I/D, and one exploration for foreign body.

Numerous Centers for Disease Control and Prevention (CDC) Morbidity and Mortality Weekly Reports (MMWRs) have provided data on flood and hurricane/flood injuries. In 1999, flooding from Hurricane Floyd's 20 inches of rain resulted in 52 deaths, with drowning in cars the leading cause; 10% of deaths were rescue workers. Four conditions accounted for 63% of emergency department visits: orthopedic and soft tissue injuries (28%), respiratory illnesses (15%), gastrointestinal illnesses (11%), and cardiovascular diseases (9%). Other conditions included 10 cases of carbon monoxide poisoning, and hypothermia. Increases in suicide attempts, dog bites, febrile illnesses, basic medical needs, and dermatitis occurred in the first week after the floods, whereas increases in arthropod bites, diarrhea, violence, and asthma were seen 1 month later [17].

Other CDC MMWRs provide essentially the same information on injuries in or around the home in the aftermath of these events. Most injuries are mild, predominantly consisting of cuts, lacerations, puncture wounds, and strains/sprains to extremities. Winds from Hurricane Charley in 2004 caused blunt trauma that resulted in more deaths than did drowning. Preexisting conditions such as cardiovascular diseases and diabetes were exacerbated [18–23].

Carbon monoxide poisonings are caused by placing generators indoors, in garages, or outdoors but near windows. After the 2004 hurricanes in Florida, 157 persons were treated from 51 exposure incidents, with six reported deaths [23]. Carbon monoxide poisonings were recently associated with Hurricane Katrina. Of the 167 cases, 48.5% were treated and released without undergoing hyperbaric oxygen therapy (HBOT), 43.7% were released after undergoing HBOT, and 7.8% were hospitalized (most for just 1 day). Among the patients, 80% complained of headache, 51.5% nausea, 51% dizziness, 31.5% vomiting, and 16.4% dyspnea, and 14.5% experienced loss of consciousness. The mean carboxyhemoglobin level was 19.8%, with a range of 0.2% to 45.1%. Practitioners must be aware of this risk and how to prevent, recognize, and treat it.

The CDC Katrina updates provide excellent summaries and recommendations for prevention, recognition, and treatment of conditions associated with hurricanes, floods, and disasters. These can be found at www.cdc.gov/od/katrina.

The clinician must consider a wide spectrum of illnesses in the aftermath of a disaster; common illnesses are still most common among the conditions seen (Table 3).

Infectious diseases associated with flooding

When the incidence of an infectious disease increases after a natural disaster, usually that agent was present in the environment before the disaster. Therefore, because the victims may be ‘‘exposed to potentially contaminated flood waters and crowded living conditions, and have had many opportunities for traumatic injury,’’ a broad differential diagnosis must be formed. Diseases associated with contaminated water include leptospirosis and *Vibrio vulnificus*. Leptospirosis is a zoonosis that has many wild and domestic animal reservoirs, including rats. Humans become infected after contact with contaminated water, whereby the organism enters skin abrasions or the conjunctiva. *V vulnificus* is a halophilic gram-negative bacterium found in salt water. Eighteen wound-associated cases of *V vulnificus* were reported after Hurricane Katrina. Workers with exposure to brackish waters should take precautions. Patients who have immunosuppression or chronic liver diseases are at increased risk. The wound infection begins with increased redness and local swelling and rapidly progresses, with characteristic findings such as vesicles and hemorrhagic bullae. Late-stage infections may result in gangrene, necrotizing fasciitis, systemic illness, and, potentially, sepsis. Treatment is with antibiotics (doxycycline and a third-generation

Table 3
Top 10 conditions: from limited needs assessments among persons staying in evacuation centers between September 10 and 12, 2005

Condition	Incidence per 1000 residents
Hypertension/cardiovascular	108.2
Diabetes	65.3
New psychiatric condition	59.0
Preexisting psychiatric condition	50.0
Rash	27.6
Asthma/Chronic obstructive pulmonary disease	27.5
Flu-like illness of pneumonia	26.3
Toxic Exposure	16.0
Other infections[a]	15.6
Diarrhea	12.8

Data from Centers for Disease Control and Prevention. Available at: www.cdc.gov/od/katrina/09-19-05.htm.

