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PATHOPHYSIOLOGY OF BLASTING INJURIES[2]

SUMMARY: Explosions have the capability to cause multisystem, life-threatening injuries in single or multiple victims simultaneously. The physical and chemical effects of blasting: overpressure, fragments, acceleration, fire and poisoning gases cause special injuries of human body. Many times these injuries don't have any external symptoms, but often occur severe amputation and destruction or death. The health service specialists and military personnel should to know and recognize the blast effects. These special damages are classified on the base of the mechanism, because these determine the seriously and the type of injuries, and these influence the treatment, the healing, the complications and the residual symptoms. The most often damaged organs are the ear, the lungs, the bowel and the brain, but the fragment can hurt on the total surface of body. In this presentation I give some information and explanation from mechanism and classification of blast injuries.

Keywords: explosion, overpressure, fragments, injuries

INTRODUCTION

The terrorism has become a real threat. Since Hungary participates in international military operations it becomes a target of terrorists, who execute their objectives by explosive attempts. The fight against the use of improvised explosive devices (IED) is accomplished by development of reconnaissance and destruction, elaboration of new devices and protection of human resources.

The military and health specialist need to know the mechanism of blasting to evaluate and treat the damaged patient by the terrorist attack or any other explosion events. The blasting have the capability to cause multisystem, life-threatening injuries in single or multiple victims simultaneously. There is no mark of injury in many cases, but there are deathly injuries inside the human body. In the other cases the damaged patients have head, chest or abdomen injury or amputation of extremities.

THE MECHANISM OF EXPLOSION EFFECT

Blast overpressure

Blast overpressure results from explosions and is characterized by super atmospheric pressure which is produced by compression of the air located in front of the blast wave. In this phase, which is defined as positive phase of the blast wave on the pressure-time curve, air molecules are heated and accelerated. The subsequent sub atmospheric pressure is described as negative phase of the blast wave. The specific pressure-time curve representing explosions in open field is named Friedlander wave. Pressure-time curves of explosions in enclosure significantly differ due to reflections and increase of the pressure. [1,2]

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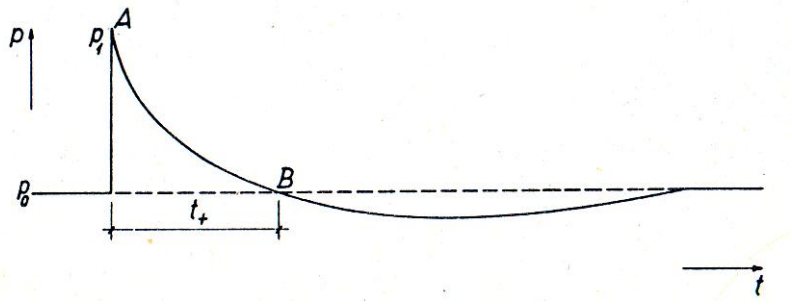

Fig. 1. Overpressure-time curve [1,3,4]

Injuries arise mainly in the positive phase. Primarily air-filled organs and organs with various densities are affected such as ear, lung and intestines. [1,4]

