Blast Trauma Care

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1 On-Site Assessment and Management of Blast Injuries

Blast injuries are common, whether it is a war or a peaceful era, accidental or deliberate, which cause huge losses to people's lives and property, and pose great challenges to the work of medical staff. To save the wounded to the utmost extent, different departments should collaborate closely, medical resources should be allocated properly, and the basic principles of emergency treatment should be followed, given the complex environment at the detonation site, the large number of casualties, and the severe injuries. Nurses work together with other professionals on the front line of rescue in various rescue activities, who play an important role that cannot be ignored.

1.1 Assessment of the Detonation Site

1. **Priority at the detonation site**. The explosion could destroy the foundations of tall buildings and others, to make the main structure collapse and unstable. The chaotic and noisy scene, with widespread panic, could cause a large number of casualties. In this condition, it is necessary to immediately establish a command organization to ensure the safety of all people at the scene, as well as to guarantee smooth medical rescue. Followings are the work focus at the scene in order, including establishing a command organization, ensuring people's safety, ensuring smooth communication, assessment at scene, triage, treatment, and transportation. As one of the medical rescue team, nurses must, like all the other rescue personnel, wear personal protective equipment before entering the scene to work after ensuring their own safety. Before entering the scene, nurses must ensure that it is safe to enter the scene. They can enter the scene for rescue only if the scene is safe and the scene commander's permission is obtained. Follow the 1-2-3 safety guidelines: Am I safe? Is the site safe? Is the injured safe?

   Rescuers on the scene should first avoid secondary disasters, such as damage caused by scattered debris and collapse of buildings after the explosion. Besides, contamination should also be considered, including chemical, biological, and radiological pollution from the environment and the injured. Self-protection measures are needed, such as appropriate decontamination, if necessary. If it is a terrorist attack, be wary of a second explosion, and the radio should be off to avoid a radio-controlled secondary explosive device. Relevant data indicate that the second explosion was usually set to 30–100 min after the first one in terrorist attacks, mainly targeted at emergency rescuers, firemen, and police. Terrorists should be identified, who sometimes may monitor the scene somewhere, and detonate a second explosion at a distance, or use high-energy weapons to kill the rescuers. Rescuers should also be alert that the injured may have weapons or explosive devices.

   In addition to preparing sufficient supplies and mobilizing spare ambulances, medical rescuers must also be fully prepared for various situations at the scene, such as deformed remains, mangled extremities, massive bleeding, and severely damaged wounded, etc.
2. **Casualty assessment at the detonation site**. During the on-site rescue, medical personnel can evaluate the intensity of the explosion and the overall casualties based on some evidence at the scene in order to guide the follow-up preparation of related supplies, rescue teams, and in-hospital medical management. Explosive craters, damage to nearby personnel, and collapsed buildings are important evidence of blast wave intensity. Explosive craters could occur with the explosive overpressure exceeding 300 psi (2 MPa), which could cause lethal tearing of the

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human body. Some buildings may collapse when the external overpressure reaches 10 psi (68 kPa). The intensity of blast waves that cause tympanic membrane rupture is about the same as that shattering the windshield of a car, shaking a telephone pole, or shattering a brick wall. First-aid personnel can estimate the general situation of the incident through the car collision and the object damages after the explosion, as well as the characteristics and the total number of casualties when combined with the location of the detonation, the range of the affected area, and the time of detonation.

Unlike general emergencies, most of the explosions caused injuries to a large number of casualties. The management of a huge number of the wounded often exceeds the rescue capacity of a hospital or a region. Fixed rules exist in batches of the wounded after the explosion, that the closer to the explosion, the higher the mortality rate, and vice versa, the further from the detonation center, the weaker the impact. If the explosion occurs in a relatively closed space (such as vehicles, mines, buildings, subway stations, etc.), the casualties will be more serious; if a building collapses, the mortality rate will increase significantly. Analysis of a number of explosions shows that the total mortality rate at the scene was 25%, most of which occurred at the time of the explosion or within a short period after the explosion, where most of the survivors required medical intervention, 30% required hospitalization, and many without any physical injury suffered from severe mental disorders and disorientation. The overall assessment of the wounded includes looking for wounds or burns caused by debris and shrapnel. Explosives may produce high-humidity air currents that can cause severe burns when in contact with the wounded, resulting in a large number of burn patients. Severe burns have become the focus of attention of clinicians. Although burns may be fatal, deaths caused by potential trauma cannot be ignored.