[a] Pertussis, varicella, rubella hepatitis, tuberculosis, and other communicable illness of outbreak concern.

cephalosporin) or fluoroquinolone [24]. Aggressive wound-site therapy may be needed. The CDC provides further recommendations for managing *V vulnificus* infection at www.bt.cdc.gov/disasters/hurricanes/katrina/vibriofaq.asp, information on wound injury and emergency management of wounds at www.bt.cdc.gov/disasters/emergwoundhcp.asp, and recommendations for prevention and treatment of immersion foot at www.bt.cdc.gov/diasaters/trenchfoot.asp. Additional diagnoses to consider are provided at www.bt.cdc.gov/disasters/hurricanes/katrina/medcare.asp. Table 4 summarizes the direct and indirect effects of floods on human health.

Heating, ventilation, and air-conditioning (HVAC) systems may be submerged after floods and become health hazards from microorganism contamination. Either replacement or proper cleaning and disinfection are required to prevent respiratory allergic manifestations. The CDC provides recommendations for proper cleaning at www.cdc.gov/niosh/topics/flood/cleaning-flood-HVAC.html. *Legionella pneumophila* may occur in HVAC systems and lead to Legionellosis, either a severe form with pneumonia, or a milder form (Pontiac Fever).

Finally, molds present a significant hazard in houses after floodwater exposures. Fungal infections are possible in individuals who are immune suppressed. Allergic manifestations such as cough, hay fever, rash, or asthma exacerbation are most likely. Molds can produce toxins that are hazardous if eaten or taken internally.

The number of deaths that resulted from the tsunami of December 26, 2004, will never be certain because the exact number of people who were in many areas is unknown; Fig. 1 provides an estimated summary. In the World Disaster Report of 2005, the International Federation of the Red Cross and Red Crescent Societies (IFRC) reported 164,000 dead or missing and more than 400,000 homeless In Aceh, Indonesia alone [25].

Regardless of the numbers, this tsunami is of unprecedented enormity (Tables 5, 6a, and 6b). “It rapidly became the most reported and well-funded disaster in history. Over 200 humanitarian organizations—plus 3,000 military troops from a dozen countries—arrived to offer aid” [25]. By one to two orders of magnitude, this tsunami caused more deaths than any other in the past 100 years (Fig. 2).

History

The mythical Atlantis may have been a real site destroyed by a tsunami, perhaps one produced when Santorini exploded. Other famous tsunamis include the one produced by the explosive destruction of Krakatoa in 1883, which Killed 36,000 persons. The 1700 Cascadia Earthquake in Vancouver, Canada, caused the subsequent distant tsunami in Japan and a local tsunami that was recorded in Native American oral tradition. In 1755, approximately 100,000 people died in Lisbon, Portugal, from earthquake, tsunami,

Table 4
Effects of floods on human health

Direct effects	
Causes	Health implications
Stream flow velocity; topographical features; absence of Warning; rapid speed of flood onset; deep flood waters; Landslides; risky behaviour; fast-flowing waters carrying boulders and fallen trees	Drowning; injuries
Contact with water	Respiratory diseases; shock; hypothermia; cardiac arrest
Contact with polluted water	Wound infections; dermatitis; conjunctivitis; gastrointestinal illnesses; ear, nose and throat infections; possible serious waterborne diseases
Increase in physical and emotional stress	Increased susceptibility to psychosocial disturbances and cardiovascular incidents
Indirect effects	
Causes	Health implications
Damage to water supply systems; damage to sewerage and disposal systems; insufficient supply of drinking-water; insufficient supply of water for washing	Possible waterborne infections sewage (enteropathogenic *E. coli, Shigella,* hepatitis A, leptospirosis, giardiasis, Campylobacteriosis); dermatitis; conjunctivitis
Disruption of transport systems	Food shortages; disruption of emergency response
Disruption of underground piping; dislodgment of storage Tanks; overflow of toxic waste sites; release of chemicals; Disruption of petrol storage tanks, possibly leading to fire	Potential acute or chronic effects of chemical pollution
Standing water; heavy rainfall; expanded range of vector Habitats	Vectorborne diseases
Rodent migration	Possible rodent-borne diseases
Disruption of social networks; loss of property, jobs and family members and friends	Possible psychosocial disturbances
Clean-up activities following flooding	Electrocution; injuries; lacerations; puncture wounds
Destruction of primary food products	Food shortages
Damage to health services; disruption of ‘‘normal’’ health Services activities	Decrease in ‘‘normal’’ health care services; insufficient access to medical care

Data from Menne B, Pond K, Noji EK, et al. Floods and public health consequences, prevention and control measures. UNECE/MP.WAT/SEM.2/1999/22, discussion paper presented at the United Nations Economic Commission for Europe (UNCE) seminar on flood prevention, Berlin, 7–8 October, 1999. WHO European Centre for Environment and Health, Rome, Italy.

