Review Article

Blast injures to the thorax

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Abstract: One out of 10 of military casualties and 6–9 out of 10 civilian victims of terror incidents suffer pulmonary blast injuries when the attackers use explosives as weapon. No specific therapy exists for the primary, shock-wave injury to the lung. The treatment protocols are based on mechanical ventilation, intensive therapy and supportive care. Secondary and tertiary blast structural injuries to the thorax require damage control surgery, dominated by pleural space management (drainage) and haemorrhage control (thoracotomy if needed). Parenchyma resection of irreversibly destroyed lung is rarely needed, and non-anatomical resections are to be preferred. Delayed chest wall reconstruction follows haemodynamic stabilisation and completion of demarcation process. Blast injury to the chest requires a multidisciplinary approach, where the outcome is strongly influenced by the concomitant injuries.

Keywords: Blast lung injury; thoracic trauma; military medicine

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Introduction

Blast injury to the body sadly elevated into the focus of mass injury treatment protocols of the civilian emergency medical care due to the sharply increasing number of terror attacks (1,2). Recent industrial accidents also contribute to the intensive interest. Improvised roadside devices, born in the asymmetric warfare in the new millennium reshaped military injury profiles, and the previously dominating penetrating trauma lost its pole position. As far as the injury mechanism concerned, there is a certain overlapping between blunt and blast injuries to the torso, however their distinctive discussion is necessary in order to deeper understanding (3). Here we discuss the injuries and optimal treatment of the thorax caused by explosions.

Blast trauma had its anecdotic appearance in belles lettres, well before the medical profession had to face the industrial scale of mayhem in the First World War were treated. An explosion blows up the plot in Shakespeare's contemporary, Ben Jonson's comedy "The Alchemist" (year 1610). Leo Tolstoy makes Prince Andrei Bolkowsky seriously injured in the Battle of Borodino (year 1812) when a grenade blows next to him in the War and Peace (year 1867). Joseph Conrad's hero, Verloc (*The Secret Agent*, published in 1907) an agent provocateur persuades Stevie to carry to the blow up the Greenwich Observatory. The unlucky man blows up himself by accident. Two eminent writers used the explosion and the blast injury as crucial element in the plot. Flying bomb explosions motivated the characters in Graham Greene's The End of the Affair (year 1951), while Robert Jordan, the protagonist of Ernest Hemingway's "For whom the Bell Tolls" meets his fate as he is a demolition expert.

Fabricated explosives have been with us in the last 1,000 years ago. The mixture of the original gunpowder came to Europe from China sometimes in the eleventh century. Nitro-glycerine was discovered by the Italian Ascanio Sobreno in 1846 and the days of the black powder were over. High energies were freed on an industrial scale thanks to Alfred Nobel's dynamite and the invention of the blasting cap from the mid-1860s onward (4). Smokeless powders like cordite, ballistine and others were more than ready to be deployed when the Great War came. The suffocated dead in the immediate vicinity of an explosion without visible external injury to the chest gave the idea of the "blast", or pulmonary concussion (5). These experiences were revived 20 years later, when bombing of the civilian population produced similar phenomena (6). The Spanish civil war, not only Guernica provided a tragic test field for the subsequent Second World War (7,8). Both the English speaking and the German dominated surgical medical terminology had to give up the Latin-rooted expression of concussion (concussio pulmonis) as neurotraumatology expropriated the expression, reserving it for the brain injuries. Blast injury to the thorax and the lung within, as a monotrauma among immediate survivors of an incident is practically a non-existing entity. However, the lung injury treatment is a major challenger and important determinant of the medium- and long-term outcomes.