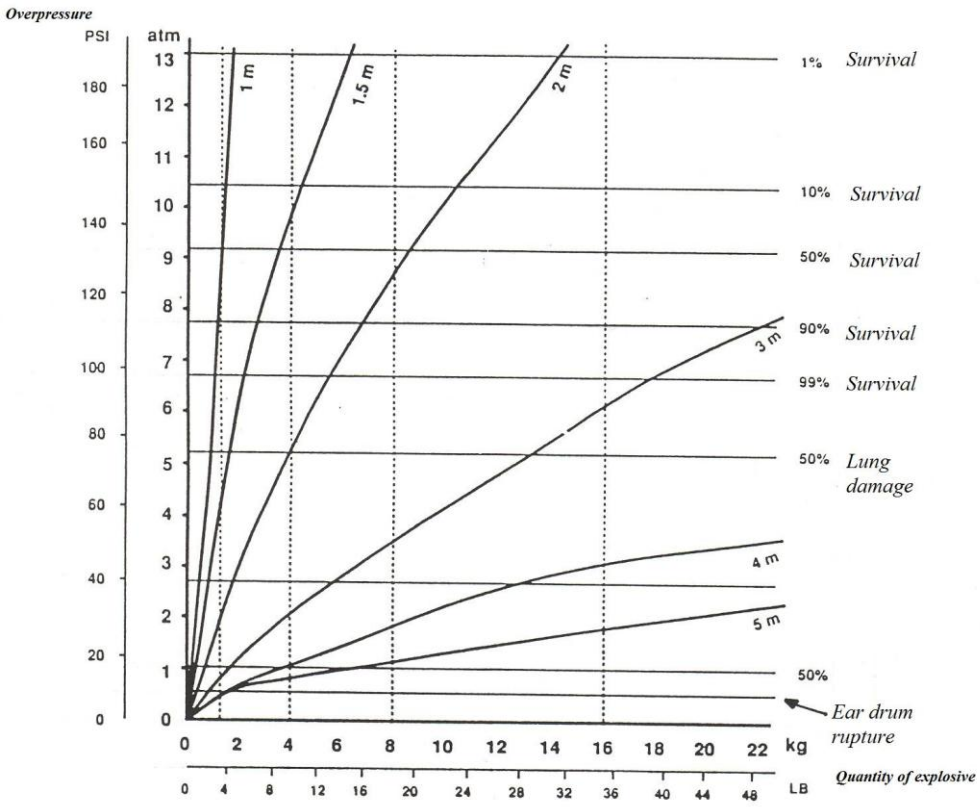

Fig. 2. Correlations between overpressure and injuries [3,4,5]

Explosion specialist may use figure 2. for determination of safety distance. The diagram is simplified in order to easier use. Values refer to explosions in the open: the vertical axis represents the overpressure, the horizontal axis describes the weight of the explosive and the oblique lines illustrate the distances from the explosive. The figure pertains to TNT[3] as explosive, in case of other agents TNT equivalent should be taken into consideration. Vertical lines show the threshold values of blast injuries. Values refer to non-armored personnel in open field but in enclosure different values are valid owing to reflected waves. [4,5]

Severity of blast injuries are influenced by:

- independent from the explosion: age, sex and co-morbidity.
- dependent from the explosion: distance between the injured person and the explosion, peak pressure, rise of a curve, duration of the positive phase of the blast wave and reflection of the wave.

[3] TNT = Tinitrotoluene.

- environmental factors: wind, terrain and temperature. [4,5]

Fragments

The fragment may originate from the exploded device (primary fragment) or from the explosion flung objects (secondary fragment). There may be a metal, wood and glass splinters, pieces of buildings, furniture, stones. Their size and their mass may be variable from a few millimeters to more meters and from a few grams to more ten kilograms. [4,6]

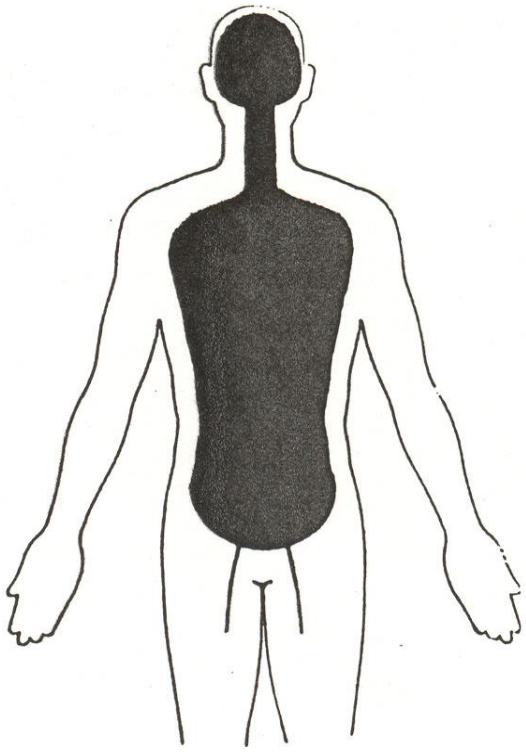

Fig. 3. The critical surface of human body [4,6]

Numerous factors define the seriousness of the injuries caused by the splinters. There are the moving energy of fragments, the figure, structure and density of these, the possibility of breaking after impact, the rotation of splinters. Important factors are the location of injury and the protection of body too. On the figure 3. the most vulnerable parts of human body are shown.

The irregular figure fragment give their energy before the target, especially they damage the clothing and the skin. The sharp splinters go to the deep of body, sometimes pass through it.

