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Pulmonary Effects Of Combined Blast Injury And Radiation Poisoning

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Introduction

Pulmonary contusion from blunt trauma has been recognised as a clinical entity since the 18th century. It is typically caused by military or terrorist explosions or in industrial explosive accidents. The characteristic pulmonary haemorrhages caused by blast injury were described in the First World War and Spanish Civil War. However, it was not until the Second World War that the pathophysiology of pulmonary blast injury was elucidated in animal models. There are relatively few publications specifically on pulmonary blast injury and some fail to discriminate clearly between pulmonary blast injury and other pathologies such as fat embolism and non-cardiogenic pulmonary oedema from head trauma (2).

Pathophysiology Blast injury causes compression of the thoracic cage, with pulmonary contusions, similar to those seen after blunt trauma, but often without associated chest wall or rib injuries. The pathological hallmark is pulmonary haemorrhage, thought to be due to transmission of force through tissues with different densities; tearing of less dense alveoli away from the bronchovascular bundle; and compression then rebound of intra-alveolar gas (3). The severity of pulmonary blast injury is related to the duration and intensity of the blast wave. Injury is typically more severe if the patient is in an enclosed space such as a bus, or if the explosion occurs underwater (4). The phase of respiration (i.e. whether the patient's lung volume is near its maximum at end inspiration or its minimum at end expiration) does not appear to significantly influence the severity of injury (5). Although it was thought that pulmonary blast injury would evolve over several hours or days recent experience suggests it may be evident almost immediately (1).

The blast wave formed by detonation of conventional explosives takes a few milliseconds to pass the patient, but the blast wave from a nuclear detonation takes hundreds of milliseconds to seconds to pass (4), with a consequent increase in the potential for injury to the lung and other organs.

In addition to the direct effects of the blast wave on the lung, there is an increased likelihood of penetrating injury from missile fragments and blunt trauma from the patient being thrown against other structures. These are potentially greater with nuclear explosions due to the magnitude of the explosion.

The NATO medical handbook on the Medical Aspects of NBC Defence (6) gives predictions of the lethality of various amplitudes of blast wave and also points out the predicted probabilities of injury from missiles formed by the action of a nuclear detonation in relation to weapon yield and distance from ground zero. In addition it gives similar predictions of the risk of the patient being thrown with sufficient force to cause injury.

Combined Blast and Radiation Injury

Following the detonation of the 13 kiloton (kt) Atomic bomb in Hiroshima there were 136,000 casualties, 53% of the population. Of these, 78,000 had blast injuries and 35,000 had radiation injuries, some in combination. Within four months, 64,000 of them died, a third dying on the first day. This excluded military casualties who would have been very numerous. At Nagasaki the figures were not dissimilar although the local geography meant that a smaller proportion of the population were injured or killed. It is difficult to determine what proportion of the population had combined blast and radiation injury, partly because many died from trauma in the first few days, before the radiation syndrome became manifest (7). Specific estimates of the median lethal dose of radiation at Nagasaki did not take account of blast injuries as those in the subpopulation studied who had severe blast injuries also received high doses of radiation and died. However, it is clear that when radiation is combined with other injuries, the threshold dose of radiation causing death diminishes (8).

Predictions from the Cold War based on airburst detonation of one megaton strategic nuclear warheads over Atlanta and Nashville do not give a breakdown of the proportion of the population with combined blast and radiation injuries. However, with a one megaton yield, all people within the area of "prompt" radiation (released during the detonation, as opposed to subsequent fallout) would be killed by thermal radiation or blast. Both predictions suggest 100% mortality within a radius of 2.4km from

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ground zero and near 100% mortality within a radius of 5km. Between 2.4km and 5km the 2% not killed would be critically injured (9,10). In a related paper discussing the health care effects of nuclear detonation, the authors suggest that in the civilian setting it is effectively impossible to train and prepare for the resulting devastation (11). Thus, in scenarios involving strategic nuclear weapons, medical resources would be overwhelmed and medical staff would attempt to treat patients with a reasonably high chance of survival - the more severely injured would be treated palliatively, if at all. It should be remembered that these authors were anticipating a massive attack from the Soviet Union with thousands of warheads targeting the infrastructure of NATO countries. In the current geopolitical climate this seems less likely, and more plausible scenarios include a Radiologic Dispersal Device (RDD) or "dirty bomb"; a smaller number of ballistic nuclear weapons launched by a rogue state; or a sub-10kt Improvised Nuclear Device (IND) detonated at ground level by a terrorist organisation or rogue state.