1.2 Emergency Management at the Detonation Site

1. **Injury assessment**. Explosion injuries are divided into four types. The primary blast injury is the direct effect of the blast wave passing through the body. Due to the violent vibrations at the air–liquid interface, the air-filled organs of the human body are particularly vulnerable to damage. When the explosion occurs in the air, the lungs are easily damaged; when it occurs in the water, the risk of gastrointestinal injury is high. The secondary blast injury is caused by fragments from the explosion hitting the human body. When casualties are lifted or thrown by the explosion blast waves against relatively stationary objects, it could lead to the tertiary blast injury. Other indirect effects of explosions are categorized into the quaternary blast injury, including inhalation of harmful substances, burns, and crush injuries, etc. Rescuers may face multiple traumas after the explosion, where the most common are penetrating injury, blunt injury, thermal injury, and blast injury. Blast injury is mostly manifested as multiple injuries and combined injury, which is complicated with damages to both internal and external organs, but mild external wounds and severe internal injuries, which are easy to miss the diagnosis. Meanwhile, negative mentality, such as panic, anxiety, irritability, is common. The severity of the injury is affected by the strength of the explosion, the surrounding environment, and the distance between the injured and the detonation center. The severity of the survivor's injury is inversely proportional to his/her distance from the detonation center. However, debris or other objects can cause fatal secondary wounds.
2. **Triage**. In disaster rescue, triage of the injured is a key factor for successful on-site treatment in order to provide the greatest assistance to the most injured when resources are limited. Although there are a variety of methods for triage, there is no uniform standard for the classification of injuries for pre-hospital treatment of batches of wounded patients. After understanding the general situation of the detonation site, caretakers should classify the injured according to the priority order of treatment. Triage sieve can be used first to quickly identify the people most in need of medical treatment, while triage sort needs more detailed examinations, but generally only with sufficient medical resources and anatomical and physiological parameters. During the triage sort, over-prioritizing usually exists, which disperses the limited medical resources and increases the mortality of the injured who need the treatment most, although it can enable the injured to receive more treatment at once. Due to the limited ability of each medical institution to meet the needs of the injured, the negative impact of over-prioritizing intensifies with the increasing total number of the injured.

   Among the triage strategies, START (simple triage and rapid treatment) has been widely used which was first adopted as a triage method in medical rescue in the USA, with a purpose of simple triage and rapid treatment, mainly for the triage of mass casualty incidents with insufficient medical resources. Through STAT, rescuers should quickly judge the severity of the injury by assessing mobility, breathing, circulation, and consciousness and then make decisions about the treatment priority of the injured. In this system, the injured are quickly divided into four categories through a simple clinical assessment, which are green (mildly injured/walking wounded), yellow (moderately injured/delayed treatment), red (severely

injured, immediate treatment), and black (expectant treatment). Its application in the triage of blast injury is given in Table 1. What's simpler is to divide the injured into emergency and non-emergency treatment. Immediate treatment is required for those in emergency treatment with single or multiple site injury, limited to simple management, such as opening airways, controlling bleeding by compression, etc. For those in need of delayed treatment with stable hemodynamics, their survival will not be affected if they are not treated or simply treated for a certain period of time. Expectant treatment is only be used for mass casualty incidents. The probability of survival and the available resources are the foundation to judge whether the injured should receive expectant treatment. The injured who are sorted as expectant treatment are injured seriously with a survival rate, so that rescue and treatment will consume a lot of time and resources, which will reduce the chances of survival of those with a high probability of survival, such as those with systemic smashed wound, and traumatic limb dismemberment. However, the former are not left untreated but given comfort and analgesic treatment. When signs of improvement occur, they should be actively treated. In the management of batch wounded, CPR is not recommended due to limited on-site resources.

Table 1 Triage strategy for explosion blast injuries

Type (by color)	Requirements	Examples
Minor injuries (green)	Move quickly from the triage area to other staff	Psychological trauma, simple auricular injury (no lung injury), small area injury
Delayed (yellow)	Simple management is needed within hours	Burns to the epidermis or part of dermis. Extremity injury without large blood vessel injury combined. Stable condition after chest drainage
Immediate (red)	For those with severe trauma but a high probability of survival, immediate treatment, and rapid intervention are needed in a short period of time to relieve respiratory and circulatory dysfunction caused by airway obstruction and tension pneumothorax	Airway obstruction, hypotension, active extremity bleeding, penetrating trunk trauma, vascular trauma, extensive damage to the limbs, deep or full-layer skin burns
Expectant (black)	Treatment may waste limited resources where the probability of survival is low even with sufficient resources For complicated and time-consuming cases, proper measures should be taken to make the injured feel comfortable	Limb dismemberment (damaged by blast waves instead of fragments); open skull fractures with spillage of brain contents; dilated pupils with no vital signs (CPR is not recommended at the rescue site)

As a dynamic process, triage needs to be repeated throughout the entire treatment and further transportation. When the condition of the injured deteriorates or improves, another evaluation is needed to ensure that all the injured are treated correctly. For the injured exposed to chemical, biological, or radioactive materials, the triage sort is based on the medical or surgical treatment they need, not on whether they need decontamination. After the explosion, many walking wounded or uninjured people tend to go to nearby medical institutions for treatment by themselves, while the severely injured usually stay in place for examination and triage. Current studies suggest that more accurate evidence for predicting severe internal blast injuries includes the following: four or more body surface injuries, burns over 10% of body surface area, cranial or facial fractures, and penetrating trauma of brain or trunk. In the suicide bombing in Istanbul, Turkey, 52% of the 184 wounded who arrived at the trauma center within 1 h were not medically transferred but went by themselves. In many cases, walkable wounded walked to medical institutions on their own, causing a lot of congestion, thus affecting the management of really serious wounded.