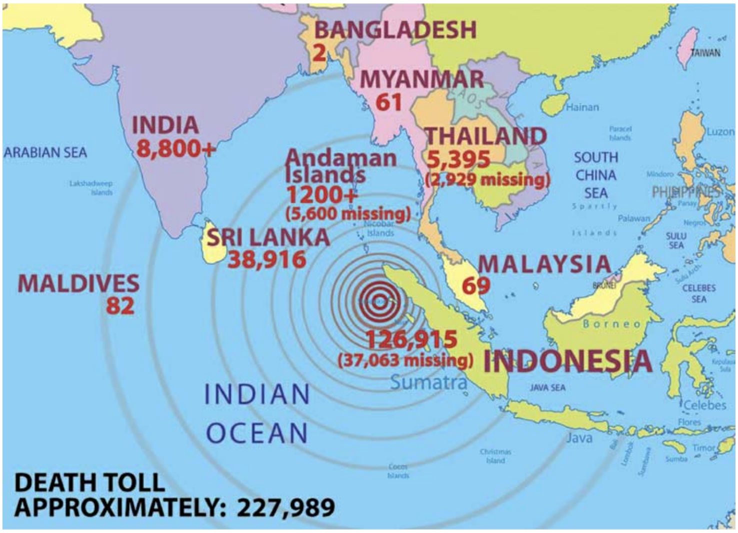

Fig. 1. Map showing death toll resulting from the massive tsunami of December 26, 2004. *From* the Pacific Disaster Management Information Network. Indian Ocean Earthquake and Tsunami Emergency Update, December 29, 2005. The Center of Excellence in Disaster Management and Humanitarian Assistance, Honolulu HI; with permission.

and fire. Tsunamis caused 40,000 deaths in the South China Sea in 1782, and 27,000 deaths in Japan in 1826. And in 1868, 25,000 deaths in Chile were tsunami-related. Two Hilo Hawaii tsunamis have occurred, one in 1960 that killed 61 people, caused by the largest earthquake (magnitude 9.5)

Table 5
The United States Agency for International Development data

Region	Individuals Dead/Missing	Individuals Displace/Affected
Indonesia (12/26/04 tsunami)	128,645 dead, 37,063 missing	532,898 displaced
Indonesia (3/28 earthquake)	39–626 dead	34,000 displaced
Sri Lanka	31,147 dead, 4,115 missing	519,063 displaced
India	10,749 dead, 5,640 missing	647,599 displaced
Maldives	82 dead, 26 missing	21,663 displaced
Thailand	5,395 dead, 2,845 missing	N/A
Malaysia	68 dead, ±6 missing	±8,000 displaced
Somalia	±150 dead	±5,000 displaced, 54,000 affected
Seychelles	±3 dead	40 households displaced

Data from the US Agency for International Development; Bureau for Democracy, Conflict and Humanitarian Assistance; Office of U/S Foreign Disaster Assistance; Bureau for Asia and the Near East; Government of Indonesia, 04/28/05; Government of Indonesia, 3/31/05; U.N. Office of the Humanitarian Coordinator for Indonesia; Government of Sri Lanka, 04/28/05; Government of India, 04/28/05; Maldives National Disaster Management Center, 04/28/05; U.N. Office for the Coordination of Humanitarian Affairs (OCHA), 1/18/05; Government of Thailand, 04/19/05; U.N. Consolidated Appeal, 1/06/05; U.N./Seychelles and USAID, 1/12/05.

Table 6a
Top 10 countries affected by wave/surge sorted by number of people killed

Country	Date	Killed
Indonesia	26 Dec 2004	165,708
Sri Lanka	26 Dec 2004	35,399
India	26 Dec 2004	16,389
Thailand	26 Dec 2004	8345
Japan	3 mar 1933	3000
Soviet Union	4 Nov 1952	2300
Papua New Guinea	17 Jul 1998	2182
Japan	1 sep 1923	2144
Japan	7 mar 1927	1100
Indonesia	18 Jul 1979	539

Data from EM-DAT: The OFDA/CRED International Disaster Database. Available at: www.em-dat.net. Universtié Catholique de Louvain; Brussels, Belgium.

ever recorded, and one in 1946 that killed 159 people [25a]. More recently, a 1998 tsunami in Papua, New Guinea, killed more than 2000 people. Since 1850, more than 420,000 deaths have been caused by tsunamis [25b]. "Most of these casualties were caused by local tsunamis that occur about once per year somewhere in the world" [26].

