Current Status of Preparedness for Blast Injuries in Japan

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Abstract

In recent years, blast injuries worldwide have primarily been caused by explosions of improvised explosive devices detonated in terrorist attacks. The most common mechanism of injury among U.S. soldiers in Iraq and Afghanistan war is explosions. Blast injuries are complicated, being compounded by injuries caused by blast waves in addition to penetrating and blunt trauma. Moreover, maintaining safety and security is a major concern in providing medical care and requires an understanding of blast physics and blast injury pathophysiology, especially in cases of blast lung injury (BLI) and blast-induced traumatic brain injury (bTBI).

In this paper, we present our review of the current status of preparedness for blast injuries, which was conducted with the cooperation of the Cabinet Office of the Government of Japan and the Japan Self Defense Force. Based on this review, we created two action card systems and a medical record system in Japanese for blast injuries: "Survival Cards for Explosive Events for the First-on-scene Responder," "Survival Cards for Explosive Events for Medical Staff Providing Prehospital and Hospital Medical Care," and the "Medical Records System for Blast Injuries." These were developed with reference to preparedness guidelines issued by the United States and European countries and are available on the Cabinet Office website.

As the next step, guidelines for the treatment of blast injuries should be established and full-scale drills should be conducted as preparedness activities.

Key words Blast lung injury, Blast-induced traumatic brain injury, Terrorism, Explosive event

Introduction

On March 20, 1995, Aum Shinrikyo terrorists released sarin gas on five subway trains running in the Tokyo Metro subway system, killing 12 and injuring more than 5,500 persons. This was the largest chemical terrorism-related event the world experienced during the 1990s.[1] In 2004, nine years after this event, the Law Concerning the Measures for Protection of the People in Armed Attack Situations etc. (Civil Protection Law) was finally enacted with the aim of making the entire nation fully prepared for armed attack situations (including nuclear, biological, and chemical weapons attacks) and emergency response situations. This requires the implementation of appropriate and prompt measures to protect the people of Japan in such situations. Since FY 2005, all of Japan's 47 prefectures have held tabletop or field exercises, although the latter have been conducted only for chemical and biological terrorism situations.[2]

As terrorist groups in recent years have been carrying out bombings and explosions with greater frequency, medical responses to explosive events due to terrorism have become widely discussed[3,4] and guidelines for preparedness have been issued by the United States and European

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countries. In Japan, it is imperative that medical responses to terrorist bombings be developed.

This review outlines the issues of blast physics, the pathophysiology and classification of blast injuries, essential medical support for blast events, and the treatment of blast injuries as discussed with members of the Cabinet Office of the Government of Japan and the Japan Self Defense Force in order to determine the medical responses required for such blast events should they occur in Japan. We then introduce two action card systems for medical responders and a medical record system for blast injuries we developed based on these discussions.

Terrorist Blast Events

Terrorism can be defined as having four key elements: 1) it is premeditated, being planned in advance rather than being an impulsive act of rage; 2) it is political and not criminal, being designed to change the existing political order; 3) it is aimed at civilians and not at military targets or combat ready troops; and 4) it is carried out by sub-national groups, not by a state army.[3] Under this definition, bombings and explosive events are the most commonly perpetrated acts of terrorism. Examples of such attacks in recent years are the 2010 Moscow Metro bombings, the 2008 Mumbai attacks, the 2006 Tel Aviv suicide bombing,[5] the July 7, 2005 London bombings,[6] and the 2004 Madrid train bombings.[7]

Like many countries, Japan has experienced terrorist bombings for many decades.[8] One of the largest terrorist bombings in Japan occurred on August 30, 1974, when a bomb exploded on the sidewalk outside the main office building of Mitsubishi Heavy Industries in Marunouchi, Tokyo. Eight persons died and 297 were injured. The explosive device used was a time bomb made from high-quality chloric acid. The impact of the blast shattered the glass in all of the building's front windows, injuring numerous office workers inside.

Blast Devices

Improvised explosive devices (IEDs) are handmade or improvised bombs used by terrorists. They can be made from stolen explosives, commercial blasting supplies, or from fertilizer, fuel oil, or other household ingredients. Often IEDs are packed with metal objects such as nails or ball bearings and could in theory contain toxic chemicals or radiological materials (dirty bombs).

Explosives are categorized as either high-order explosives (HE) or low-order explosives (LE).[3] The former produce a defining supersonic over-pressurization shock wave, examples of which include TNT, C-4, Semtex, nitroglycerin, dynamite, ammonium nitrate fuel oil, and triacetone triperoxide. The latter create a subsonic explosion and lack the over-pressurization wave of HE. Examples of LE include pipe bombs, gunpowder, and most pure petroleum-based bombs such as Molotov cocktails and aircraft improvised as guided missiles.