The energy what causes injuries is determined by the weight and velocity of fragments. The primary fragments are more rapid than secondary, especially what come from military devices and shrapnel. [4,6]

Acceleration

Sudden acceleration occurs if the shock wave of the explosion flings the body or a splinter strikes or shoves it. The acceleration of body or only part of it depends from the measure, figure and weight of body and the parameters of shock-wave. The sudden deceleration occurs when the victim laps into a rigid surface after the explosion.

The scale of injuries may occur from mild abrasion to amputation of extremities or rupture of life-important organs. With help of mannequins the acceleration and deceleration have been defined in the event of different charge of explosive and different distance between

explosion and mannequins. The acceleration of head what is the vulnerable part of body was the largest. The acceleration and deceleration change very rapidly. [4,7]

Distance (m)	Charge of explosive (kg TNT)
5	20
4	12
3	4
2	1,5
1,5	0,5

Table 1. The distance and charge of explosive what need to same effects [4,7]

The specific brain injury what come from acceleration-deceleration effect is the coup-contrecoup contusion in occipital and frontal lobe of brain. [8]

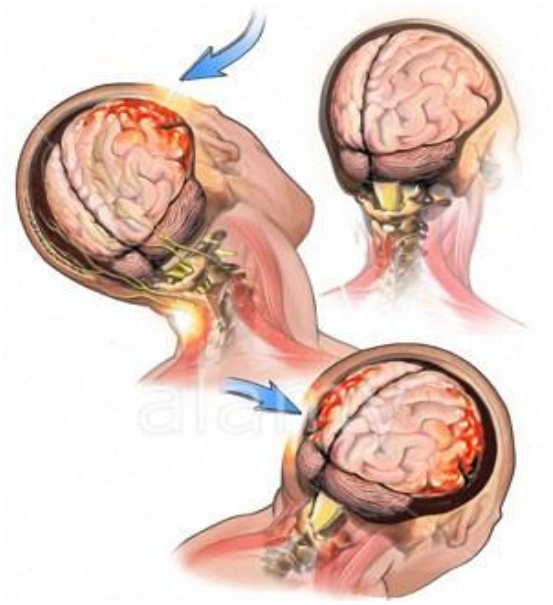

Fig. 4. Coup-contrecoup injury of brain [8]

High temperature

Burn lesions are caused by direct flame effect, the detonation fire-ball, the hot fragments and the fire after the explosion. The upper airway burn lesion is possible because the casualty may inhale the hot air. [4,7]

Toxic gases

Vast volume of gas is produced in explosions which expands in milliseconds and therefore induces shock waves resulting work. This gas contains poisonous and less poisonous compounds.

Organic explosives mainly consist of carbon, hydrogen, oxygen and nitrogen, but may contain sulphur, chlorine and metals also. Therefore in the explosive products many various gaseous and solid compounds occur. The ratio of the above-mentioned components depends on the oxygen balance of the explosive substance:

- CO_2, H_2O, CO, O_2, H_2, CH_4, C;
- N_2, NH_3, C_2N_2, HCN, NO, N_2O, NO_x;

- SO_2, H_2S, HCl, Cl_2;
- metal-oxide, -carbonate, -bicarbonate, -cyanide, -sulphate, -sulphite, -sulphide, -chloride.[9]

The other components of toxic gases are come from the flame of exploded objects, there are acrolein, cyclopentatone, benzene, formaldehyde, fosgene, polychlorinated biphenyls, isocyanates. These substances are very toxic, they have long-term effects to the organisms and have high cancer risk.

Pathophysiology of blast injuries

Blast injuries are accompanied by the following pathophysiological processes:

- psychotrauma provoked by explosion and stress reaction;
- acoustic trauma;
- damaging effect of the blast wave /general shaking, pressing and pushing effect/;
- barotraumas;
- mechanical injuries;
- burn injuries;
- intoxication. [1,4]

However pathophysiological processes develop in all cells and tissues, the clinical signs are different depending on the organs.