3. **Management strategy**. In the process of blast injury treatment, it is very important to clarify the specificity of blast injury treatment and confirm the specific problems related to the explosion. Emergency treatment includes resuscitation, stabilization of the severely wounded, identification, and prevention of blast injury complications. In the early management of blast injury, from group triage to individual treatment, the initial assessment and treatment are the same as trauma, following the principles of ABCDE, that is, A (airway), stabilizing the cervical spine, and opening the airway, B (breathing) maintaining effective ventilation and breathing, C (circulation) controlling bleeding and stabilizing circulation, D (disability), assessing neurological function, E (exposure/environment), exposing and keeping warm. ABC should be first focused on. Although ABC is commonly used for advanced life support for traumas, previous experience and evidence of battlefield rescue show that 10% of deaths on the battlefield are caused by extremity bleeding. According to data analysis of the Vietnam War, among the preventable deaths on the battlefield, greater than 50% was caused by extremity bleeding, while limb tourniquets can prevent 7% of battlefield deaths. Therefore, ABC was corrected to <C>ABC, where <C> means catastrophic or fatal bleeding. Lives can be saved by quickly identifying fatal external bleeding, controlling the bleeding, and applying tourniquets early, especially

for those with severe multiple injuries. For high-energy trauma, there are six potentially fatal situations be clarified in the initial assessment, namely airway obstruction, pressure pneumothorax, open pneumothorax, massive bleeding, floating chest (flail chest), and cardiac tamponade. During the reassessment, rescuers should focus on the head, chest, abdomen, and extremities damaged by blast waves, about whether there are thermal burns, contusions, or penetrating fragments, or shrapnel injuries. Through the assessment, medical staff should discover and deal with the injury that endangers the injured person's life in time, understand his/her problem, how to be treated at present, the focus of further treatment, and the hospital most suitable to accept him/her.

Those with blast injury may suffer from inhalation burns, which will cause pharyngeal edema within a few minutes, so tracheal intubation should be used as soon as possible to open the airway; and oxygen should be given, whenever possible. If the injured suffer from breathing effort, abnormal auscultation, and definite evidence of chest trauma, high-flow oxygen should be given, and the corresponding injury should be assessed and treated immediately. During chest assessment, the focus should be laid on pneumothorax, hemothorax, or pressure pneumothorax (caused by rapid changes in air pressure of blast waves). For those with chest trauma suffering from respiratory distress, which is suspected of tension pneumothorax, thoracic puncture should be given for decompression; and if symptoms do not improve, closed thoracic drainage should be given instead. As for the abdomen, it is important to note that hollow organs (stomach, spleen) may be damaged by rapidly changing air pressure. For spleen rupture, tenderness in the left abdomen and other typical signs of bleeding can be found. If an injury in solid organs is suspected, rescuers should also be alert for hollow organ damage.

The tympanic membrane is very sensitive to pressure. Those severely affected by blast waves generally have suffered from tympanic membrane injury or rupture, which can be diagnosed by bleeding in the external auditory canal or hearing loss. If the injured has bleeding in one or two auditory canals or sudden hearing loss, he/she may have been near the detonation center and should be considered as severely injured (yellow tag) until the next deep evaluation. When the injured has bleeding in the external auditory canal or bloody foamy secretions in the mouth and nose, or he/she is in shock without obvious trauma noted, or he/she suffered from dyspnea, irritability, hemoptysis, chest pain, or abdominal pain, rescuers should contact the hospital and transport the injured as soon as possible. Blast lung injury is the most common fatal injury for early survivors. Medical treatment outside the hospital can follow the following simple principles. (1) Early treatment is the same as a conventional trauma treatment. (2) Quick transportation can improve the survival. (3) Follow the principles of disaster management, namely no treatment during the triage. (4) Because of the number and the survival rate of the injured, on-site resuscitation should be avoided as little as possible. For those with abdominal blast injury combined with hemorrhage, aggressive resuscitation is needed, and low-pressure resuscitation is feasible (to keep systolic pressure 80–90 mmHg) in order to avoid excessive resuscitation, which may aggravate lung damage. If continuous intracranial hemorrhage occurs, the massive intravenous infusion should be avoided, while if signs and symptoms of hypovolemia appear, such as deterioration of consciousness, an appropriate fluid supplement should be given. A tourniquet or similar is used to bandage a bleeding limb, and for those with unstable hemodynamic parameters without external bleeding, the pelvis should be wrapped and fixed. In the beginning, attention should be paid to reducing heat loss and preventing hypothermia. As for screening radioactive contamination, if radioactive materials are detected, decontamination equipment is needed, and the hospital that received the injured should be notified.