Basic science

The word *tsunami* is Japanese and means "harbor wave." The word may have been created when fishermen did not notice the open-ocean tsunami waves while in their boats and only realized the destructive power when they returned to port.

Tsunamis are generated when a massive amount of water is displaced, usually by an underwater earthquake. Volcanic eruptions or large

Table 6b
Top 10 countries affected by wave/surge sorted by number of people affected

Country	Date	Affected
Sri Lanka	26 Dec 2004	1,019,306
India	26 Dec 2004	654,512
Indonesia	26 Dec 2004	532,898
Somalia	26 Dec 2004	105,083
Thailand	26 Dec 2004	67,007
Korea Dem P Rep	21 Aug 1997	29,000
Maldives	26 Dec 2004	27,214
Myanmar	26 Dec 2004	12,500
Bangladesh	30 Aug 2000	12,010
Papua New Guinea	17 Jul 1998	9867

Data from EM-DAT: The OFDA/CRED International Disaster Database. Available at: www.em-dat.net. Universtié Catholique de Louvain; Brussels, Belgium.

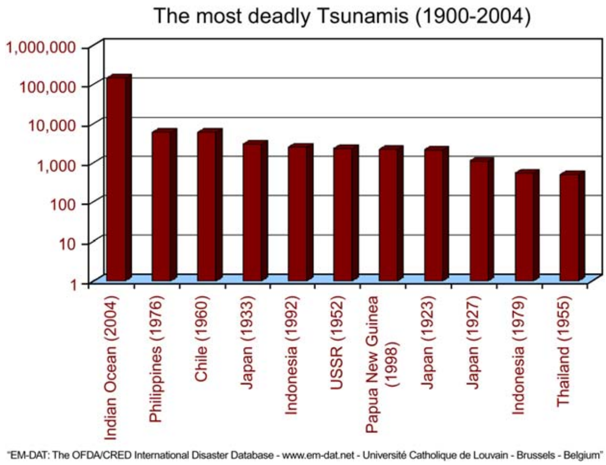

Fig. 2. The most deadly tsunamis (1900–2004).

underwater landslides can also produce tsunamis. The tsunami of December 26, 2004, was caused by an earthquake occurring 255 km SSE of Banda Aceh, Indonesia. Events leading up to that earthquake began "about 50 million years ago when the Indian Subcontinent collided with Asia raising the Himalayas." Parts of China and Southeast Asia are still being forced eastward. A plate boundary exists along the west coast of Sumatra where the heavier Indian plate is subducting beneath a lighter continental plate, the "Burma plate, which is a microplate between the Indian Plate and the Sunda Plate that contains much of Southeast Asia…Strain builds up and eventually the accumulated strain exceeds the frictional strength of the fault, and it slips in a great earthquake. The overriding plate that is dragged down rebounds and displaces a great volume of water" [27]. The magnitude 9.0 to 9.3 earthquake occurred along a 1200-km rupture on the ocean floor, causing the 2004 tsunami. "The fault slide was up to as much as 15 meters near Banda Aceh…The earthquake lasted at least 10 minutes—longer than any earthquake ever recorded" [28]. Along the entire 1200-km fault, the average vertical movement of the ocean floor was 4 meters. Lay and colleagues [28] warn that "there will be more earthquakes of this type, and with more humans exposed to the hazard there will be more devastating losses of life."

Once the entire water column is displaced, the initial tsunami splits into a "distant tsunami" that travels into open ocean and a "local tsunami" that moves toward the shore. The distant tsunami travels faster, because the speed of a tsunami is proportional to the square root of the water depth. Wave heights in deep water can only be tens of centimeters high, but move very quickly, up to 800 km per hour. However, the energy in the wave essentially goes to the bottom of the ocean and very little energy is lost as it moves large distances. The tsunami waves typically come in trains of 3 to 10 waves, separated by minutes. As the waves move closer to shore, they slow down to about 30 to 40 kilometers per hour, compress, and build in height. Finally the waves run ashore like a very strong and fast-moving tide, traveling much further inland than a normal wave [28a]. Tsunami waves do not look like a curling surfer's dream wave, but rather like a wall of water or ''bore.'' Eyewitnesses often describe the tsunami as being black (Fig. 3). The waves can scour away the shoreline and anything in its path. Large objects, such as large boats, can be carried a few kilometers inland, as was seen in Banda Aceh. A negative wave may reach shore first, as it did on Sumatra, causing the waterline to recede and coax some people to venture out to retrieve stranded fish, only to be followed by a devastating incoming tsunami wave of ferocious strength (9–15 m high in Banda Aceh).

