Narrative Review

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Biophysics and physiopathogenesis of blast wave traumatic injury. Narrative review. Part I

Abstract

Explosions are physical, chemical or nuclear reactions that produce a rapid release of enormous amounts of energy (mechanical, kinetic, radioactive, etc.). The chemical explosion is produced by the molecular breakdown of the elements that make up the explosive device. It is an oxidation-reduction process without the intervention of any gas (oxygen) that generates a powerful blast wave. Its harmful effect on living beings and destructive effect on nature is included in the generic term of traumatic injury by blast wave. The categories of explosion by explosive device are: combustion, deflagration and detonation. Explosive devices are classified as high power and low power. The former cause a detonation and the latter a deflagration. Traumatic injury, both physical and psychological, by blast wave is multimodal and its didactic taxonomy refers to the predominant etiological factor. The physical aspects of the explosion and the blast wave are the subject of this narrative review.

Keywords: Explosives. Blast wave. Blast injury. Expansive wave taxonomy

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Introduction

The word explosion derives from the Latin *explosio, -ōnis*: 'booing', 'action of throwing out a person or animal with noise'. In English *explosion* is a sudden, violent burst of energy, (e.g., a bomb). Another meaning is to break violently or burst into pieces. Explosions are physical, chemical or nuclear reactions that produce a rapid release of enormous amounts of energy. In chemical explosions, the energy is released when the chemical bonds of the explosive device component are broken, which as a result generates the blast wave.[1] Explosives (hereinafter we will only refer to conventional or chemical explosives) produce a "blast" wave; it is wrong to speak of an "explosive" wave. The main components of the blast wave are the shock wave and the wind wave. In this section we will only refer to those of chemical origin, since the mechanical, electrical and nuclear ones present other physical-chemical considerations.

An explosion quickly becomes associated with an image of destruction. Explosions, whether accidental or intentional, wreak physical and psychological havoc[2] on the injured, as well as on the professionals involved in responding to the incident and caring for the victims.[3] Explosions may be primary by the explosive device, or secondary by fire, shrapnel or similar, which deforms/ruptures structures with explosive agents. A special feature of explosions that differentiates them from other accidents typical of industries using hazardous substances is the short duration of the phenomenon, which prevents the application of mitigation measures that can be used for other types of accidents, such as large fires and toxic leaks. Thus, the only way to act against explosions is through prevention.

Understanding the basic concepts of the triggers and pathophysiology of blast injury provides a solid foundation for the proper management of victims and ideally prevents its sequelae.[4,5]

Type of explosions: combustion, deflagration (*backdraft*), detonation and implosion

Explosions can be categorized according to their nature: physical by mechanical phenomena (volcano, compressor and others), electrical (electric arc, lightning), nuclear (atomic fusion) or chemical[6] (super-rapid oxidation of hydrogen and carbon atoms of a solid or liquid compound, which converts it into a large volume of ultra-thermal gas).

a. Combustion is a rapid oxidation reaction that takes place between a combustible body and a comburent (oxygen in the air). When a fire occurs and is not followed by an explosion, it is classified as combustion.

b. Deflagration is an isobaric explosion (at constant pressure) and sudden combustion with flame at low velocity of propagation, e.g. butane explosions. A *backdraft* (or *backdraught*) is a deflagration that occurs when in a confined fire, in which there are incomplete products of combustion due to lack of oxygen as a result of limited development by ventilation, there is a sudden supply of air.

c. Detonation is a very rapid exothermic chemical reaction, in which large amounts of energy are released, in the form of large volumes of gas and heat, which forms a fireball, with pressure, noise, flash and smoke. Detonation is a property of high explosives and is a supersonic combustion process, unlike deflagration by low explosives, which is subsonic combustion (Table 1).

Table 1 High-energy events in which a liquid or solid is rapidly converted to a gas can occur at 3 speeds

Combustion	Rapid ignition, but minimal explosion (e.g. gunpowder).
Deflagration	Subsonic ignition and wind wave (low grade explosive).
Detonation	Supersonic ignition and shock wave (high explosive).

