Health Consequences and Management of Explosive Events

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ABSTRACT

Background: Explosive events refer to events, either natural or man-made, that occur advertently or accidentally. This article aimed to study epidemiology of explosive events and investigate the health consequences of such events. It also aimed to discuss the prevention and management of these events from a healthcare provision viewpoint.

Materials and Methods: This descriptive study comprised 2 sections. First, following an extensive review of the literature, a database, containing the related articles was developed. Then, the core research group drafted the first adapted version of the results. Using a Delphi panel methodology, the results were finalized based on the consensus of 11 experts.

Results: Terrorist explosion is the most common type and of ever-growing explosions worldwide. It accounts for the largest proportion of casualties caused by man-made events. Health consequences of explosions can be classified into physical, mental, and social ones, which can appear immediately or a long time after the event and affect individuals, families, and societies.

Conclusion: Because of the wide range and adverse impacts of explosions, healthcare authorities and staff should have a good grasp of preventive principles, as well as protection and management of explosion sites. Besides they have to be familiar with treating the injured. It is recommended that training courses and simulated explosive events be designed and run by the healthcare sector.

1. Introduction

Explosive events refer to events, which can be natural or man-made, occurring intentionally or accidentally [1, 2]. Although most of these events can bring about financial losses, they are also associated with a high fatality rate [2, 3]. As explosive events nowadays are mainly used for terrorist ends, they are now considered the main cause of fatality and injury among man-made explosive events [1]. Unfortunately, the terroristic use of explosives is rising, becoming a serious threat against public security and a growing alarm for the world community [4]. Apart from their danger, the main aim of terrorist attacks is to create an insecure atmosphere of terror and coercion in society [1, 2]. Accordingly, healthcare staffs, especially in prehospital or hospital sections, must be familiar with the consequences of explosive events and how to prevent and manage them [1, 2, 5, 6]. This article aims to survey the epidemiology of explosive events,

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the health consequences of such events, and appropriate preventive methods and management strategies from a healthcare perspective.

2. Materials and Methods

This study comprised 2 stages. To start, the authors searched the PubMed, Web of Science, and Scopus databases for the keywords "explosion" plus "health". All articles related to health issues were collected in the Endnote software program (Version X3). By scanning the abstracts, researchers chose the relevant articles and excluded the irrelevant ones (connected to industry, chemistry, and war).

In addition to the international databases, the Iranian internet databases, including SID, IranMedex, and IranDoc were also searched for keyword "explosion". Related books and websites were also browsed through and consulted. Based on the purpose of the study, the resulting data source was classified into 3 general categories, namely "health consequences", "prevention", and "management of explosive events". At the second stage, the edited data source was presented to 11 experts in the field of health and disasters. Their feedbacks were applied to the final data source.

3. Results

Explosion and its mechanisms

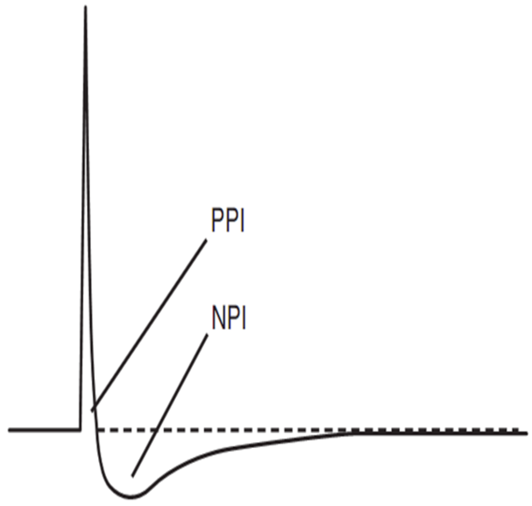
Different definitions have been proposed for the "explosion". According to the National Fire Protection Association of America (NFPA), the term "explosion" refers to the sudden dispersion and release of a high-pressure gas in the surrounding area followed by a shock wave [7]. It is also defined as the abrupt transformation of physical or chemical energy to the energy of motion accompanied by a shock wave [8]. Despite different descriptions, there are 3 common features, namely, 1) an explosion occurs in a brief time span (in a fraction of a second), 2) it is followed by a high pressure, and 3) it affects its surrounding environment [2, 8-10].