Sudden change in air pressure gives rise air embolism resulting in obstruction of vessels, tissue damage and oedema. Severe damages may lead to permanent paralysis, speech disorder, blindness or death. Rarely air embolism develops in the retinal vessels or rupture of the eye may occur. [1,4]

The air-contained tympanic cavity of the ear is the most vulnerable to the blast induced air-pressure changes. Blast injuries of the ear induce combined type of hearing loss due to damages of the middle and inner ear. Tympanic membrane rupture, haemorrhage in the middle ear, luxation or disruption of auditory ossicles, rupture of oval fenestre, laceration of basal membrane and damages of organ of Corti or of cilia may appear dependent upon the severity of blast injury. Unilateral injuries are present caused by the shielding effect of the head. Hearing loss, tinnitus, otalgia, bleeding from the external canal and vertigo are present. [10] Threshold value for tympanic membrane rupture is 0.35-0.45 bar. [4,5]

Pulmonary injuries vary from lung contusion and haemorrhages to pneumothorax. Autopsy may reveal minimal structural changes or fatal lung contusion. Surface haemorrhage may be observed corresponding the neighbouring ribs. After the pressure wave reaches the body it may be reflected or penetrate. Air in the alveoli is compressed and the alveolar and vessels walls are injured. Haemorrhage and oedema can develop therefore the ventilation is obstructed. After the pressure, sucking effect makes the gas bubbles to penetrate into the vessels resulting in fatal air embolism of the brain or heart. Some toxic gases cause airway obstruction or pulmonary oedema. The cianids and carbon monoxide damage the oxygen transport system in the blood. [2,4]

Signs of cardiac contusion are haemorrhages. Occlusion of coronary arteries results from air embolism or fibrin formation. Pathological neurocardial reflex may lead to arrhythmias such as asystolia, bradycardia, tachycardia and ventricular fibrillation. In severe cases laceration of the myocardium may occur. [1,4]

Among abdominal organs the GI tract is the most vulnerable to primary blast effect. This can cause petechiae, bowel perforation, damages and its complications. The injury most commonly appears in the large bowels especially the cecum where gases usually accumulate. Air embolism may develop in the mesenterial vessels. Abdominal solid organs are also affected such as the liver, spleen and kidneys. Explosion induces a reflex to close the epiglottis as a defensive mechanism. [2,4]

Severe limb injuries may occur following a peak pressure higher than 15 bar, however acceleration may lead to amputations and mechanical injuries caused by fragments. [2,4] Compartment syndrome is a common complication of extremity injuries. [1,4]

Crush syndrome is a complication affecting the whole body. Tissue damages causes toxaemia and acute renal failure. [1,4]

Clinical signs of blast injuries show a various pattern such as cyanosis, bleeding from the nose, mouth, ear, haemorrhage or rupture of the tympanic membrane, dyspnoea, hemoptoe, tachypnoe, crepitation as auscultatory finding, pneumothorax. Common sign are ranging from tachycardia, hypertension to ischemic findings on ECG[4]. [1,4]

Classification of blasting injuries

In the following table there is the classification of blasting injuries. It helps to recognize and diagnose the patient's problems and helps to the anti terrorist specialists and investigators to detect the traces.

Category	Mechanism	Body parts affected	Injuries
Primary blast injury	Blast overpressure, barotraumas	- air-containing organs (lungs, gastro-intestinal system, middle ear) - solid organs located next to the air-containing organs (heart, spleen, liver, kidneys) - Great vessels	- Pulmonary barotraumas - Tympanic membrane rupture - Perforation of the GI tract, bleeding - Rupture of the eyeball - Traumatic brain injury without physical signs of head injury - Lacerations of the liver, spleen and kidneys - Contusion to the heart - Lacerations of the great vessels - Air emboli
Secondary blast injury	Impact on the body from flying fragments	- Any body parts may be affected	- Contusions, fractures - Penetrating injury of the eye, skull, thorax, abdomen and pelvis
Tertiary blast injury	Sudden acceleration, impact of the body	- Any body parts may be affected primary head, neck and extremities	- Closed-head injury - Fracture of the cervical spine - Extremity injury;
Quaternary blast injury	Heat injuries and toxic gases	- skin and eyes - airways and lungs	- Burning - Burning of the airways - Intoxication
Collateral injuries	stress	- Systemic response to the trauma	- Angina - Hypertension - Hyperglycaemia - Asthma

Table 2. Categories of the injuries due to explosions [1, 12]

[4] ECG = Electrocardiogram.

CONCLUSION

In my publication I summarized the effectiveness of explosion in human body. In the early phase it can be difficult to diagnose blast injuries because it is not accompanied by obvious clinical signs. The injuries, the state of the injured person and his or her medical history determine the treatment and the prognosis. Lung haemorrhage, air embolism of coronary arteries or injuries of the nervous system may be lethal. [4]

We need to know the mechanism, the pathophysiology and classifications of injuries, because these information help us to exam the blasting patients and diagnose the damages so to treat these.

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