Mechanisms

A stepwise description of the blast injury to the thorax and their immediate consequence follows five stages of any blast injury (9-11). The academicals deconstruction and dissection of the complex event makes a clear difference with anatomic or mathematical clarity in spite, the fact, that only milliseconds are separating them. The different mathematical models (12), offering explanation gained in animal experiments (13,14) agree in the stepwise description. The very first injury is the direct tissue damage caused by the blast shock wave (primary) followed by the flying pieces hitting casualty (secondary). The body takes a trajectory and inevitably hits other objects/persons, becoming a projectile himself/herself (tertiary). Caloric insults, chemicals and toxins are the quaternary effects. The nearly immediate systemic inflammatory response of the surviving person is the quandary effect. Kinetic energy conflicts different densities (gas/body) resulting in spallation. Extra high-speed compression and expansion of gas-containing tissue causes implosion. Different tissues exposed to the acceleration of the shock wave will be sheared, leading to inertial damage. High pressure causes immediate cell death. Compression and sharing lead to tissue disruption subsequent extravasation and oedema.

The musculo-osseal complex of the chest wall is subject of the secondary and tertiary injuries, while the air-filled lung and the blood-containing heart/major vessels are susceptible for the primary effect of the blast injury. Ruptured alveoli, haemorrhage from the vessels, pleural injury causing haemothorax and pneumothorax are the main anatomical consequences, while reflexes are partly responsible for the cardiorespiratory collapse (15,16). Pleural surface, especially blebs are surprisingly strong structures resisting more than 2 atm blowing pressure (17). Caloric insults, toxic fumes are to be evaluated in the context of the central and peripheral airways. This last element needs particular attention when biology weapons are applied.

Pathology

Destructive chest wall injury, haemothorax and pneumothorax are mechanical in origin and are circumscript. The lung parenchyma injury, which is an actual structural damage without sharp borders, leads to hepatization and results in an immediate loss of function in the O_2-CO_2 exchange, and triggers a cytokine storm, acting as a shock-organ at the same time. Walls of the major vessels/myocardium develop haematoma within the layers if immediate disruption does not lead to immediate exsanguination (18,19).

Diagnosis

Thoracic blast injury might result in obvious macroscopic destruction and subcellular level injury as well. Chest wall and underlying organ wounds are speaking for themselves, and further diagnostics are dependants of the urgency of the case. Haemodynamically unstable patient needs an absolute minimum of diagnostics before surgical exploration and attempt at haemorrhage control. However, potentially lethal blast lung injury can be sustained in the absence of any other external signs of thoracic trauma, but the opposite is more frequent observation. The clinical diagnosis of blast lung is based on the actual context of the injury, clinical symptoms and radiology. Up to 80% of battlefield injuries caused by explosion develop blast lung (15). Significant differences exist between the blast confined to closed space (bus, train: usually terror attacks) and explosions in open air (military settings) (20,21). Symptomatology is disturbingly multifaced, and the specificity of signs to lung parenchyma blast injury is quite low: respiratory distress, restlessness, moderate haemoptysis, associated with cyanosis and hypoxaemia. In some patients' symptoms may be significantly delayed. Images show unilateral or bilateral focal opacities diffuse loss of lung translucency which, if unilateral, may be associated with reduced rib-expansion, and radiological evidence of barotrauma. Pneumothorax, pneumomediastinum, pneumopericardium, surgical emphysema, interstitial emphysema is secondary to pulmonary parenchymal lacerations. Significant haemothorax and profuse haemoptoe suggests major vascular disruption. While respiratory symptoms are reported in 22–50% of blast lung patients, abnormalities on plain chest films have been reported in 52–91.7% (22). This observation supports the philosophy of a symptom/physiology led treatment tactics, with other words: treating the patient himself/herself rather than his/her images. Early plain chest radiographs are abnormal in around 70% of cases. Diffuse loss of translucency, focal opacities in combination with diffuse loss of translucency are usual signs. Thoracic CT is more sensitive, but the development of abnormalities needs time. Again, pictures on their own, without corresponding abnormalities in the oxygenation and circulatory parameters of the patient are misleading (23). Following the initial 24–32 hours it is hard to differentiate between the consequences of structural damages caused by the blast and the trauma-related acute respiratory distress syndrome (ARDS). Blood gases and even pulse-contour-cardiac-output are helping in the close monitoring of the patient. Blood gases are steering the diagnosis and the therapy, alternating the ventilatory strategies. Inflammatory markers are for the monitoring of fifth stage of the blast injury, where the immunological events are determining the fate of the patient, the fact and degree of the recovery of the lung tissue.