Explosions can be classified from different aspects. Some divide explosions into natural and man-made. Volcanic eruptions are natural explosions, whereas explosive bombs are examples of man-made explosions [1, 2]. They are also classified according to being accidental or intentional. Terrorist bombings are considered as the major example of intentional explosions [4]. With regard to the cause of explosions, such events can be divided into chemical and physical. The former refers to explosions in which one chemical reaction occurs, like the explosion of dynamite, while the latter occurs as a result of the sudden release of a material under pressure, like the burst of a steam boiler [6, 8, 11].

Knowledge of explosion mechanism can help in the diagnosis of injury and predicting possible damages, as in some cases no signs of injury are seen in the early aftermath of the explosion. In an explosion, whether physical or chemical, highly condensed molecules of a substance disperse in a fraction of a second and at an extremely high speed (5000 m/s), transforming into gas. The ensuing wave creates a layer of condensed molecules, which may be water or air, depending on the explosion environment. The passage of this condensed layer through any point in space creates a wave known as the positive-phase impulse.

Since the existence of condensed molecules at a specific point move the adjacent molecules away, after the passage of positive-phase impulse through an object, another wave known as the negative-phase impulse will pass through. Obviously, the passage of the positive-phase impulse condenses the object while the passage of the negative-phase impulse leaves somewhat of a vacuum in the object. These waves are called shock waves.

In addition to shock waves, the pressure difference between positive and negative impulses creates another separate movement in the surrounding molecules known as blast wind [2, 6, 9, 12]. Figure 1 illustrates how posi-



PPI=Positive Phase Impulse; NPI=Negative Phase Impulse

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Figure 1. The pressure generated by explosions on a fixed point in the area. The x-axis depicts the time and the y-axis the amount of pressure on a fixed point [2].

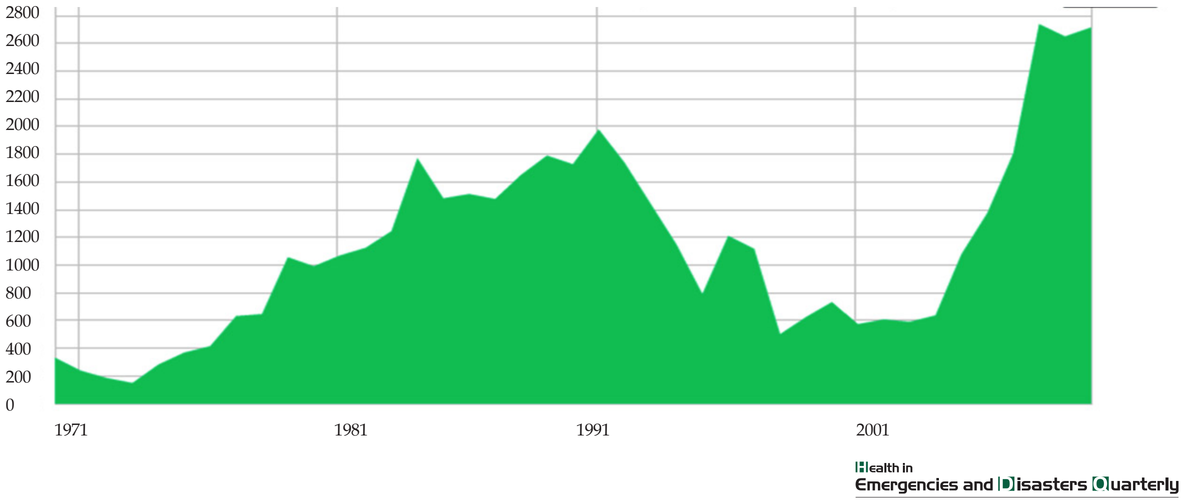

Figure 2. Terrorist explosions in the world from 1970 to 2007 (Incidents per year grouped by type of attack) [4].

tive and negative impulses pass through a fixed point in space.