It is not most suitable to assess or treat trauma before arriving at the hospital, and the injured should be safely transferred to an ambulance as soon as possible. No matter at the rescue scene or during the rapid transportation in the ambulance, the principle of "no further harm" should be observed, that is the absence of "faults of inaction" and "faults of acting." For example, the airway should be open before transporting the injured to ensure that the airway of the injured is unobstructed, the circulation should be stable, and the fracture should be fixed. Intravenous infusion is a routine process in the hospital, but not as a routine requirement before arriving at the hospital because this will prolong the transportation time, and intravenous channels should be established in the ambulance as needed. For those who need fluid resuscitation for a good prognosis, a large venous channel should be established, and low-pressure resuscitation is required. Faults of inaction refer to unnecessary venous passage established before the hospital, unnecessary secondary physical examinations, unnecessary diagnostic tests performed before the hospital, and some measures that are not important to survival but delay the rescue of the critically injured, which will aggravate the injury.

2 In-Hospital Management and Care for Common Blast Injury

Terrorist attacks have increased in modern society, and accidents have occurred from time to time. Blast injuries that were previously only seen in wars can now be seen at ordinary times. Pre-hospital rescuers and in-hospital medical staff should be familiar with relevant knowledge, signs and

symptoms, diagnosis, and treatment of blast injury, which will help the triage and treatment of the blast injured. General treatment is according to the standard procedure of trauma. After the injured is stabilized, corresponding organs should be carefully evaluated, focusing on the fatal injuries of the chest and abdomen. Among survivors, penetrating and blunt wounds of the body surface are the most common. The mortality rate is high in blast lung injury and abdominal blast injury, where among early survivors, blast lung injury is the most common fatal injury.

2.1 Key Points of In-Hospital Emergency Management

2.1.1 Management Plan

1. **Preparation of emergency medicines, equipment, and personnel**. Prepare materials, equipment, medicines, and manpower in a foreseeable manner. According to the needs of treatment, the Care staff prepares corresponding equipment and items according to the key points of emergency treatment to ensure that they are kept in good condition and ready for use.
   (a) **Respiration**. Prepare tracheotomy, tracheal intubation, closed chest drainage, oxygen inhalation device, simple respirator, ventilator, etc.;
   (b) **Circulation**. Hemostatic materials, medicines, and equipment, simple fixing devices, infusion devices, blood products, etc.;
   (c) **Body temperature and pain**. Insulation and rewarming items and equipment, painkillers, etc.;
   (d) **Manpower**. Initiate the emergency rescue manpower contingency plan, recall the rest of personnel, mobilize the emergency and critical care reserve personnel of the hospital, organize teams, and allocate the work.
2. **Initiation of the emergency treatment plan**. If a batch of wounded is accepted, the emergency treatment plan for the batch of wounded should be activated immediately. Form teams with the predetermined system and personnel to make sure each member carries out the tasks assigned in advance simultaneously and orderly so as to provide fast and effective treatment. It is very important for team members to clarify the tasks of themselves and others. Each person's specific tasks can be displayed by post boxes, reminder notes, etc., to avoid interference from other tasks and confusion of responsibilities. Shunt patients in the hospital, adjust the treatment site and set up various functional areas, such as emergency command, personnel reception, press release, decontamination, triage, and graded treatment areas.

   Before the injured arrive, all members of the rescue team must be in place and wear protective gloves, plastic aprons, goggles, lead suits, etc. If the injured are contaminated by radioactive materials, medical staff should take standard protective measures and wear personal protective equipment, including long white coats, surgical masks, waterproof shoe covers, eye masks, and double-layer gloves. Severely injured patients should be actively treated before they are formally removed from the contamination. Rescuers should ensure a smooth flow of the wounded, contact the first-aid personnel in the hospital to understand the condition, type, and quantity of the injured. The injured transferred out of the emergency room should be treated as far as possible to meet the needs of emergency rescue in priority. Divide the site to treat the wounded of different severity, and each area should be equipped with correspondingly competent medical staff. Slightly injured patients should be discharged as soon as possible after simple treatment to avoid occupying the hospital's medical resources. The severely injured who need emergency treatment should be transferred out of the emergency room after emergency treatment to the ICU, an operating room, or a specialized ward for further management. For the injured who need emergency surgery, a green channel should be opened, and the nurse should prepare relevant documents, coordinate relevant personnel, and send them to the operating room. The injured who are severely injured but not fatal should be treated aggressively and, at the same time, be watched closely in order to adjust the treatment step at the proper time.