Source: MSD Manual. 2021 Merch & Co. Kenilworth, NJ, USA.

d. Implosion. Boyle's law states that at constant temperature, the volume of the gas is inversely proportional to its pressure. Implosion occurs when the external pressure is higher than the internal pressure, so that the structure breaks inward, and ends up exploding with a soft roar.[7,8] Among other examples: lung implosion by shock wave, underwater implosion by hydrostatic water pressure, implosion of stars to form black holes, and nuclear weapons implosion.

Characteristics of explosive devices

Explosives are substances capable of releasing a large quantity of gases and heat through a rapid chemical reaction produced by an external mechanical or thermal cause. The explosion is a process of internal oxidation-reduction in which the elements of the explosive molecule are combined, without the intervention of oxygen. A substance is said to be explosive when it is capable of very rapidly generating a large volume of hot gases when properly stimulated.[9] A substance is pyrotechnic when the self-sustained, non-detonating exothermic chemical reaction, intended to produce a luminous, sonorous, fumigating or calorific effect, or a combination of them. The energy released by an explosive depends on its thermochemical properties. As a rule of thumb, one gram of explosive material generates approximately one liter of gases and releases one kilocalorie in the form of heat of reaction. Whether or not this released volume and energy forms an appreciable pressure wave depends mainly on the reaction rate at which the process takes place.[10] There are different types of explosives; those designed to cause a rapid rise in pressure, others designed to cause damage by conflagration and others used to propel objects capable of causing penetrating injury.

In ballistics, explosives are classified as high potency explosives (HPE) and low potency explosives (LPE).[11] The HPE (e.g. TNT or trinitrotoluene which is the reference explosive, cyclonite, pentrite, amonal plastic explosives and others) are derived from dynamite, invented by Nobel in 1866 and produce a shock wave of atmospheric and supersonic hyperpressure. The LPE (e.g., chlorothite, nitrocellulose and others), led by black powder, create a subsonic wave, lack a hyperpressure wave, and are used as propellants[6] (missiles) or in pyrotechnics. Ammonium nitrate fuel oil (ANFO) is considered intermediate grade. Therefore, HPE and LPE cause different patterns of body injury, due to the presence or absence of the shock wave, respectively.

Almost all chemical explosives contain O_2, N_2, and oxidizable fuels, such as C and H. The O_2 and N_2 are often bonded together to form chemical side chains, such as nitrate (NO_3), nitrite (NO_2) and nitric oxide (NO). The bound O_2 facilitates rapid oxygenation of the fuel, as compared to conventional fuels, such as coal, which rely on atmospheric O_2 to oxidize and release energy.[12] Among the general characteristics of explosives are: chemical stability, ignition sensitivity and explosive power referred to as blasting/demolition force due to the combined action of the shock wave and gas pressure; and shattering effect (*brisance*), due solely to the shock wave, thus measuring the speed with which maximum pressure is reached. This makes it possible to distinguish "breaker" explosives (e.g. RDX or cyclonite and other plastic explosives) from "booster" explosives, which, as their name suggests, serve to initiate the action of other explosives.[7]

Industrial, civil or military explosives have an officially defined and regulated composition. They are known as improvised explosive devices (IED), e.g. the pipe, fertilizer or barometric bomb and the Molotov cocktail, to which technological advances (electronic power devices) and small metallic objects (nails, balls, screws, etc.) are often added to increase their effectiveness and the secondary fragmentation effect of the device.[13,14] At the industrial level, another explosive is the BLEVE (*Boiling Liquid Expanding Vapor Explosion*), which literally translates as: explosive expansion of the vapor of a boiling liquid. It is a special case of "bursting of a tank" inside which a liquid is stored under pressure. The main characteristic of a BLEVE is precisely the explosive expansion of the entire mass of suddenly evaporated liquid, which gives rise to the corresponding blast wave (overpressure, shrapnel and fireball).[15]