Global and regional epidemiology of explosions

Although the proportion of injuries caused by explosions has not been considered separately in the world, it is estimated that the injuries caused by fires (including those caused by explosions) is about 1% of the total injuries [13]. The majority of explosions in the world are man-made, but natural explosions also create many health consequences, the most notable of which dates back to 1980, when St. Helen volcanic blast led to the death or missing of 57 U.S. citizens [2]. Regarding man-made accidental explosions, the explosion of Halifax Harbor in Canada in 1917 claimed more than 2000 lives and injured 9000 people [14].

According to the Global Terrorism Database (GTD), terrorist attacks, including explosive attacks and bombings, are on the rise throughout the world, such that between 1970 and 2007 the total number of explosive attacks reached 44777 incidents, while this number was only 334 in 1971 which increased to 1805 in 2007. Figure 2 shows the trend of explosive attacks and bombings in the world [4, 15]. Although due to various reasons, such as security confidentiality, there is little available information on the explosions toll, a study conducted between 1991 and 1995 in Finland indicates that 29% of explosions are caused by firework, 25% by explosives, and 13% by bursts of under-pressure containers [2]. As for the degree of injuries caused by explosions, studies show that 30% of casualties by terrorist explosions left severe injuries, more than 50% required surgery, and 25% were hospitalized in ICUs [16].

According to GTD, the highest number of terrorist explosions (n=18638) were recorded in the Middle East and North Africa whereas the lowest number were in Central Asia (n=219). In particular, Iraq had the highest incidence (n=6.575) and Yemen the lowest (n=2) [2].

Iran has not had any incident of natural explosion; however, its history is full of man-made explosions, whether accidental or intentional. The explosion in an ammunition dump in Bidganeh Fort in Alborz Province is a case of accidental man-made explosion, in which 17 soldiers were killed and 16 injured [17]. Moving to terrorist explosion, especially after the Islamic Revolution of 1979, Iran had its share of terrorist attacks. In the Middle East and North Africa region, between 1970 and 2007, Iran had the seventh standing with 619 incidents of terrorist attacks. As indicated in Figure 3, the highest number of terrorist attacks (n=108) happened in 1981, and the lowest (n=5) in 2001. The last incidence of terrorist attacks in the GTD comprised 10 explosions in 2007 [4]. In April 2008, in the wake of a terrorist explosion in Seyed al-Shohada Mosque in Shiraz, 12 people were killed and 202 injured [18].

Health consequences of explosions

Health consequences of explosions can be generally divided into physical, mental, and social consequences. Each of the consequences will be discussed briefly below.

Physical injuries

Physical or bodily consequences refer to injuries to the body of the persons present at the explosion site, probably leading to their death. The severity of injuries ranges from a minor injury to the complete disintegration of the body. The signs of injuries may appear shortly after the event or over the following days. The amount of injury is directly associated with the blast load. Blast load indi-