Interventions, procedures

Thoracic injuries caused by explosions need thoracic surgical competencies in the immediate trauma phase (secondary and tertiary effect of the blast), rather than in the subsequent stages. Poly or multitrauma patient needs a quick evaluation and triage if a mass casualty incident is present. Haemorrhage of extremities as primary cause of preventable death needs control, followed by the orthodox ABC of resuscitation, where airways/breathing are the main concerns in thoracic trauma. Life before limbs rule commands the strategy following tourniquet application. As far as the thorax is concerned, tension haemo/pneumothorax requires chest drainage first and thoracotomy if it fails. Extensive chest wall injury is to be treated according to the cover&drain protocol in the prehospital stage (24). Common feature of wounds caused by explosives is the uncertainty in the extension of definite cell death and consequently grey zones in the tissue viability. Conservativism in surgical aggressively is recommended. Strategies to reconstruction are referred in the relevant chapter of this issue (25). In the rare cases where lung parenchyma resection is required, non-anatomical, parenchyma sparing procedures are to be performed. Lung gangrene, a late complication should be kept in mind, the only condition, where formal anatomical resection might be justified as a planned procedure in blast injury to the thorax (26).

Thoracic surgeon as a member of the multidisciplinary team might have a limited role as the primary blast lung injury is "per sé" an acute lung injury (26) and is the territory of the intensive therapists and pneumonologist. Ventilatory management of the lung blast injured is crucial. Lung protective strategies are in the focus of the procedures, developed by the ARDS network protocol (27). Low tidal volumes and PEEP and plateau pressures below 30 cmH_2O are the cornerstones. Permissive hypercapnia application is dependent on the central nervous system condition of the victim. Intracranial pressure monitor is advantageous. The target pH is between 7.25–7.3, as metabolic acidosis is one of the dreaded triads of trauma death.

Separated lung ventilation is one option. High frequency oscillatory ventilation and extracorporeal membrane oxygenation offer further solutions (22). Knowledge transfer from non-invasive ventilation, an excellent modality in ventilator insufficiencies from other reasons (chronic obstructive pulmonary disease) is another possibility. The higher incidence of severe respiratory distress among the victims of the civilian terror attacks than the military series might be attributed to the fact, that the former takes place in enclosed place, but the different age distribution and pre-existing disease profile also plays a role.

Outcome

Paradoxically enough, the mortality of blast injury to the lung among those, who reach the hospital, is low, below 5% (3,22). Concomitant injuries—central nervous system injuries and polytrauma—are decisive factors in term of survival. Thoracic empyema is the most frequent chest complication.

Conclusions

Blast lung injury with or without blunt/penetrating thoracic injuries is a relative late comer in the group of traumatic lethality. Early detection of impending pulmonary insufficiency resulting in hypoxia straight referral and access to facilities with dedicated ventilatory support teams/hardware are the key elements in avoiding preventable death. The present triage systems seem to underscore the importance and severity of the blast lung injury. The task is complicated by the fact, that early diagnostic signs are scarce and have a low specificity. Majority of casualties surviving the acute lung injury stage is successfully manageable with conventional ventilatory support employing a lung protective strategy. However, concomitant injuries—especially central nervous system damage among the military casualties and previous, underlying lung pathologies in the civilian population—limit the chances of long-term survival. A conservative, predominantly expectant surgical approach seems to be advantageous in the complex treatment protocols of blast lung injuries.

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Footnote

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