New explosive weapons have now been developed.[16] These include thermobaric weapons, also known as Fuel Air Explosives (FAE), vacuum or aerosol bombs, dual-stage explosives or enhanced-blast weapons (EBW), as they are very efficient against closed targets (bunkers, caves and tunnel systems).[17,18] They are very efficient against closed targets (bunkers, caves and tunnel systems). The EBW release a gas prior to detonation; resulting in a longer-range blast wave with lower pressure amplitude that can diffuse around corners. The weapon uses oxygen to generate an intense, high-temperature explosion, generating a sustained blast wave of longer duration than conventional detonation. Its terrible effect on living things is the vacuum effect of a thermobaric fireball, as it creates a negative pressure that "sucks all" available oxygen from anywhere within its radius, including the oxygen within the lungs of any soul caught in the blast.[19]

Physical aspects of the explosion

A chemical explosion is a molecular phenomenon that releases/generates a large volume of gases at high pressure and very high temperature in a very short time. This abrupt and instantaneous release of gases causes an increase in the surrounding atmospheric pressure, which is transmitted as a wave from the source to the environment in all directions. This powerful wave is called a blast wave (BW) (*onde de souffle, Ausladende welle;* in French or German respectively).[20] From the physical point of view, in an open air environment, BW has three fundamental elements[20]: a) static hyperpressure wave, b) dynamic hyperpressure wave, and c) thermal effect.

I.- Static hyperpressure wave. Under ideal conditions, in an open-air site, after detonation, the expansion of gases generated originates an atmospheric hyperpressure wave known as shock wave (SW), shock front, Friedlander pressure-time curve, which expands faster than sound;[17,21,22] which expands faster than the speed of sound. The SW in an initial phase, travels at supersonic speed (3,000 m/s to 9,000 m/s), but as it moves away from the origin, the magnitude of the shock wave decreases in inverse proportion to the cube of the radius of its sphere of expansion.[23] In other words, in free air, the damping of the SW is exponential and inversely proportional to the cube of the distance.[20] That is, a victim who is three times the distance from the blast has a 27-fold reduction in the magnitude of the blast force relative to a victim who is at a referential distance of one.[24] This exponential decrease in pressure amplitude explains why injuries in outdoor blast survivors are rarely caused by shock wave barotrauma.[17] The morphology of the ideal Friedlander curve varies depending on the environment: presence of walls or solid objects, and whether the environment is closed or open. This hyperpressure wave is static, i.e. it is not accompanied by any propagation of gases; and consists of two phases (Figure 1):

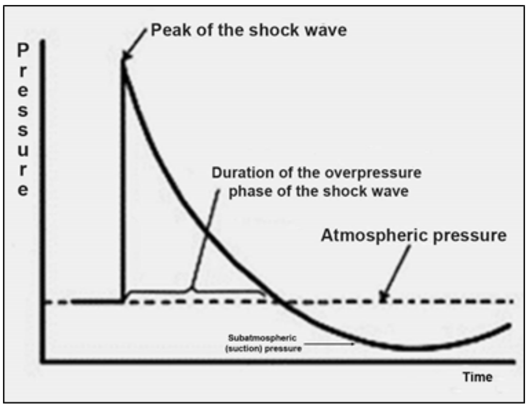

Figure 1 Shock wave diagram. Time-pressure relationship in an open environment (Friedlander curve): sudden, almost instantaneous and very brief increase in atmospheric pressure (overpressure peak), followed by a phase of subatmospheric (suction) pressure. Figure modified by the authors: Harrisson SE, Kirkman E, Mahoney P. Lessons learnt from explosive attacks. Journal of Royal Medical Corps 2007; 153 (4): 278-82

a) The positive pressure phase: it presents a sudden ascent until reaching the maximum or peak overpressure. This peak, of the order of hundreds of kPa, decreases exponentially and inversely proportional to the cube of the distance from the center of the explosion, so if the distance increases by 2 times, the maximum overpressure will fall to 1 of the initial value. [3] This hyperpressure phase is of short duration (≈ ms) and varies according to the type of HPE.