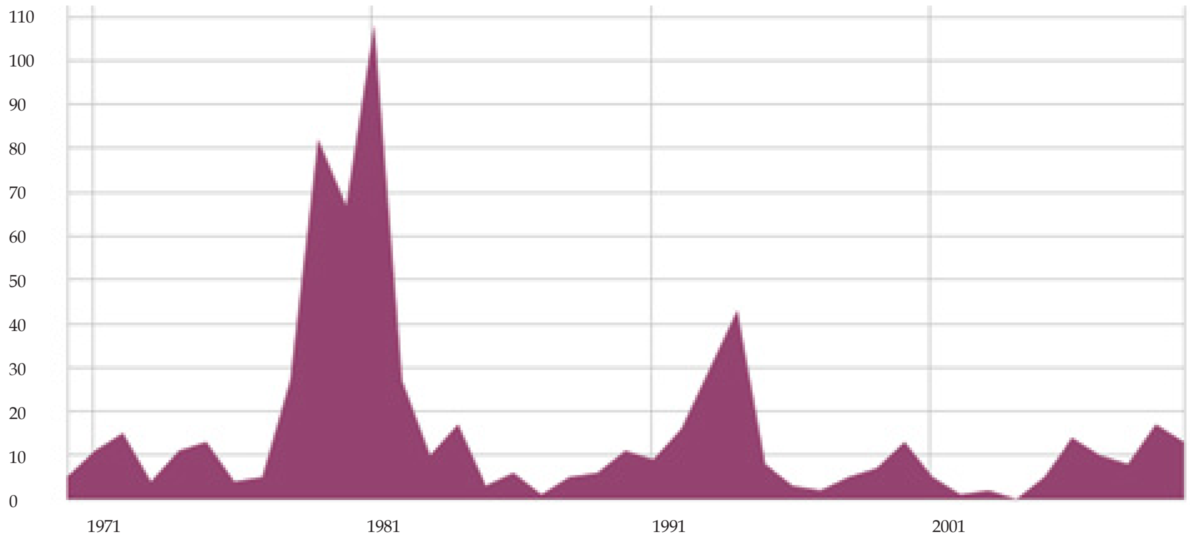

Figure 3. Terrorist explosions in Iran from 1970 to 2007 [4].

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cates the degree of the explosion power for causing physical damages. This amount is determined by 3 factors: size of the explosion (the amount and power of explosives), the environment of explosion (water or air), and the distance of the victim from the center of explosion.

Figure 4 shows that the type of injury may change depending on the distance from the center of explosion, such that in very short distances all types of injures might be expected, while over longer distances the possibility of injuries caused by the blast wave and propelled sharp objects are respectively higher [3, 9, 18-21]. Explosion victims may receive different kinds of physical injuries. For a correct diagnosis as well as providing proper medical services, they are divided into 5 categories.

Primary blast injuries

Primary blast injuries are caused by the passage of the blast wave through the body with its ensuing pressure on different organs. It comprises 3 main phases as mentioned already. At first, the positive-phase impulse and then the negative-phase impulse move passes through the body. The passage of these waves causes a shock wave and explosion blast, which may harm various parts and organs. Accordingly, primary blast injures caused by explosions are classified under the category of barotrauma. Although a blast wave can affect all organs of human body, the hollow organs, such as the hearing system, respiratory system, gastrointestinal tract, and brain, are more susceptible. The most prevalent injury to the hearing system is an eardrum burst, which usually heals without treatment within a few weeks. Other injuries include the dislocation

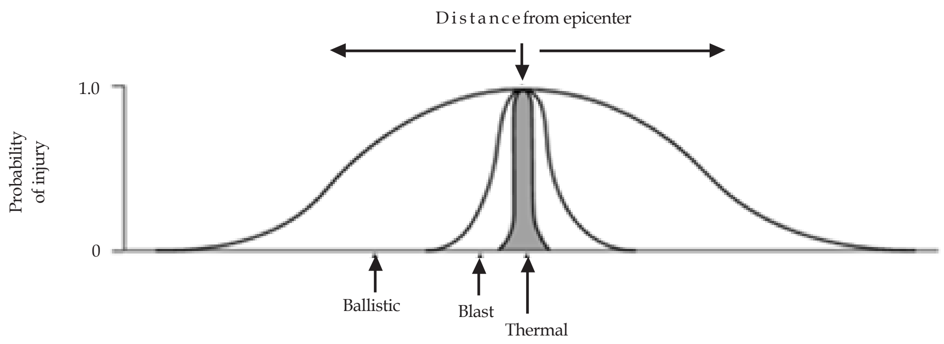

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Figure 4. The relationship between the type of injury and the distance from the center of explosion.