Medical teams should understand the nature of different blast devices. Primary blast injuries (PBIs) occur most often with HE and treatment should be provided with an understanding of the potential for PBIs among casualties. The severity of blast injuries is influenced by a variety of factors, including type of blast device, amount of explosive used, space in which the device is detonated (open/closed), distance from ground zero, and screening or protective gear available.

Table 1 Classification of blast injuries

	Features
Primary blast injuries	Caused by the impact of the over-pressurization wave
Secondary blast injuries	Caused by flying debris and bomb fragments
Tertiary blast injuries	Caused by the person being thrown by the blast wind
Quaternary blast injuries	All explosion-related injuries, illnesses, or diseases not due to other mechanisms as well as the exacerbation or complication of existing conditions

Classification of Blast Injuries (Table 1)

Blast injuries are classified into four categories: 1) PBIs, which are most common with HE and result from the impact of the blast over-pressurization wave on the body surface; 2) secondary blast injuries, which result from flying debris and bomb fragments causing shrapnel wounds; 3) tertiary blast injuries, which result from individuals being thrown by the blast wind; and 4) quaternary blast injuries, which include all explosion-related injuries, illnesses, or diseases not due to the primary, secondary, or tertiary mechanisms, as well as the exacerbation or complication of existing conditions.[3]

Primary blast injuries (Table 2)

Blasts most frequently injure the tympanic membrane, and can do so at low pressures, so this injury represents the primary effect of a blast. A traumatic perforated tympanic membrane has an irregular margin or rim with blood or a blood clot present, and thus might be overtriaged at an explosive event. Although primary blast effects on other air-containing organs are unlikely if there has been no rupture of the tympanic membrane,[4] data have shown that PBI is not necessarily associated with a ruptured tympanic membrane. In the current Iraqi-US conflict, the use of tympanic membrane perforation as a biomarker for PBI resulted in a sensitivity of 50% and specificity of 87%,[9] while it was reported that there was a significant association between barotraumatic tympanic-membrane perforation and concussive brain injury.[10] These findings suggest that physicians who are treating blast survivors with tympanic-membrane perforation need to be cognizant of the potential for concomitant neurologic injury.[10]

Blast lung injury (BLI) is a major cause of morbidity and mortality among blast victims (**Table 3**). Major clinical manifestations of BLI are tachypnea, hypoxia, cyanosis, apnea, wheezing, decreased breath sounds, hemoptysis, cough, chest pain, dyspnea, and hemodynamic instability. BLI usually occurs in the early phase and rarely in the delayed phase (24–48 h). BLI is visualized as a bihilar "butterfly" pattern on chest radiographs because of disruption, hemorrhage, and pulmonary contusion. To prevent hypoxemia in patients with BLI, sufficient high flow oxygen should be administered via a non-rebreather mask or continuous positive airway pressure device, or in the case of respiratory failure, endotracheal intubation should be performed.[3]

Pulmonary barotrauma is the most common critical injury to those close to the blast center. Systemic acute gas embolism from pulmonary

Table 2 Organs affected by primary blast injuries

Organs	Features
Lungs	Major cause of morbidity and mortality Pulmonary barotrauma, systemic acute gas embolism
Brain	Edema, contusion, diffuse axonal injury, hematomas/hemorrhage
Tympanic membrane	Injured most frequently and at low pressures
Gastrointestinal tract	Most common critical injury, possibility of delayed rupture
Eyes	Rupturing of the globe, serous retinitis, and hyphema

Table 3 Blast lung injuries

	Findings
Symptoms	Dyspnea, hemoptysis, cough, chest pain
Signs	Tachypnea, hypoxia, cyanosis, apnea, wheezing, decreased breath sounds, hemodynamic instability
Chest radiograph	"Butterfly" pattern due to disruption, hemorrhage, and pulmonary contusion

disruption occludes the blood vessels of the brain or spinal cord. If patients are ventilated, caution should be exercised to prevent alveolar rupture or air embolism due to positive pressure ventilation. Patients with air embolism should be positioned in prone, semi-left lateral, or left lateral positions and transferred to a hyperbaric chamber.[3]