b) The negative pressure phase (subatmospheric), known as the suction wave. The positive component is followed by a negative pressure phase, a relative vacuum, which sucks in air and debris. The vacuum is produced due to the large displacement of air from the center of the explosion by the positive phase of the SW, which leaves behind an air mass deficit[3]. Its amplitude (underpressure peak) is much smaller than that of hyperpressure, but its duration is three to ten times longer. On the other hand, the negative phase of a detonating explosion is much larger than that of deflagration explosions. For calculation purposes, this phase is negligible, since its absolute value is much lower than that of the positive phase. However, in the case of a vapor cloud explosion it can give rise to extremely high values of the negative phase; and during its initial part, be associated with an energy as destructive as that of the positive hyperpressure phase.[25]

The SW profile of the detonating explosive is different from that of the deflagrating explosive (Figure 2: A and B). The former is sharper, so that the maximum (peak) value is reached suddenly. In the latter, the rate of increase of overpressure is much slower. Another significant difference is that the duration of the negative phase of detonators is longer than that of deflagrants. As the SW of the detonating explosion progresses and moves away from the origin of the explosion, it becomes softer and its profile ends up being similar to that of the deflagrating explosion. Another difference between the detonating and deflagrating waves is related to their audibility, so that only the former is audible. With conventional explosives the duration of overpressure phase usually lasts ≈5 ms and the underpressure phase ≈25 ms. In contrast in atomic explosions the estimated duration of hyperpressure is 1 min and suction 10-15 min.

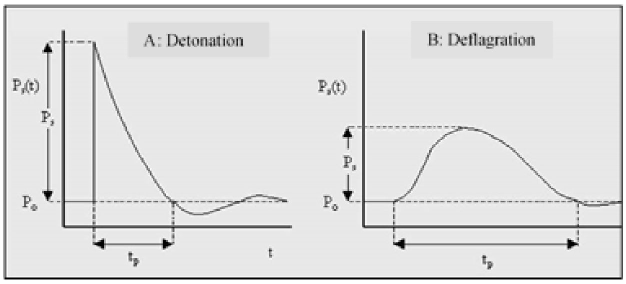

Figure 2 Evolution of the shock wave over time for detonating (A) and deflagrating (B) explosions. Po atmospheric pressure. Ps shock wave amplitude. Ps(t) shock wave peak. tp: duration of the positive phase of the shock wave. t, time. Source, modified from: TNO: Green book, Methods for the determination of possible damage to people and objects resulting from release of hazardous materials. CPR 16E. 1992.

The threshold for tissue damage by SW is related to the slope of ascent, the magnitude of the peak (kPa) (Table 2) and the duration of the hyperpressure component, not forgetting, in some types of explosions, the underpressure component.

The composition of the shock wave is gaseous (CO_2, N_2, O_2, H_2O_{vapor} and others) therefore in a way it follows the law of perfect gases (PV = nRT), i.e. gases expand when heated (Charles' Law: $V \propto T$). Moreover, the *shock wave* has the properties predicted by the physics of sound waves, so there is no sound or SW in vacuum.[26] As the initial, quasi-spherical SW propagates, it interacts with the surrounding environment, including the ground, which although absorbs much of its energy; but it also causes reflection/diffraction. This *ground bounce* causes reverberating waves that increase the power (amplitude and duration) of the SW, thus further increasing *ground* blast.[27] The active edge in the air of the SW is called the "expanding front" and can be seen visually due to the way it refracts light. The overpressure of the expanding front causes a destructive effect that is called explosive power, or *brisance*. Explosive power is a measure of how quickly an explosive develops its maximum pressure, and results from the combination of its detonation velocity and the volume of gases produced in the explosion. However, although *brisance* is a measure of the explosive's destructive/bursting capacity, it may not be related to the explosive's total working capacity.[28]

Table 2 Effect of the shock wave according to different pressure levels (1 kPa = 7.50062 mm Hg).

Pressure (kPa)	Effect
15	Hearing impairment
35	Possible tympanic perforation
105	50% risk of tympanic perforation
200 - 275	Low risk of lung injury
550	50% risk of lung injury
690-830	Low risk of death
900-1.240	50% risk of death
1.380-1.700	Probable death.