Radiologic Dispersal Devices

Radiologic sources obtained from industrial or medical settings and dispersed by conventional explosive are termed Radiologic Dispersal Devices (RDD). An RDD may kill a relatively small number of people in the local area by the effect of conventional explosives and contaminate the surrounding area and people close to it with radioactive isotopes. It would generate a great deal of public panic and likely fulfil the terrorists' objectives from this point of view, but is not likely to cause large scale casualties. RDDs have been discussed elsewhere (12,13). The management principles for casualties within the blast radius are as discussed below.

Improvised Nuclear Devices

An Improvised Nuclear Device is the basic nuclear bomb taught in secondary school physics, and has a yield in the 10 kt range, similar to those at Hiroshima or Nagasaki. It is difficult to obtain the fissile material to make one of these devices and technically difficult to ensure it will cause nuclear detonation. An Improvised Nuclear Device may "fizzle" as the conventional explosive part of the bomb detonates, an initial burst of radiation is released as critical mass is achieved, but nuclear detonation per se does not occur for technical reasons. This could have a greater effect than a dirty bomb, with a 50% mortality from the blast wave and thermal radiation within a radius of 60m, and as far as 250m from prompt radiation (13). Dispersal of the radioactive fissile material would occur due to the conventional explosive used.

Tactical Nuclear Weapons

Fifty to one hundred man portable tactical nuclear weapons are said to be missing from the nuclear arsenal of the former USSR (12,14). Detonation of one of these 1kt "suitcase nukes" could cause 50% mortality from blast within a radius up to almost 300m with prompt radiation extending twice as far (13).

Treatment

The immediate treatment of patients with injuries from detonation of a nuclear bomb is guided by the principles of Advanced Trauma Life Support (15) or Battlefield Advanced Trauma Life Support (16), as appropriate. Contamination of the patients skin or clothing does not pose an immediate risk to the patient or those carrying out treatment and, therefore, life saving treatment should take precedence over decontamination, when removal of clothing will get rid of most of the contamination (12,13,17-19). Emergency medical staff should observe universal precautions and wear waterproof aprons, gowns or chemical resistant suits, theatre caps, surgical masks, waterproof shoe covers and double gloves (13,19,20).

A clear airway should be maintained using chin lift or jaw thrust whilst ensuring cervical spine immobilization. High-flow oxygen should be given if available. Oropharyngeal or nasopharyngeal airway insertion may be necessary. Casualties who are not breathing, despite a patent airway, will be managed differently depending on the number of other casualties present. In a mass casualty situation these patients would potentially not be treated further as they have a reduced probability of survival even with aggressive treatment and will divert resources from others more likely to benefit. Tracheal intubation should be considered in patients with a reduced conscious level, severe maxillo-facial injuries, excessive haemoptysis (3) or haemorrhage into the pharynx, or injuries to the neck larynx or trachea that threaten to cause obstruction of the airway. Patients with respiratory failure as manifested by hypo- or hyperventilation, hypoxia or cyanosis should be intubated. Tracheal intubation may be achieved orally, nasally or by placement of a tube at cricothyroidotomy or tracheostomy depending on the injuries involved and experience of the operator (15).

Tension Pneumothorax

Tension pneumothorax is more common after pulmonary blast injury. This should be considered if the patient is rapidly deteriorating with hypoxemia or cardiovascular compromise (21). Needle decompression should be carried out pending intercostal tube (ICT) placement and the decision to do this should be based on clinical signs rather than radiological appearances. Two large bore intravenous cannulae should be in place before insertion of an ICT to allow fluid resuscitation in the case of massive haemothorax.