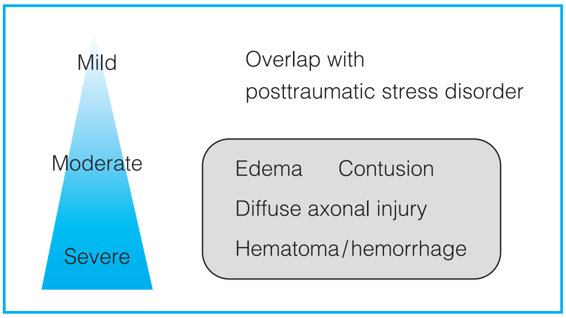
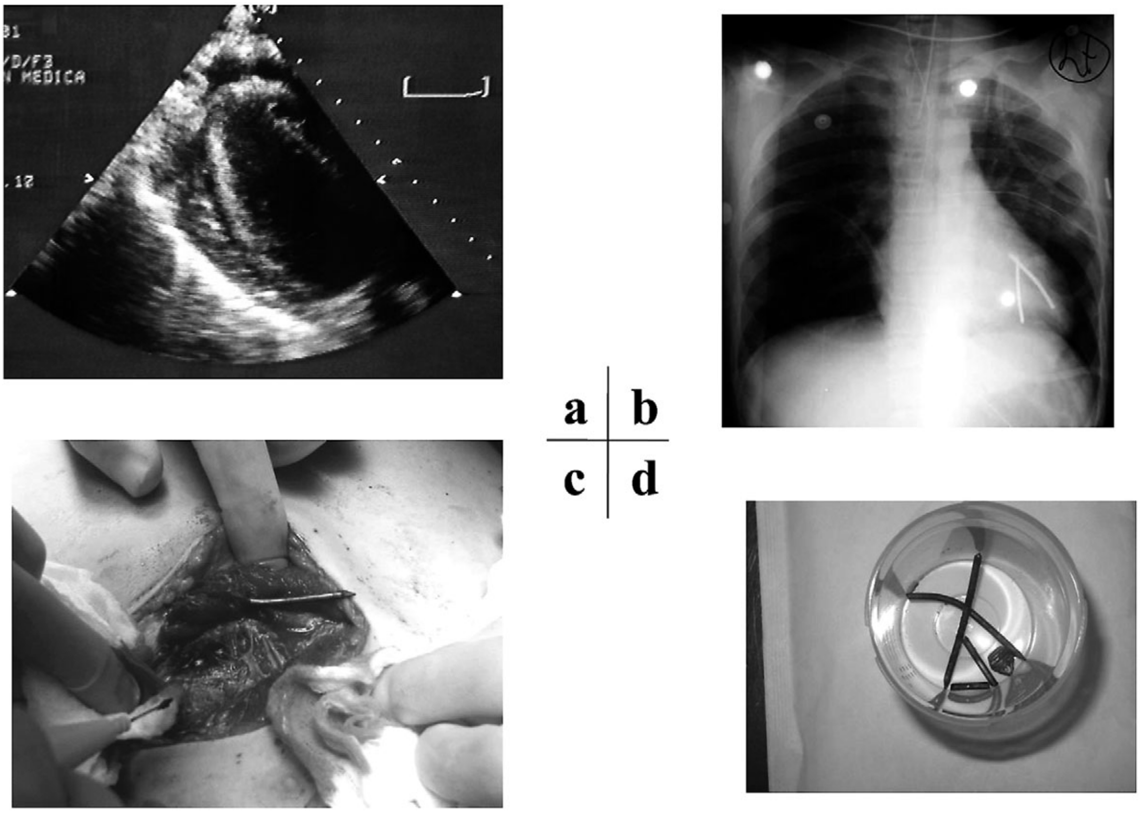


Fig. 1 Blast-induced traumatic brain injuries

The most frequently affected visceral structure in PBIs is the colon. Rupture of the colon and, less frequently, the small intestine may occur as an immediate result of a blast; mesenteric ischemia or infarct can cause delayed rupture of either organ and these injuries are difficult to detect initially.[4]

PBIs to the eye include rupturing of the globe, serous retinitis, and hyphema, and among PBIs to the brain, blast-induced traumatic brain injury (bTBI) is a major concern.[11] During the Iraq conflict, nearly half of the soldiers who were injured experienced blast exposure resulting in neurotrauma,[12] and bTBI has been called the



(Courtesy of Kobi PELEG, Ph.D., MPH, from Israel National Center for Trauma.)

Fig. 2 A 13-year-old boy injured in a suicide bomb attack; shrapnel and nails penetrated his heart and liver

"signature wound" of the Afghanistan and Iraq wars.[13] Injury severity can range from mild effects to fatal injuries depending on the person's exposure to the blast (**Fig. 1**). Edema, contusion, diffuse axonal injury, hematoma, and hemorrhage have all been observed after bTBI,[14] and in an important study on military populations, Armonda et al.[15] reported that persistent traumatic focal cerebral vasospasm occurred in a substantial proportion of soldiers injured in blast events.