Sources: *Martinez T, Boye M, Py N, Swiech A, Boutonnet M, Pasquier P (2020) Blast and blast injuries. EMC Anest Reanim 46:1-12*

Champion HR, Holcomb JB, Young LA (2009) Injuries from explosions: physics, biophysics, pathology, and required research focus. J Trauma 66:1468-77.

In medicine, SW has therapeutic application. The extracorporeal shock waves of the lithotripsy machine and physiotherapy equipment are similar to the shock waves after detonation, only that the hyperpressor phase is of shorter duration (lithotripter: duration 0.002 ms, very short ascent period: 1 nanoseg), and of low frequency to facilitate its penetration and not to damage the tissue.[29] On the other hand, in the shock wave detonation of 1,500 kg of TNT, the duration of the hyperpressure phase is ≈10 mseg.

II.- Dynamic hyperpressure wave. The rapid expansion of the gases generated by the explosion displaces an equal volume of ambient air, and this combination generates a "dynamic" wave, known as wind wave (WW) or explosive wind. The WW is a high flow of forced, superheated gas-air, and is therefore another factor in the severe somatic and structural damage (*blast wind*). This mass movement of super-heated gases and air (≈7,000 °C) creates a "dynamic" overpressure wave that travels immediately behind the blast wave. The WW is smaller in amplitude than the shock wave, but lasts much longer and travels a much greater distance. This large mass of moving gas-air (density) imparts abrupt acceleration to any living thing or moveable object in its path. The initial velocity of this wind is very high in the immediate vicinity of the detonation, on the order of several hundred km/h, which is higher than a hurricane or a tornado. Such a powerful WW ("hurricane" ≈ 2,400 km/h), propels exposed individuals on the ground and hard surfaces, destabilizes material structures and accelerates fractions (splinters, pebbles) of environmental structures ("flying missiles"). Its duration is determined by the duration of the hyperpressure phase of the shock wave. In contrast to the shock wave, individuals behind a barrier or in a trench are protected against the effect of flying fragments of structures. The WW occurs with both low

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and high explosives. Some explosives are manufactured to produce a relatively low energy BW, but large quantities of gaseous products. These explosives produce prolonged and localized WW, with minimal *blast wind*. They are particularly useful in mining and demolition projects.

The combination of shock wave (SW) and wind wave (WW) is known as blast wave (BW). The shock wave only occurs with HPEs; while the wind wave can occur in both, HPEs and LPEs.

III.- Thermal effect. The three components of an explosion are: the shock wave, the wind wave and the heat.[6] An explosion is an exothermic reaction that is accompanied by a large release of thermal energy (heat), which causes burns and fires. The explosion causes the instantaneous formation of a high-pressure sphere of gas at elevated temperature. This thermal effect is limited in time and depends on the nature of the explosive and the possible presence of additional flammable products (napalm, phosphorus, etc.). Deflagrating explosives that act by slow combustion are the source of a greater thermal load than detonating explosives.[26] The *flash* burn is an external burn due to the instantaneous flame (flash) after the explosion of the device.

Blast wave propagation medium

The characteristics and propagation of BW are different depending on where the detonation takes place. In a broad sense they are called BW injuries (*blast injury*), and depending on the type of environment: air, fluid or solid; and the medium of propagation we speak of air, water or solid *blast* respectively. It should be noted that, like sound (which propagates at 300, 1,500 and 5,000 m/s in air, water and metal), the denser the medium, the faster the shock wave propagates. The speed and radius of propagation are four times greater in water than in air and 15 times greater in metal. On the other hand, the propagation of the BW is altered and its power increases in the presence of obstacles or when channeled along streets, corridors, pipes or tunnels, and even more so in an enclosed environment, due to the reverberation phenomena (reflection / diffraction / refraction) of the BW.

a. Aerial *blast injury* and its characteristics.