Tsunamis are most common in the Pacific basin and usually require an earthquake with a magnitude of at least 7.0 for generation. The U.S. Geological Survey's earthquake magnitude policy is to use the term *magnitude* alone. *Moment magnitude* is currently the preferred method of recording earthquakes, but information can be confusing to non–earth scientists. The famous logarithmic Richter scale was devised by Charles Richter of Cal Tech in 1935 to measure local Southern California earthquakes of moderate size (3 to 7 on the Richter scale) using a seismograph to measure movement [29]. (A 3 on the Richter scale is the smallest that can be felt by humans.) The Richter scale is usually used by the lay media, ''But Richter's original method is no longer used because it doesn't give reliable results for larger earthquakes and for those far away [29].'' Newer methods, designed to be consistent with Richter's logarithmic scale, measure movement from zero on a seismograph. The energy of an earthquake is proportional to the square root of the cube of the amplitude, or approximately 31.6 times more energy for each step of the Richter scale. The newer moment magnitude scale, devised in 1979, was ''designed to be consistent with Richter's

Fig. 3. Tsunami waves pictured by young witness.

logarithmic scale [29]" and is related to the dimensions of the earthquake and the energy released. Intensity scales are also used in some parts of the world to describe earthquake effects in the local area; however, the term *magnitude* avoids confusion [29].

Illnesses and injuries related to tsunamis

On July 17, 1998, a tsunami caused by a magnitude 7.0 earthquake that generated an underwater landslide devastated the north coast of Papua, New Guinea. Waves of 7 to 15 meters hit the coast within 10 minutes of the earthquake. Three coastal villages were swept away completely, 16 villages were destroyed, and 2200 people died [30].

The Australian Defense Force (ADF) responded to this disaster and reported their experiences [31,32]. Over 10 days, 251 patients were treated and 209 surgical procedures were performed. Only two deaths occurred, both related to aspiration pneumonitis and near-drowning. The Australian unit had two operating tables (with a third for minor wound debridement) and 20 beds. The ADF arrived 52 hours after the tsunami and reported that they "treated no patients with intracranial, intrathoracic, abdominal or spinal injuries as these patients had already succumbed before our deployment. Furthermore, few infants and elderly people had survived [31]." Every patient the ADF treated on the first day had some aspiration pneumonitis from near-drowning. Injuries consisted of lacerations, including numerous large-flap scalp lacerations, and open and closed fractures and dislocations.

"All wounds were grossly septic and contaminated with foreign material…Many victims had been impaled upon the mangroves [32]." The ADF performed many wound debridements and 14 amputations. They saw "patients with every imaginable limb injury [33]." Necrotizing fasciitis was common. "All surgical wounds were left open, using ample absorbent gauze dressings." Delayed primary closure of wounds occurred approximately 5 days later. As expected, many patients had underlying respiratory diseases and anemia secondary to malaria or intestinal parasites, which were prevalent. Dehydration compounded blood loss; blood transfusions were available but limited. Patients who had long bone fractures were transported unsplinted to the ADF because the medical capabilities in the villages had been destroyed.

In many ways the experiences after the December 26 tsunami were similar, but on a much larger scale. Tragically, a huge number of people washed out to sea and drowned. Some were likely killed or injured by the large earthquake that hit Sumatra before the tsunami, and many were killed by blunt or penetrating trauma from objects in the fast-moving water. Notwithstanding lessons from the past, the number of serious injuries was much lower than many emergency medical teams expected. Many of the injured suffered extremity trauma.

Maegele and colleagues [33] reported on 17 tourists who were severely injured in this tsunami and were returned to Germany. Of the 17 patients, 15 had large soft tissue injuries of the leg or hip; 7 had thoracic trauma with rib fractures, 3 with hemopneumothoraces; 6 had closed fractures; 5 had large soft tissues injuries of the arm; 4 had open fractures; and 3 had head lacerations. All patients had clinical and radiologic evidence of pneumonitis. The wounds were grossly contaminated and cultures grew bacteria common to the marine environment. Wound infection with sewage contamination was suspected. Also, wounds grew highly resistant organisms that are uncommon to an aquatic environment, such as *Acinetobacter*, beta-lactamase producing *Escherichia coli*, methicillin-resistant *Staphylococcus aureus* (MRSA), and *Candida*.