2.1.2 Emergency Management Strategy

1. **Principles of early management**. Follow the hospital and local disaster emergency plans. The severity may be reversed, where the severely injured may arrive at the hospital later than the slightly injured. Estimate the total number of the first batch of wounded roughly as twice the number of the wounded arriving in the first hour. If buildings collapse, the injury will be more severe, and the injured will arrive later. In batch wounded treatment, the general principle is that the wounded should receive the "minimum acceptable treatment," that is, relatively brief damage control treatment and short-term stable injury treatment, rather than a few hours of definitive treatment. "One-way treatment principle" should be followed, that the injured should be transferred from the emergency room to the operating room, ICU and then discharged, not returning to the emergency room halfway.
2. **Injury assessment and management**. Because of the complicated mechanism of the blast injury, re-evaluation in the emergency room is particularly important, focusing on ABC, which is opening the airway while fixing the cervical spine, maintaining ventilation, controlling bleeding, and stabilizing circulation. Treat life-threatening injuries urgently. Severely injured patients with

unstable hemodynamics should receive concentrated red blood cells, frozen plasma (1:1), and platelets; if possible, fresh whole blood should be given as soon as possible. For the injured with severe trauma, cryoprecipitate and recombinant factor VIIa can be used. If the injured suffers from a traumatic brain injury, it is essential to prevent hypoxia and hypotension. Because lung contusion may progress within a few hours, close observation and repeated radiographs are required, as well as definitive airway establishment and respiratory support. If abdominal pain persists with vomiting, the injured should be sent to the emergency room for observation. Common treatment operations include chest drainage, fracture fixation, gastrointestinal decompression, bladder decompression, wound coverage, application of broad-spectrum antibiotics, injection of tetanus antitoxin, and pain relief. Routine radiographic examinations, MRI, CT, angiography, laboratory examinations, radiological diagnosis, etc., are not recommended because they will interfere with the shunt of the injured. For the injured with traumatic brain injury, if the GCS is low or worsening, CT should be performed to rule out the large-scale injury and decide whether or not to take a surgical intervention. For the injured around the detonation center, FAST is recommended, especially for those with signs of primary blast injury, where FAST can be used to determine whether there is abdominal effusion and important abdominal injury.

2.1.3 Routine Care Measures

1. Assess the condition of the injured, open the airway, keep the airway unobstructed, assist the physician in performing tracheal intubation and tracheotomy when necessary, and routinely give oxygen inhalation.
2. Immediately establish dual venous channels to expand blood volume to prevent the development and deterioration of shock. Peripheral veins of the upper limbs are recommended first. And large blood vessels and large indwelling needles (#14 or #16) should be selected. Generally, for the fluid therapy, isotonic saline or balance solution should be given first, followed by concentrated red blood cells or whole blood, and then crystallized solution, albumin or plasma if needed. For the injured with uncontrolled bleeding, restrictive fluid resuscitation is advocated. In other words, the blood pressure is controlled below the normal level, but the tissue perfusion can be satisfied, and fluid supplementation can be strengthened after the bleeding is controlled.
3. Indwell catheter. Urine volume is a sensitive indicator of the blood volume state and the renal perfusion of the injured. A urinary catheter should be indwelled as soon as possible when conditions permit. When a urethral injury is suspected, it is contraindicated to insert the catheter through the urethra, where an emergency bladder fistula is recommended.
4. Closely observe the changes in the vital signs of the injured and report and treat any abnormalities immediately.
5. Preoperative preparation. Blood samples should be taken for the corresponding examination of the injured who need surgical treatment, and the skin preparation of the operation area should be performed.
6. Safe transfer. Before transfer, the condition of the injured should be fully assessed to make sure the vital signs are stable. Before transfer, caretakers should communicate with relevant departments and bring necessary first aid supplies and equipment.

2.2 Care of Common Blast Injuries

The interface between gas and tissue is most susceptible to direct blast injuries. Gas-rich organs, such as the lungs, gastrointestinal tract, and auditory system, are the most vulnerable. When the overpressure exceeds 35 kPa, the auditory system will be damaged. When the pressure is 75–100 kPa, lung and gastrointestinal tracts are more likely damaged. Other systems that can be damaged by overpressure include the central nervous system, musculoskeletal system, and, relatively rarely, visual and cardiovascular systems. The main work of caretakers is to evaluate and observe the condition of the injured, understand the treatment principles of blast injuries in each system, prepare for and assist in treatment in advance, actively prevent various complications, and provide care, help, encouragement, and humanistic care to the injured.