Table 1. Psychological disorders caused by explosions.

Psychological effects	Behavioral-Emotional effects	Cognitive effects
Tiredness	Anxiety and fear	Paramnesia
Nausea and vomiting	Sense of guilt and sadness	Impaired mental calculation
Nervous shocks	Irritability and anger	Dizziness and confusion
Mild paresthesia	Conflict with environment and family	Impaired concentration
Chest pain	Sense of futility and despair	Crisis of belief in God
Shivers	Isolation	Recurring nightmares
Chronic pain in joints and limbs	Self-harming and abusing others	Impaired decision-making
Sweating profusely	Changes in sleep	Reduced ability to solve complex problems
Dizziness and confusion	Impaired balance and gait	Fear and alienation from society
Digestive disorders (diarrhea, constipation, and stomach cramps)	Over vigilance	Fear of being alone
Headaches	Mood swings	
Heartthrob	Crying	
	Dysfunctions	

of ossicles in the middle ear and the inner ear damage, which may cause temporary or permanent hearing loss.

Next, the upper and lower respiratory tract systems can receive various injuries, the major ones are rupture of the lungs or pleural membrane, which may lead to hemothorax or pneumothorax. Also, the passage of the blast wave through the gastrointestinal tract may rupture intestines and make blood and air enter the abdomen, causing pneumoperitoneum or hemoperitoneum [2, 9, 20, 22, 23]. Primary blast injuries caused by explosions may not appear immediately. In most acute cases, however, it may lead to death within 2 hours. On the other hand, those remaining alive after 2 hours have a better chance of recovery [21].

Secondary blast injuries

This type of injury is caused by fragments or splinters due to explosion that strike the body. These propelled objects move so fast that are capable of penetrating the body and cause injury. Thus, this type of injury is classified as penetrating trauma, and treated like other cases of penetrating trauma. As exploded fragments propell over a wider space and, more victims get susceptible to receive injuries, secondary blast injuries are more prevalent than the primary blast injuries [2, 3, 9, 18, 22].

Tertiary blast injuries

The power of explosions in some events is strong enough to send the persons around flying and hit them against doors and walls. As the type of these injuries is different from penetrating trauma, they are classified as blunt trauma. Orthopedic injuries to the head and spinal cord are the main ones in this category [2, 9, 18, 24].

Quaternary blast injuries

This type of injury is not caused directly by the passage of the blast wave, but is somehow connected to the explosion. In other words, the extreme heat, ignited fire, toxic gas, or radiations (in case of nuclear bombs) can cause suffocation, poisoning, or burns and put the health of the surrounding persons at risk [2, 24].

Collateral blast injuries

These injuries defer depending on the type of environment in which the explosion occurs. Collapse of buildings or car accidents due to explosions are examples of collateral blast injuries [2, 3].

Psychological consequences of explosions

Explosive events may result in a wide range of mental, behavioral, emotional, and cognitive disorders. Examples of these problems include anxiety disorders (especially after a trauma), affective disorders (e.g. depression), cognitive impairment (e.g. amnesia), and sleep disorders [25, 27]. Table 1 briefly illustrates such disorders [28]. Although mental disorder can be acute, we should bear in mind that they may appear over a long time, even 2 to 3 years after the explosion. Thus, diagnosis and treatment of the persons exposed to an explosion demand an overall and long-term supervision [29-31]. Women, people with a history of depression, and close relatives of the victims are more at risk of psychological impairments and should be kept under medical supervision for several years [32-34].

Social consequences of explosions

In addition to physical and psychological consequences, explosive events can also negatively affect the social health of victims. In this regard, 2 points should be considered. Firstly, contrary to physical injuries, social damages do not appear quickly, but may several years after the explosion. Secondly, such damages are incurred to those who are exposed for a long time to explosions, like soldiers serving at war. Drug addiction, suicide, work or social dysfunctions, disorders in family relationships, heavy drinking, anti-social behaviors, violence, inappropriate change in life style, and disorders in adaptation mechanisms are some of the social consequences of explosions [26, 30, 35, 36]. It is noteworthy that psychological and social consequences of explosions are not only limited to those present at the explosion site, but also their families and relatives [2].