In an accompanying editorial, Masur and Murray [34] comment on and provide additional information about infectious organisms associated with the tsunami. Seawater may contain *Vibrio* spp, *Aeromonas*, and *Mycobacterium marinum*. Sewage contamination would add enteric organisms. Furthermore, other organisms, including *Pseudomonas* spp*, Aeromonas, Legionella, Burkholderia, Chromobacterium*, and *Leptospira*, present risks for those patients who were swept inland and landed in freshwater. (In Banda Aceh, the Aceh River flows right through the middle of the city and empties into the sea where the tsunami hit the city.) Traditional nosocomial pathogens could be contracted, such as MRSA and *Enterococcus*, especially in overwhelmed and damaged hospitals. *Acinetobacter*, with multiple drug resistances, was reported in 20% of the patients. Respiratory and contact isolation were recommended until infectious agents could be identified.

The infectious disease specialists on the USNS Mercy in Banda Aceh observed drug resistance to be "remarkably prevalent," including an extremely high incidence of MRSA and multiply-resistant gram-negative pathogens and a very high rate of fluoroquinolone resistance. The specialists found it "surprisingly hard to distinguish between nosocomially acquired multiply resistant organisms and true community-acquired resistance" (Ed Ryan, MD, and Mark Pasternack, MD, unpublished material). Antibiotics are much more casually prescribed in some parts of the world, which may have contributed to this effect.

Tsunami-related aspiration pneumonia was not uncommon in individuals who were exposed to the deluge. Allworth [35] reported a case of "tsunami lung." He reported on the Australian experience, with 1 specific case and 10 similar cases [36] presenting with cavitary, necrotizing pneumonia approximately 1 month after immersion. Some patients developed empyemas and pneumothoraces. These patients did not experience response to many broad-spectrum antibiotics, but did experience response to carbapenems, and therefore carbapenems became first-line or early second-line treatment for immersion-related respiratory infections. Allworth reports that *B pseudomallei* were cultured from pleural fluid in four patients, and because many patients described a "black wave," muddy water aspiration was suspected, making *B pseudomallei* a likely causal agent of the infections. However, polymicrobial infections or other agents could have caused the pneumonias. Chierakul and colleagues [37] described their experience in Thailand, reporting on six cases of melioidosis in tsunami survivors. All six cases had aspirated tsunami water, and four also had significant lacerations. One patient had major anterior and posterior tibial artery damage, severe bleeding, and extensive wound contamination, eventually necessitating a below-the-knee amputation. Three of the six patients had diabetes mellitus. One patient died. All presented with signs and symptoms of pneumonia 3 to 38 days after the tsunami. *B pseudomallei*, which is a gram-negative bacillus found in the soil and water of endemic areas, was cultured from three blood samples and four respiratory secretions. These patients were treated with ceftazidime or a carbapenem for 2 weeks, followed by oral trimethoprim-sulfamethoxazole plus doxycycline to complete a 20-week treatment course.

Kao and colleagues [38] reported on one experience of the USNS Mercy involving an aspiration pneumonia. This patient also developed a brain abscess with a dense hemiparesis that responded to aggressive antibiotic therapy, which favorably reviews the pulmonary, neurologic, and infectious disease possibilities. One of Mercy's first patients was a 12-year-old boy with aspiration pneumonia. He spent 1 week in the intensive care unit, followed by 1 week in one of Mercy's wards. His story was typical of many: he was washed out to sea by the tsunami and survived by holding onto floating debris. His immediate family had all been killed. After he was rescued at sea, an uncle eventually found him.

Andersen and colleagues [39] reported on a case of mucormycosis in an Australian survivor of the tsunami who had been pushed a kilometer from his beach hut through debris. He had a large deep soft tissue injury on his thigh and hip, and many other smaller lacerations and abrasions. After he was evacuated to Sydney, he was treated with meropenem, ciprofloxacin, and doxycycline, and tetanus immunoglobulin. He developed widespread necrotizing fasciitis on his chest and arm and was treated with debridement, amphotericin B (lipid formulation), and hyperbaric oxygen. His wounds were suspected to have become contaminated when his injuries occurred or during his early resuscitative care.

An increase in tetanus occurred in Aceh, with 106 cases and 20 deaths reported [40]. Before the tsunami, Aceh had approximately 30 cases of tetanus per year. Most of the new cases developed between January 9 and January 17, 2005 [41]. The Injury Control Research Center hospital saw 15 cases, mostly men; more than required ICU care, with 100% survival [41].

Vaccination coverage for Aceh was lower than for the rest of Indonesia, with approximately 60% for children and 20% to 30% for adults. The toxin tetanospasmin is produced when the vegetative form of *Clostridium tetani* germinates in wounds contaminated with soil, dirt from the street, or feces.