The injurious effect of the BW is very different if the detonation occurs in an open airspace or in an enclosed airspace. The location of the explosion significantly affects both the quality and degree of injury from BW. The detonation of an HPE in an open medium (*free field blast*) causes from the center of the explosion, the displacement of a mass of air and/or hot gases, through the atmosphere; generating the BW, that is to say an SW and after which the WW appears. In addition, when the detonation occurs on the ground, the SW collides with the surface and the reverberation effect arises, which makes it more powerful and longer lasting, therefore more damaging. Two other effects add to the shock wave momentum: the phonic vortex (eddy) and the rarefaction wave, which increase and decrease the total pressure momentum of the SW respectively.[30]

In an open air environment, the BW travels at supersonic speed (4,000-8,000 m/s) and is rapidly damped as a function of the cube of the distance. The factors with the greatest influence on the damaging effect of airborne BW are: the mass (charge) of the explosive and the distance to the blast source (Figure 3). In airborne *blast injury*, the greatest damage occurs at a critical distance estimated at 6-7 meters from the epicenter of the detonation. On the other hand, barriers can also create BW turbulence immediately behind them (diffraction), with the formation of relatively safe zones, which explains why some people in the vicinity of the blast site are unharmed or suffer relatively minor injuries, while others in more distant areas suffer more serious or lethal injuries.[25] In addition, when the BW contacts an obstacle and is performed at a certain angle of incidence; the incident and reflected waves combine near the impact surface, forming a new wave almost perpendicular to the impact surface, called M-wave or *Mach stem*, 2 to 8 times more powerful than the incident wave; which produces even more lethal somatic damage. The point where the three waves (incident, reflected and M) meet is called the triple point.[10] Hence, the BW is damaging in areas close to the epicenter but also in a place of constructive interference (Mach front).

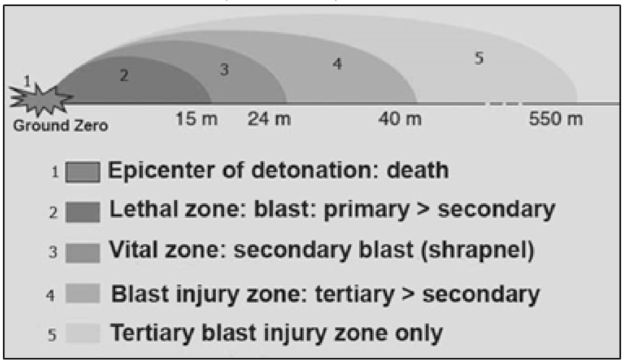

Figure 3 Distance relationship between the shock wave overpressure peak and the damaging effect. Modified, Source: Martinez T, Boye M, Py N, Swiech A, Boutonnet M, Pasquier P. Blast and explosion injuries. EMC Anest Reanim. 2020;46(3):1-12.

BW propagation is different in confined spaces, in the presence of obstacles or when channeled along streets, corridors, pipes or tunnels. In a confined environment, the BW is reflected / diffracted many times (reverberation) (Figure 4) in the structure of the shell (building, train, etc.) which amplifies its amplitude and duration and, consequently, increases (up to eight times) [17] its destructive capacity both on people and on the building.[31] The confined explosion increases the probability of fragmentation/collapse of the shell, of toxic gases and combustion/fire, which adds to the closed SW injuries, penetrating fragment injuries, *crush syndrome*, asphyxia and burns; hence the "*urban bombing*" effect is extremely lethal.[32] Some authors[33,34] taxonomize the closed blast scenario and describe five locations: enclosed space (ES), inside a bus (IB), adjacent to a bus (AB), and semi-open spaces (SOpS). The IB can also clearly be applied to subway or subway systems. They consider this classification to have better sensitivity with respect to injury severity compared to traditional descriptions of open versus enclosed spaces.

b. *Blast injury* of immersion (water).