2.2.1 Care of Blast Lung Injury

1. **Injury assessment**. Except for the auditory organs, the lungs are most susceptible to blast injury, which is caused by the blast waves affecting structures such as the chest cavity and airways. Primary blast lung injury occurred in 47% of the deaths from explosions; 44% of hospitalized injured patients and 71% of hospitalized severely injured patients suffered lung injuries. The incidence of lung injury could increase by three times under ultra-high pressure or a rapidly increasing pressure (such as an explosion in a closed space). It was previously believed that patients with tympanic membrane perforation should be hospitalized for observation because it was believed that blast lung injury might occur 24–48 h after injury. However, it is now believed that manifestations of blast lung injury do not appear after a period of time, but all appear significantly shortly after the explosion; most of the acute lung injuries that occur 48 h after the explosion are related to Systemic Inflammatory Response Syndrome

or sepsis, rather than blast lung injury. Common blast lung injuries include lung contusion, pneumothorax, pneumomediastinum, interstitial or subcutaneous emphysema. Apnea, bradycardia, and hypotension are the typical clinical trial of lung impact injury. Patients with the following symptoms should be suspected of blast lung injury, that experienced dyspnea, cyanosis, cough, hemoptysis, chest pain, etc., after the explosion. Generally, an explosion in a confined space could cause bilateral lung injury, while in an open space, the lung near the explosion is damaged more severely. It is recommended that all personnel who have experienced an explosion undergo a chest radiograph, where blast lung injury can be confirmed when the butterfly sign is noted.

2. **Care strategy**. Blast lung injury ranging from scattered ecchymosis in the lungs to obvious active bleeding usually manifests as hypovolemic shock, respiratory distress, air embolism, etc., with a mortality rate of 11%. The surviving wounded must be diagnosed immediately and resuscitated quickly. If the injured suffers from unstable conditions or requires emergency tracheal intubation immediately, positive pressure ventilation can be used to correct respiratory distress and improve hypoxia, but it can also cause air pressure injury or arterial air embolism. For those with severe blast lung injury, it is necessary to increase the positive end-expiratory pressure (PEEP) on the basis of positive pressure ventilation, but a high PEEP can aggravate lung parenchymal damage, causing pneumothorax and other complications. Therefore, for blast lung injury, it is necessary to adopt the lung-protective strategy to reduce peak airway pressure as much as possible during mechanical ventilation. If sufficient oxygenation of the injured cannot be maintained by conventional mechanical ventilation, advanced respiratory support techniques are required, such as different types of pressure-controlled ventilation to overcome hypoxia without significantly increasing PEEP. The prone position helps to improve oxygenation, but it is difficult to implement in an emergency. It is now generally believed that bilateral chest drainage is not recommended in the absence of pneumothorax, while for those suspected of blast lung injury who need general anesthesia or air transport, it is suggested to undergo preventive chest drainage.

2.2.2 Care of Gastrointestinal Blast Injury

1. **Injury assessment**. The incidence of gastrointestinal impact injury is lower than that of the tympanic membrane or lung blast injury, and the incidence rate among survivors is 0.3–0.6%. Similar to other blast injuries, gastrointestinal injury is more likely to occur in a confined space and more serious underwater because blast waves are more likely to spread in water. Because of the interaction of the blast waves with the gas–liquid interface of the intestine, intestinal contusion, rupture, and perforation will appear. Shear forces at the junction between the free part and the fixed point of the intestine, such as the liver and splenic flexure of the intestine, can cause intestinal volvulus. If the moving debris penetrates the abdomen, fatal abdominal bleeding may occur. Abdominal blast injury should be considered if people who experienced the explosion suffered the following symptoms, including abdominal pain, diarrhea, nausea, vomiting, hematemesis, bloody stool, the disappearance of bowel sounds, passive position, rebound tenderness, tenesmus, testicular pain, unexplained hypovolemia, or other signs of acute abdomen. However, in many cases, the clinical signs of abdominal blast injury are not obvious before it progresses to acute abdomen and sepsis.
2. **Care strategy**. The emergency treatment of gastrointestinal blast injury is similar to that of common abdominal traumas. First, the wounded should be resuscitated with an advanced trauma life support plan and assessed whether surgical intervention is needed. If there is a major hemorrhage in the abdominal cavity, it must be confirmed and treated immediately, and usually, a laparotomy is required. Intestinal contusion, which may be secondary to intestinal perforation, requires active management. Studies have shown that many secondary intestinal perforations occurred 3–5 days after injury and occasionally after 2 weeks; if small intestinal contusion smaller than 15 mm and colon contusion smaller than 20 mm are found during laparotomy can be treated with traditional methods. Esophageal perforation may also occur, often manifesting as chest pain, dyspnea, and subcutaneous emphysema, which can be diagnosed by esophageal X-rays. The most common treatment is one-stage repair, which, however, in many cases, it is not needed. Patients with abdominal injury should fast before diagnosis. Those with paralytic intestinal obstruction should undergo gastrointestinal decompression before an effective bowel movement is restored to reduce the risk of delayed bowel perforation and vomiting and to reduce the oppression on the diaphragm, which is conducive to lung ventilation. Patients with a non-perforated abdominal injury should be observed for another 1 week (at least) after symptoms are relieved by conservative treatment to determine whether there are signs of delayed perforation.