Pulmonary Haemorrhage

Casualties with significant haemoptysis or haemorrhage from the lung should be nursed with the injured side down to minimise overspill of blood into the less affected lung. Selective lung intubation may be considered to tamponade bleeding. In the hospital setting thoracotomy and lobectomy may be indicated for severe haemorrhage (3).

Patients who are intubated and ventilated are at higher risk of pneumothorax and air embolism (22) and in these patients prophylactic bilateral ICT insertion should be considered (22,23). Ventilation strategies that reduce peak airway pressure should be considered in order to reduce the risk of these complications (21,23).

Air Embolism

Air embolism may present with new neurological or visual symptoms or new chest pain (from coronary air emboli). The emboli may be visible in the retinal arteries. The casualty should be given high flow oxygen to encourage resorption of air bubbles and should be placed in the left lateral decubitus position with the head down. Ideally the injured lung should be dependent. This is thought to minimise the risk of further air emboli entering the systemic circulation. Hyperbaric therapy is thought to be of use in reducing neurologic sequelae. A protocol used for decompression sickness is appropriate (21). In addition, aspirin therapy may be of use as part of the damage from air emboli is believed to be due to endothelial activation on contact with air.

Investigations

All patients with suspected pulmonary blast injury should have a chest radiograph: along with clinical assessment, this will probably allow diagnosis, although thoracic CT is more sensitive. More advanced investigations will depend on the setting and may include rigid or flexible bronchoscopy to look for tracheo-bronchial injury in patients with broncho-pleural fistula. ECG may reveal changes consistent with associated blunt cardiac injury. Transthoracic echocardiography may show regional wall motion abnormalities, valvular dysfunction or pericardial effusion with or without tamponade. Transoesophageal echo should be considered if aortic injury is suspected.

Treatment

It should be noted that in a recent paper from a University Hospital in Israel following a terrorist bus bombing, 11 out of 14 intubated patients with blast lung injury survived (1). Patients were intubated either at the scene or in the emergency department. Those with mild blast lung injury required intubation and ventilation for co-morbid conditions such as head injury - low pressures were used for ventilation with positive end-expiratory pressure (PEEP) less than 5cm H_2O. Those with moderately severe blast lung received volume-controlled ventilation or pressure-controlled inverse ratio ventilation (PCIRV), that is, longer inspiratory phases than expiratory. PEEP in this group ranged from 5-15cm H_2O. Patients with severe blast lung were ventilated with PCIRV and PEEP > 10 cm H_2O. One required independent lung ventilation for massive bronchopleural fistula. The remaining two patients were treated with inhaled nitric oxide then high frequency jet ventilation with positive pressure ventilation for bronchopleural fistula. 5 Extracorporeal membrane oxygenation (ECMO) was attempted in one patient who then died of worsening pulmonary haemorrhage. The survivors had no symptoms of respiratory disease, and had normal radiographs and lung function on reassessment at one year (2).

Some of the strategies used by the authors quoted would only be available in tertiary centres, but they are potentially applicable after a tactical nuclear detonation in a developed country. Evacuation times would influence survival for patients at the more severe end of the spectrum who could not reach tertiary centres within 12-36 hours. Aeromedical evacuation of more than a few ventilated patients may reveal logistic problems (with supply of liquid oxygen, for example) but in itself would not necessarily be a barrier to survival as experience from the bombing of the USS Cole recently showed (25).

Adding in radiation poisoning as a prognostic factor

Those patients with pulmonary blast injury who are exposed to more than 2Gy are likely to be affected by the haemopoietic syndrome which is discussed in detail elsewhere in this issue. They will have a prodromal syndrome of anorexia, nausea and vomiting between 2 hours and 2 days post-exposure. They will then develop bone marrow depression 2-5 weeks later. At this time, survivors will be beginning to recover from the pulmonary injury. They will be at increased risk of infection due to immunosupression and will be at risk from bleeding due to thrombocytopaenia. Patients exposed to 5-12 Gy have a low chance of spontaneous repopulation of the bone marrow from native stem cells. In this sub-population of patients, treatment with Granulocyte-Colony Stimulating Factor (G-CSF) and Granulocyte Macrophage-Colony Stimulating Factor (GM-CSF) should be considered as well as erythropoietin, thrombopoietin or other CSF's (26). Bone marrow transplantation demonstrated lack of efficacy following the Chernobyl accident where only 2 of 13 patients survived following transplant (27). However, it has been suggested that this was due largely to comorbidities (28), so there is potential for benefit in patients recovering from pulmonary blast injury who are no longer intubated and ventilated.