In a liquid, incompressible medium, the underwater *blast* is due to the displacement of a mass of water by the positive hyperpressure phase of the SW, whose velocity is approximately 1,500 m/s, and another of its reflection/diffraction which is formed when it reaches the water surface. The effects of an underwater blast (torpedo, depth charge, sea mine) on a submerged organism are due exclusively to the SW. The underwater *blast* is a pure primary *blast*, there is no wind wave, only hyperpressurized SW. However, it has not yet been possible to identify a pressure-time curve; similar to Friedlander's that accurately describes a form of generalized underwater SW (Figure 5). On the other hand, the water surface also reflects another wave, called the rarefaction wave, which, as water returns, decreases the pressure of the primary SW.[35] The effect of the reflection of the SW on the seafloor on the submerged body is rare, except in shallow water or in closed aquatic environments. The velocity of SW in water is slower; but its radius of action is three times wider than in air (critical distance ≈ 24 m) and the time of positive pressure is also longer, with slower damping.[26] Underwater explosions propagate more, are about three times more powerful than airborne explosions and injure more severely.[36] In underwater explosions, the fusion of the reflected wave from the water surface with the incident wave causes the overpressure to be maximum at a depth of about 60 cm; therefore the effect (barotrauma) predominates on the submerged parts, not on the floating objects (which would be propelled). This explains the frequency and severity of injuries in gas (air) cavities such as abdomen (intestine) and lung (lower fields) in partially submerged and upright victims.[22] Therefore, a high index of suspicion should be maintained for late intestinal/late thoracic injuries in underwater explosions. Surfaced parts of the body (e.g., the head) are relatively unscathed, because the SW does not cross the water/air interface at all, hence the suggestion to swim on the back and maximize body buoyancy.

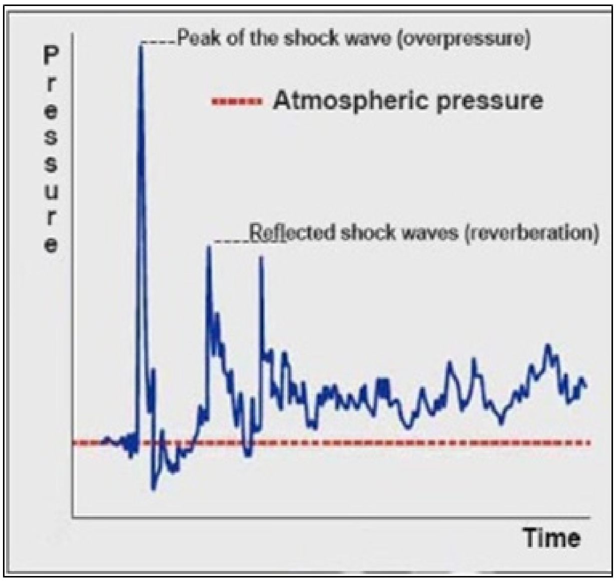

Figure 4 Time-pressure relationship of the shock wave in a closed environment: the shock wave appears as a succession of reverberant positive waves. Modified, Source: Martinez T, Boye M, Py N, Swiech A, Boutonnet M, Pasquier P. Blast and explosion injuries. EMC Anest Reanim. 2020;46(3):1.

Therefore, although the key underwater blast injuries are abdominal and pulmonary; in addition to rapidly restoring body temperature and not providing oral food or water prior to diagnosis; close attention should be paid to changes in blood glucose, as to some extent they predict the development of a lung injury.[36]

c. *Blast* of solids

The *blast* of solid materials arises when the SW propagates through solid structures, including the surface of the earth's soil (*blast ground*). In this high-density medium, the shock wave propagates very rapidly (≈ 5,000 m/s), and sometimes does not cause shell disruption. The part of the body in contact with the structure, through which the wave diffuses, presents serious injuries, especially bone fractures (of the calcaneus if the person is standing, and of the spine if seated, due to transmission through the seat), vascular-nerve fractures and even damage to internal organs remote from the point of contact.[26]

This type of *blast* is usually seen in warships (*deck-slap injury*), and after the explosion of an anti-personnel mine (closed/open foot mine) or anti-vehicle (chain or wheel) and by IED in civilian vehicles (bus, train). Like underwater blast, in *underground blast* the SW front travels faster and much farther, as in a denser medium, the speed of sound is higher. Therefore, the injuries caused, at the same distance as the aerial *blast*, are more severe and enhanced by the synergistic effect of the reverberation of the SW.