2.2.3 Care of Tympanic Membrane Blast Injury

1. **Injury assessment**. The hearing apparatus is so fragile that the incidence of auricular blast injury is high. Life-threatening injuries must be treated first during the rescue, instead of nonfatal hearing damage, which is often overlooked. After the life-threatening injury has been managed, the hearing damage should be assessed. Signs

of ear damage could appear at the initial evaluation, often including hearing loss, tinnitus, earache, dizziness, bleeding through the external auditory canal, tympanic membrane rupture, and otorrhea. Basic hearing tests and otoscopy should be routinely performed. The most common type of middle ear injury is tympanic membrane perforation. Hand-held otoscope examination, which is simple and easy to perform, can be used to observe the injury of the external auditory canal and tympanic membrane. Factors that affect tympanic membrane damage include blast wave pressure, the position of the head and ears relative to the detonation center during the explosion, whether there is earwax, whether the injured has worn protective equipment, ear infection history, past illness history, and injury history, etc. For children whose tympanic membrane owns better compliance, the probability of tympanic membrane perforation of children is lower than that of adults at the same distance from the detonation center. In addition, the cerumen in the external auditory canal can protect the tympanic membrane like earplugs.

2. **Care strategy**. Patients with tympanic membrane perforation are mainly treated with conservative therapy, disinfection and rinse, and removal of a foreign object to prevent further damage. If the tympanic membrane is invisible due to earwax or blood clots, ask an otolaryngologist to carefully suck and clean the perforation. Keep the ears clean and dry when no professional is present. Non-ototoxic antibiotic drops should be used for tympanic membrane perforation and ear canal tears, which can help flush and clean ear canal debris. Generally, quinolone pharmaceutical preparations such as ciprofloxacin and ofloxacin should be used instead of ototoxic local ear drops. If the tympanic membrane ruptures more than 1/3, surgical repair is recommended. Irregular perforation combined with everted tympanic membrane wings, recombination repair, can promote healing. The prognosis is good for most patients with tympanic membrane perforation, which can heal without treatment, but 30% of the injured will suffer from permanent hearing loss. Tympanic membrane perforation increases the incidence of cholesteatoma, especially for large perforation, which has no tendency to heal itself, so that follow-up screening is required. The management of outer ear injury is the same as other soft tissue injuries, that is, removal of foreign bodies, flushing and cleaning wounds, drainage of ear hematomas, and soft tissue repair for broken auricle and exposed ear cartilage. Due to tinnitus, hearing loss, temporary or permanent deafness, and other reasons, medical staff should pay attention to communication skills and methods when communicating with the injured and use writing boards, hearing aids, and other auxiliary appliances when necessary.
3. **Screen primary blast injury**. Those with tympanic membrane perforation should be highly suspected of primary blast injury to the lungs and abdomen, which are generally delayed. The tympanic membrane perforation was previously believed as a clear sign of an explosion, while other blast injuries were common but not easy to identify. Therefore, the empirical approach is to closely observe the blast injured patients with tympanic membrane perforation overnight to make sure whether there is delayed dyspnea caused by occult lung injury. Although its necessity is yet to be proven, this principle is followed in many practices. In 2009, Harrison et al. conducted a landmark study. Of the 167 U.S. blast wounded in Iraqi field hospitals, 16% suffered from tympanic membrane perforation, and 7% suffered from blast injuries such as pneumothorax, pneumomediastinum, lung contusion, nasal sinus injury, or intestinal perforation, however, only half of whom had tympanic membrane perforation at the same time. This result was repeatedly confirmed by other studies, indicating that tympanic membrane perforation is just an insensitive sign of blast injury. Therefore, it is now recommended that if there is simple tympanic membrane perforation without any evidence of other trauma, the injured should be closely observed for 6–8 h, including blood oxygen saturation monitoring and chest X-ray examinations. The injured without symptoms can be discharged after preventive measures for lung and abdomen injuries. Supportive treatment is needed if there are positive findings in radiological examinations or clinical symptoms. Primary blast injury can be excluded if the injured has no damaged tympanic membrane without respiratory and abdominal symptoms and complaints.