One obvious feature of mild traumatic brain injury that can be observed in veterans of the wars in Iraq and Afghanistan is the high association of this injury with posttraumatic stress disorder. The overlap in their symptoms has made distinguishing them clinically challenging. Moreover, the high rates of these co-existing disorders in recent military operations are of significant concern in terms of the long-term health of US veterans, as well as of their associated economic implications.[16]

Secondary blast injuries

Secondary blast injury is the most common cause of death in a blast event. These injuries are caused by flying debris, with the most common injury types being trauma to the head, neck, chest, abdomen, and extremities in the form of penetrating trauma (**Fig. 2**), blunt trauma, fractures, traumatic amputations, and soft tissue injuries. Terrorists often add screws, nails, and other sharp objects to bombs to increase injuries, and in penetrating trauma (typically shrapnel wounds), foreign bodies follow unpredictable paths through the body. This can sometimes leave only mild external signs and can have a low threshold for imaging studies; thus, when providing medical care we should consider wounds to be contaminated as well as often infected.[3]

Tertiary blast injuries

Tertiary injuries result from individuals being thrown by the blast wind or being crushed under collapsed structures. Head injuries, skull fractures, and bone fractures are the most common types of tertiary blast injuries. In the case of entrapped casualties, field amputation is sometimes necessary. Indications include the inability to safely extricate the injured person, the continued presence of environmental toxins that pose a hazard to victims or rescuers, and a prolonged period until definitive treatment is available after extrication. Field amputations are best performed by trauma or orthopedic surgeons, and adequate analgesia and anesthesia should be ensured.[3]

Quaternary blast injuries

All explosion-related injuries, illnesses, or diseases not due to primary, secondary, or tertiary mechanisms—including the exacerbation or complication of existing conditions—are considered quaternary blast injuries. The most common of these injuries include burns, head injuries, asthma, chronic obstructive pulmonary disease, other breathing problems, angina, hyperglycemia, hypertension, and crush injuries. Response staff should also be cognizant of CO intoxication, cyanogen intoxication, and methemoglobinemia.

Essential Medical Support for Blast Events (Table 4)

Prehospital medical support

While the basic protocol for medical activities carried out for blast events is the same as that for other disasters, several additional points need to be considered. First, decisions regarding the need for decontamination at the site should be made in cooperation with other reinforcement personnel.

Table 4 Essential medical support for blast events

	Essential medical support
Prehospital	Decontamination Remain alert for secondary devices (e.g., bomb, sniper) Other hazards (sharp debris, fragile structures, air contamination, etc.)
In-hospital	Preparation for capacity surge Operating theater Irrigation/debridement

Medical teams mainly work in the "cold zone" and usually only work in the "warm zone" if rapid triage, intubation, or administration of antidotes is necessary as Japanese law prohibits emergency medical technicians from performing life-saving interventions.

In the case of a terrorist attack, the utmost care and attention should be paid to the potential presence of a secondary device, and terrorists tend to target first responders. Secondary devices can be bombs or snipers. Other hazards include sharp debris, fragile structures, and air contamination; terrorists have been known to pose as casualties and should be identified immediately. As it is extremely difficult for medical teams to manage an emergency situation without other reinforcement, it is necessary that they actively share information about safety and security at the scene.

In Japan, disaster medical assistance teams (DMATs) play a major role in the event of natural disasters, but are not officially to be deployed in the event of terrorist attacks. In reality, however, medical teams are deployed to a scene before it has been determined whether or not a criminal event has taken place, and such teams would be likely to work onsite at a blast event in the future.

In-hospital medical support

Hospitals can expect a capacity surge within the first hour after the event. Also, as the more severely injured arrive at hospitals after some delay because they are typically entrapped close to ground zero in areas with many collapsed structures and much debris, the remaining causalities arrive within 24 hours after the event. It is therefore vital that operating theaters be managed efficiently as many surgical patients can be expected following a blast event. Irrigation and debridement of wounds is most often carried out following a blast event, and surgeons must be prepared to do this even if they are not orthopedic surgeons.

Treatment for Blast Injuries

Treatment for blast injuries should be decided on the basis of the mechanism and classification of the blast injuries present; however, there are no guidelines or protocol for such treatment currently available in Japan.