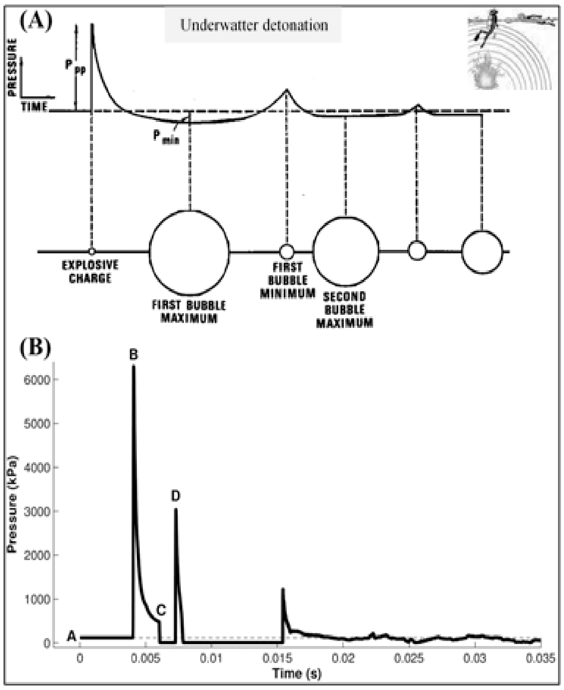

Figure 5 Example pressure-time curves for underwater blasts. (A) Idealized curve. (B) Example curve for an underwater blast with surface and bottom reflections. A: ambient pressure. B: peak positive overpressure. C: onset of pressure reduction from surface rarefaction wave. D: secondary peak from bottom reflection. Source, modified from: Lance RM, Capehart B, Kadro O, et al. Human Injury Criteria for Underwater Blasts. PLoS One. 2015;10(11):e0143485.

General aspects of the shock wave

Explosion is a complex process involving various physical and chemical phenomena. The destructive capacity of an explosion depends mainly on the physicochemical properties of the explosive substance, which determine, among other parameters, the evolution of the blast wave. The chemical explosion of an explosive device is usually accompanied by other relevant physical phenomena such as: the emission of heat in the form of a flame or fire, the rumbling sound and the generation of heated toxic gases, as well as the origin of a seismic wave that propagates in the earth and the flashy luminous glow.

In mass casualty incidents involving a blast wave, 3 zones are identified[26] a) epicenter of the blast (kill zone), most people are dead or fatally injured, b) secondary perimeter (critical casualty zone), there are more survivors, but most of them probably have multiple injuries (Figure 6), and c) periphery of the blast (injured walker zone), most victims have non-life threatening injuries and others have psychological trauma (anxiety, panic, etc.). This zonal distribution corresponds to the pattern of occurrence of blast wave injury types: a) primary injury zone (barotrauma damage), b) secondary injury zone (shrapnel injuries), and c) tertiary injury zone (acceleration-deceleration injuries).

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Figure 6 Wounded by blast wave in the Afghanistan War in the Spanish Military Hospital (photograph by the author -RNS-).

Keypoints

An explosion is due to the ultrafast transformation of an explosive compound (solid or liquid) into gases, which reach very high temperatures. The expansion of this gas causes a sudden increase in pressure which propagates centrifugally, generating a shock wave.

a) High-order explosive agents are detonators, while low-order explosives are deflagration agents. The difference lies in the presence or not of a hyperpressurizing shock wave, respectively.

b) The components of a detonation are: shock wave, wind wave and thermal effect, without forgetting the seismic, sound and glare.

c) Both physical and psychological blast wave injuries are multimodal and are taxonomically classified according to the predominant etiological factor.

d) The blast wave causes a large-scale casualty incident that overwhelms the healthcare assistance (*overcrowding*) of any hospital, whether military or civilian.

e) Understanding the biophysics and pathophysiology of blast injury is critical to optimizing casualty outcomes after an explosion.

Conflict of interest

I. Ingelmo states that there is no conflict of interest.

R. Navarro Suay states that there is no conflict of interest.

Ethical clearance statement

This narrative review paper does not contain any studies with human or animal participants conducted by any of the authors.

Statement of informed consent

Informed consent for the use of photographs taken by the author R.N.S.

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