2.2.4 Care of Other Blast Injuries

1. **Blast-induced traumatic brain injury**. Blast-induced traumatic brain injury is more common than previously thought. Through a retrospective cohort study in 2011, Dougherty et al. found that 37% of the 2254 U.S. bombing casualties in Iraq had varying degrees of nerve damage. It is also reported that among the 3000 casualties caused by the recent terrorist bombing, brain injury is the main cause of early and late death. Blast-induced traumatic brain injury varies from mild to severe. The main symptoms include headache, tinnitus, noise intolerance, degenerative or anterograde amnesia, and post-traumatic stress disorder (PTSD), which were previously known as “bomb shock,” “bomb concussion,” and “combat fatigue”, etc., with clinical manifestations ranging from mild dysfunction to complete loss of response, but normal GCS scores for most of the injured. Care staff should closely monitor the brain signs and intracranial pressure of the injured, properly manage temperature, and limit fluid

infusion, which can reduce intracranial hypertension and maintain cerebral oxygenation.

2. **Cardiac blast injury**. Cardiovascular injury often occurs in a small part of the injured close to the detonation center. Those injured may fall into severe shock even in the absence of bleeding or other common causes of hypotension, which does not respond to resuscitation. Shock is considered to be a direct effect of shock waves, leading to decreased cardiac index and bleeding, systemic vasoconstriction, and tachycardia without compensation. In addition, the bleeding caused by the explosion can also cause hypotension in the injured with cardiovascular injury. Air embolism is more common in patients with cardiovascular injury, manifested as stroke, myocardial infarction, acute abdomen, blindness, deafness, spinal cord injury, and claudication. The greatest risk of air embolism occurs within 24 h after the blast injury and increases during positive pressure ventilation. Therefore, the peak airway pressure should be decreased to reduce the risk of embolism for the injured who requires positive pressure ventilation. If air embolism is suspected, empirical treatment, mainly supportive treatment, should be initiated. Nursing staff can place the injured lying on the left with feet higher than the head to limit the gas to the apex of the left ventricle to prevent subsequent air embolism. Caretakers can place the injured lying on the left with feet higher than the head to limit the gas to the apex of the left ventricle to prevent subsequent air embolism. For the injured with air embolism, their oxygenation generally reaches the lowest point within the first 24 h, so that they need to inhale 100% oxygen. Hyperbaric oxygen therapy is useful in some cases. Interpleural syndrome, another rare cardiovascular complication, is characterized by a sharp drop in blood pressure during positive pressure ventilation, due to limited cardiac function caused by cardiac tamponade induced by mediastinal edema or hematoma, where thoracotomy is recommended.
3. **Musculoskeletal blast injury**. Musculoskeletal blast injury is very common in blast injuries. Secondary injuries are more common than primary ones. Above 80% of the operations of the survivors were related to the musculoskeletal system. Great attention should be paid to crush injuries during the rescue of the blast injured patients because, with non-timely treatment, it could develop into rhabdomyolysis, acute renal failure, acidosis, and metabolic disorders, and even death. Rhabdomyolysis may also occur without obvious crush injury, such as when the injured has been forced to stay in a small enclosed space for a long time after a building collapses. Treatment includes active hydration, urine alkalization, mannitol for diuresis, and hemodialysis when renal failure appears. Among the blast injured patients, any limbs dismemberment is a sign of multi-system injuries. Traumatic limb dismemberment and avulsion injuries occur in 1–3% of the blast wounded, which have a poor prognosis, especially those with the proximal dissection of the wrist and ankle joints, because serious internal organ injury may be complicated. Management of skeletal injury caused by explosions includes X-ray to assess fractures and foreign bodies, injection of tetanus antitoxin, and application of broad-spectrum antibiotics if the fracture is open. Many fracture injuries require early fixation, and the gap syndrome should be considered during external fixation of extremity injury. The treatment of wounds caused by small residual shrapnel has been controversial. Some studies have pointed out that such wounds should be treated conservatively in the following cases, that only involve soft tissues, but not the peritoneum, pleura, or major blood vessels, less than 2 cm in diameter, without significant infection, and not caused by a coal mine explosion.
4. **Ocular blast injury**. Ocular blast injuries are usually divided into two categories. One is caused by shock wave shear force, which is manifested as hemorrhage, retinal detachment, or eyeball rupture, and the second is more common to be caused by explosive projectiles. The incidence of ocular injury after the explosion is very high. Although the injury is less than 0.1% of the body surface area, 10% of the survivors suffered from significant eye injuries, mainly caused by projectiles, commonly manifested as intraocular foreign body, corneal abrasions, lacerations around the eyelids or orbits, retinal detachment, orbital bone fractures, and eyeball ruptures. Treatment principles: Routine eye examinations are necessary, and further in-depth examinations are recommended for vision loss. Protect the exposed eyeballs to prevent the eyeballs and wounds from drying out. Bilateral eye bandaging is needed for all eyeball perforation and rupture. Wear metal eye masks to prevent accidental injury. Mannitol can be given intravenously to reduce high intraocular pressure, and debridement and suture or eyeball removal should be performed if necessary.

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