The toxin is then taken up by the nerve terminals and transported intra-axonally to the spinal neurons. It then causes a presynaptic inhibition of an inhibitory transmitter, glycine. This loss of inhibition causes rigidity, accounting for the classic trismus (lockjaw), and other symptoms such as opisthotonos from back-muscle rigidity. The autonomic nervous system can also be affected, leading to conditions such as severe dysrhythmias, hyperthermia, blood pressure fluctuations, and urinary retention.

Treatment involves respiratory support; benzodiazepines or vecuronium for spasms, if necessary; passive immunization with human tetanus immunoglobulin; active immunization with tetanus toxoid at a site separate from the immunoglobulin site; antibiotic therapy with penicillin G; treatment of autonomic dysfunction; and surgical debridement of wounds [42].

No cases of cholera were confirmed in the 4 months after the tsunami [41]. This pathogen does not survive well in saltwater, and proactive preventive measures were enacted by the international medical teams to further mitigate the risk factors associated with potable water shortage, crowding, and lack of sanitation. Also, no increases occurred in the incidence of malaria or dengue fever, which are both mosquito-borne illnesses. Although endemic, the baseline rates of these illnesses are not as high in Aceh as they are in other Indonesian provinces. However, tuberculosis was extremely widespread and prevalent. Intestinal parasites were also common and patients often passed *Ascaris* worms, particularly when under anesthesia.

Lim and colleagues [43] reported on the observations of two Korean medical relief teams working in Sri Lanka, noting that adequate potable water significantly mitigated transmission of diarrheal illnesses. Respiratory diseases and chronic conditions were prevalent in the displaced persons camps. Skin infections and minor skin trauma were particularly common.

International collaboration, communication, cooperation

The USNS Mercy arrived more than a month after the disaster struck. The WHO, the IFRC, non–governmental organizations (NGOs), and foreign militaries working with the host nations had already collaborated to help those in need. Mercy came with a floating tertiary capability that did not exist anywhere near Banda Aceh. It had a CT scanner, angiography, an extensive pharmacy, a full laboratory and blood bank, fully equipped ICU beds, and four staffed operating rooms. The treatment team consisted of volunteer nurses and doctors from the NGO Project HOPE, commissioned officers from the United States Public Health Service (particularly strong in valuable mental health resources), and Medical staff from the US Navy. Some patients had injuries (mostly orthopedic or maxillofacial) directly related to the tsunami that only the Mercy had resources to evaluate and treat. Aspiration pneumonia cases were also treated, as were some trauma cases that occurred in the damaged city. However, most patients were seen by Mercy staff because they had lost everything and had limited access to medical care.

The local hospital in Banda Aceh, Zainoel Abidin Hospital, lost more than 50% of its staff; it had just received a CT scanner a few months before being destroyed by the tsunami. Routine illnesses became urgent. The Mercy's first patient was a boy who had appendicitis and was brought in by his father; his mother and other siblings were dead or missing and presumed dead. Mercy's experience was unique in that it had more than enough work for its surgeons because it had the complete infrastructure to support almost any surgery needed. Mercy performed 285 operations in Banda Aceh, mostly onboard. The most procedures performed onshore were cataract surgeries. Surgeries performed were predominantly orthopedic; oromaxillofacial/ear, nose, and throat (OMFS/ENT); and general surgery cases: 40 patients underwent 65 orthopedic procedures, including 25 incision and drainage; 14 intramedullary nail; and 9 open reduction internal fixation. General surgery cases, including pediatric and plastics, ranged from thoracotomy to wound drainage. Fractures and a wide range of head and neck masses dominated the OMFS/ENT workload.

Although Mercy arrived more than 5 weeks after the event, the crew still saw disaster-related injuries. However, disaster-related injuries had mostly diminished by the fourth week [41], testifying to the success of the combined efforts of the civilian and military health care providers. However, getting the right resources to the right people at the right time did not always occur. A huge gift of goodwill was bestowed by the world community, which "reflects the universality of the humanitarian impulse" [44]. However, matching the assistance with the needs was not easy. Some assistance was considered inappropriate and "the overabundance of helpers added to the problems of coordination [44]." For example, some children were given up to four measles vaccinations. The IFRC reported that one United Nations witness in Meulaboh (south of Banda Aceh on the devastated west coast of Sumatra) saw "20 surgeons competing for a single patient…Yet midwives and nurses were in short supply. Women had to give birth without medical assistance" [25]. And, alas, we are reminded that we neglect "the forgotten emergencies" – the millions, mostly children, who die each year from malnutrition and preventable diseases.