A recent case series comparing the work of forward resuscitative surgical units in Iraq between earlier and later phases of the war describes increases in the number of injuries per patient (1.6 vs. 2.4) and the number of casualties with fragment wounds (48% vs. 61%) and a decrease in the number of gunshot wounds (43% vs. 33%) with the transition to insurgency warfare.[17] Despite the increase in injury severity that occurred with this transition, mortality was unchanged.[17]

Recent studies demonstrating that the severely injured present with coagulopathy of trauma on admission have highlighted the importance of treating this disorder at an earlier stage,[18] in other words, in the field by medical emergency staff. In military combat situations, in which 7% of casualties require massive transfusion, resuscitation is at first limited to keeping blood pressure at around 90 mmHg by preventing renewed bleeding from recently clotted vessels. This is followed by the restoration of intravascular volume by infusing thawed plasma as a primary resuscitation fluid in a ratio of at least 1:1 or 1:2 with packed red blood cells (PRBCs), and crystalloid use is minimized. This protocol is indicated not only for blast injuries, but also for all severe injuries.

When it is used for blast injuries, the patient should be watched carefully for permissive hypotension as there might not be sufficient tissue perfusion because of decreased peripheral vascular resistance and lower cardiac output caused by the blast event. Moreover, blast lung and bTBI can worsen if fluid resuscitation is excessive, and so close attention must be paid to fluid management for blast injuries.

In addition, several special operations units have also encouraged tourniquet use for hemorrhage control in combat situations as the aggressive use of tourniquets among trauma patients transported to the US Air Force Theater Hospital at Balad Air Base, Iraq, led to no cases of serious complications, even when infrequent cases of inappropriate use were taken into account.[19] This is probably due to the rapid evacuation of casualties and the short time to operative intervention, which was often less than 1 hour.

This is in contrast to a longer average time to operation for similar cases in the Vietnam War, for which time to operation ranged from 90 minutes for ballistic injury to 5.5 hours for popliteal artery injuries treated aboard a United States Navy hospital ship, and in the Korean War, for which the average time to operation was 9.2 hours.[19] While military cases are clearly not always applicable to civilian cases, we believe that the appropriate indication for tourniquet use following a blast event should be considered on the basis of military experiences.

Critical incident stress management is also a major issue to consider. Mental care is necessary for even those casualties with minor or even no physical injuries. To address this issue, a registration system might be suitable for enabling follow-up. Moreover, first responders and rescuers, who work under extremely difficult conditions, also need to be supported and observed for stress.

Table 5 Outline of survival cards for explosive events for the first-on-scene responder

• Security at scene
• Pitfalls of transportation
• Classification of blast injuries
• Factor, which decide severity of blast
• Triage and first aid for blast injuries
• Primary care for each blast injuries
- Primary/secondary/tertiary/quartery)
• Miscellaneous
- Tourniquet/CO intoxication/mental health
- Crush syndrome/compartment syndrome
- Protection of infection/civil protection law

Table 6 Outline of survival cards for explosive events for medical staff providing prehospital and hospital medical care

• Security at scene
• Factor, which decide severity of blast
• Pitfalls of triage in blast events
• Mechanism of each blast injuries
• Algorithm of initial care for blast lung
• Treatment of blast lung
• Miscellaneous
- CO intoxication/crush syndrome/compartment syndrome
- Pitfalls in air evacuation/protection of infection/mental health
- Tourniquet/for children/civil protection law

Based on the findings of our review, we created, in Japanese, two action card systems[20] and a medical record system[21] for blast injuries: "Survival Cards for Explosive Events for the First-on-scene Responder" (**Table 5**), "Survival Cards for Explosive Events for Medical Staff Providing Prehospital and Hospital Medical Care" (**Table 6**), and the "Medical Records System for Blast Injuries" (**Table 7**). These were developed with reference to preparedness guidelines issued by the United States and European countries and are available on the Cabinet Office website.[3,20,21]

Conclusions

In this paper we discussed the mechanisms and classification of blast injuries and summarized the essential medical support required for blast events. Our review of the current status of blast injury medicine and response measures in Japan, as discussed with members of the Cabinet Office of the Government of Japan and the Japan Self Defense Force, was undertaken because preparedness for explosive events and blast injuries has not yet been adequately addressed in Japan in spite of the fact that Japan experienced explosive terrorist attacks and has the risk of these attacks.

Japan should have measures in place to respond medically to blast events, and to this end the authors created the two action card systems and the medical records system for blast injuries. Further understanding of the medical responses required for blast events, the establishment of a

Table 7 Outline of medical records system for blast injuries

• Patient information
• Prehospital information
• Process to admission
• Status on admission
• Initial evaluation (Primary survey)
• Secondary survey
• AIS code
• Laboratory data/imaging
• Treatment
• Outcome/prognosis

protocol for such responses, and preparation through the implementation of careful drills are necessary for the future.

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