Groups with high mortality

In a setting in which only basic first aid can be provided, the dose of radiation that is thought to be survivable by 50% of the population is between 2.9 and 3.4 Gy. With best possible medical treatment in patients with no other injuries, it is around 10-11 Gy (8,13,19). Patients with serious co-morbidities will not do well. For example, an estimate for patients with burns in Nagasaki puts the lethal radiation dose for 50% of those exposed (LD50) at 2.4 Gy (8). These patients should be considered for palliative treatment. For example patients with blast lung injury who have been exposed to more than 6 Gy will also develop the Gastro-intestinal Syndrome with early nausea, vomiting and diarrhea (19). Mortality from this combination will be very high.

Patients who are exposed to whole body doses of more than 12 Gy will almost certainly die of an untreatable combination of pulmonary fibrosis, gastro-intestinal, and hepato-renal failure after some months even if they survive the Haematopoietic Syndrome (12,13).

Internal Contamination with Radionuclides and Chelation Therapy

Internal contamination with 239-Plutonium as well as other transuranic radionuclides would be expected after detonation of an improvised nuclear device or a nuclear weapon. Patients identified from nose-blow and nasal swab specimens or portable lung monitoring of surrogates such as gamma emissions from 241-Americum (28) as having inhaled large amounts of 239Pu may be treated with the chelating agent Calcium Diethylenetriamine Pentaacetic Acid (DTPA) by nebuliser in an attempt to minimise internal contamination. This would probably only be an issue in an RDD utilising plutonium (unlikely) or an improvised nuclear device that fizzled.

Antimicrobials

In theory, antibiotic prophylaxis will prevent life-threatening infection in the pancytopaenic patient with the Haemopoietic Syndrome (29). However, there is a risk of selecting resistant organisms. Where possible, antibiotic choice should be guided by microbiologic culture results. Where this is not possible, the use of an agent such as levofloxacin should be considered, providing cover against the common pulmonary bacterial infections such as Streptococcus Pneumoniae with a lower risk of resistance than ciprofloxacin. It would also give cover against coliforms and atypical organisms such as Legionella Pneumophila.

In the mid- to longer-term there should be a high index of suspicion for fungal and viral pneumonia. Prophylactic treatment for these organisms would depend on the setting: the ideal course of management is to treat only laboratory-proven infections with appropriate antifungals and antivirals. This would only be feasible in a major hospital with facilities for bronchoscopic bronchoalveolar lavage and a sophisticated microbiology service. It is unlikely that much voriconazole or ganciclovir would be available in the austere environment of the field hospital, and patients with fungal or viral pneumonia would not do well in this setting.

Evacuation

Patients with combined pulmonary blast injury and radiation poisoning sustained overseas should preferably be evacuated to tertiary referral hospitals in the UK or Europe. These should have an Intensive Care Unit with facilities for advanced ventilation strategies such as high frequency jet ventilation and ECMO. There should be input from a respiratory physician specialising in intensive care, and also expert microbiological, and haematological advice. Concurrent injuries such as burns would also demand skilled assessment and care.

Late effects of irradiation and surveillance

Surveillance for late effects of radiation is a complex epidemiological subject, and from the Hiroshima and Nagasaki data the effects are relatively small and may be difficult to tease out of the background pattern of naturally occurring disease. Gross effects of radiation such as pulmonary fibrosis will be seen in only a few survivors who will already be identified during supportive treatment for the Haemopoietic Syndrome.

Summary

In situations with relatively small numbers of patients with pulmonary blast injury aggressive modern intensive care treatment may allow a return to normal function. The additional effects of radiation poisoning are more difficult to factor in, but new treatments such as colony stimulating factors may improve the outlook for a group with moderate to severe radiation exposure who would previously have died of infection or haemorrhage.

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