People who witnessed the December 26 tsunami and became friends with those who suffered have difficulty not getting emotional when reflecting on the disaster. The magnitude, or denominator, of the devastation is difficult to fathom; physicians and surgeons are more inclined to look at the numerator, reflected by the individual sitting on the examination table or under the drape on the operation table. A disaster by definition overwhelms the resources, and therefore the denominator must be considered so that more individual patients can be helped. For tsunamis and floods, although the deaths may be many and the destruction widespread, the number of injuries requiring sophisticated care is relatively few. Adequate water, sanitation, clothing, nutrition, and shelter are early priorities [45].

Summary

The CDC provides the following review and summary of the health effects of tsunamis [46]:

Immediate health concerns

- After the rescue of survivors, the primary public health concerns are clean drinking water, food, shelter, and medical care for injuries.
- Flood waters can pose health risks such as contaminated water and food supplies.
- Loss of shelter leaves people vulnerable to insect exposure, heat, and other environmental hazards.
- Most deaths associated with tsunamis are related to drownings, but traumatic injuries are also a primary concern. Injuries such as broken limbs and head injuries are caused by the physical impact of people being washed into debris, such as houses, trees, and other stationary items. As the water recedes, the strong suction of debris being pulled into large populated areas can further cause injuries and undermine buildings and services.
- Medical care is critical in areas where little medical care exists.

Secondary effects

- Natural disasters do not necessarily cause an increase in infectious disease outbreaks. However, contaminated water and food supplies and the lack of shelter and medical care may have a secondary effect of worsening illnesses that already exist in the affected region.
- Decaying bodies create very little risk for major disease outbreaks.
- The people most at risk are those who handle the bodies or prepare them for burial.

Long-lasting effects

The effects of a disaster are long-lasting. In the months after a disaster, a greater need exists for financial and material assistance, including

- Surveying and monitoring for infectious and water- or insect-transmitted diseases
- Diverting medical supplies from nonaffected areas to meet the needs of the affected regions
- Restoring normal primary health services, water systems, housing, and employment

- Helping the community recover mentally and socially after the crisis has subsided

One sad and unusual statistic from the Indian Ocean tsunami disaster is that many more women than men were killed. Another sad fact is that the number of children killed was disproportionately high.

The mental health needs of the victims must be addressed. Addressing these psychologic needs, De Jong and colleagues [47] wrote: "In Banda Aceh we found that most people have a strong desire to move forward and to rebuild their lives." The crew on the Mercy observed great resiliency and strength in the Acehnese people. Although most people exposed to a disaster do well and only have transient symptoms, some individuals develop psychiatric illnesses [48]. Post-traumatic stress disorder clearly increases in the disaster-affected areas.

Table 7 provides a comparison of the consequences of various disasters, including floods and tsunamis. Earthquakes cause many injuries. The working rule of thumb is to calculate three injuries for every death. Floods and tsunamis, on the other hand, do not typically cause a large number of injuries compared with deaths. This observation of 25 years ago is still valid today.

For the United States to have been part of the international humanitarian response to the 2004 tsunami disasters was an honor and a privilege. The cooperation and coordination that occurred, though it may not have been perfect, gives reason to be optimistic about the future, for the world is truly a much smaller place than it used to be and the future depends on communication and mutual respect.

Table 7
Comparison of disaster consequences

Likely effects	Complex emergencies[a]	Earthquakes	High winds without flooding	Hurricanes, floods	Flash floods, tsunamis
Deaths	Many	Varies	Few	Few	Many
Severe injuries	Varies	Many	Moderate	Few	Few
Risk of communicable disease outbreaks[b]	High	Small	Small	Varies	Varies[c]
Food scarcity	Common	Rare	Rare	Varies	Varies
Population displacements	Common	Rare[d]	Rare	Common	Varies

Adapted from Pan American Health Organization, Emergency Health Managements After Natural Disaster. Washington (DC): Office of Emergency Preparedness and Disaster Relief Occordination; 1981. Scientific Publication No. 47.

[a] Complex emergencies not in original table published in 1981. Complex emergency = human disaster situation that can follow war or civil strife.

[b] "Risk of communicable diseases is potential after all major disasters. Probability rises with overcrowding and deteriorating sanitation".

[c] Epidemics are not inevitable after every disaster.

[d] Population displacements may occur in heavily damaged urban areas.

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