4. Discussion

Prevention of explosion

To prevent explosive events, especially accidental ones occurring mainly in industrial locations, observing safety precautions is essential prior to any other action. In general, preventive measures can be divided into 2 main categories. Known as primary preventive actions against explosions, the first category refers to activities which basically avert the possibility of explosion. For instance, replacing flammable materials with non-flammable ones or omission of oxygen from the work place (while working with inert gases) are in the group. Naturally, we cannot take such preventive measures in all places. In these cases, potential hazards should be anticipated. Using standard materials in the tools and equipment at risk of being ignited, moving flammable materials away from dangerous places, and designing proper ventilation systems for reducing and controlling flammable materials are some recommended preventive measures. In cases at risk of explosion, using preventive protocols against explosion is necessary [5, 37].

Protection against explosion

Escalations of wars, use of explosive weapons, and terrorist attacks have exposed many people to explosions. Troops, bomb squads, and mine removers are in danger of explosion too. Being equipped with proper and standard personal protections is deemed as a basic and vital principle. The efficacy of using personal protective equipment in prevention or reduction of secondary, tertiary, and quaternary injuries have been proved in previous studies, but recent studies indicate that proper protective equipment can also be effective in preventing and reducing primary injuries caused by explosion. However, ensuring security and safety of the people on the one hand, and their efficacy in practice on the other hand, are still some of the challenges in this regard [8, 19, 38-41].

Management of the explosion sites

The aim of the explosion sites management is to identify casualties needing urgent medical services as quickly as possible to resuscitate and transport them to the nearest hospital. However, the risk of more explosions, fire, smoke, emission of poisonous gas, collapse of the buildings, and debris scattered over the site can hinder the rescue process [2]. As with other events, general rules of disaster management must be observed in explosive events, and mentioning some is in order:

In terrorist attacks, the initial explosion may be followed by further explosions, as in the wake of the first explosion people would often gather at the explosion site for help, paving the way for a rise in the death toll and casualties in a secondary explosion. Thus, it is essential to ascertain the safety of the area before taking any other measures. Furthermore, the management of security and safety of the area is a cycle, beginning with collecting and analyzing the information, taking the optimal decision, and action. The process is repeated [2, 3].

The first task of the rescue team dispatched to the explosion site is not giving medical services, but evaluating the situation and getting in contact with senior management officers. Although casualties may be seemingly in urgent need of medical services, a rough and quick evaluation and consultation with senior managers can lead to the provision of effective medical treatment to more casualties. In the primary assessment, the type of explosion, an estimation of casualties, the location, the safest way for rescuing the injured, and an estimation of the time needed to transport casualties to the nearest hospital should be taken into consideration.

The nature of injuries caused by explosions is such that some victims may not show any signs of injury immediately afterwards. Negligence in this regard may keep the victims away from rescuers' attention. Also the personnel at the disaster site must beware the overtriage in explosive events [43]. When a medical center is dealing with a great number of casualties, a secondary triage can considerably increase the efficiency [22, 43].

Dirty bombs are bombs detonated to disperse detrimental substances such as chemical, nuclear, and biological compounds. In the event of dirty explosion, the rescue team, aside from familiarity with the signs, must join forces with other expert teams in charge of public health, security, and hazardous materials, as well as the media [42-44].

High-tech devices, in preliminary stages of development, can be utilized in identifying the explosion type, establishing security, locating casualties, and estimating the degree of injuries. One instance of such devices is human injury predictor (HIP), designed to assist security services in estimating crowd distribution in different scenarios. HIP can also help rescue services locate individuals with particular injuries and assist emergency teams in estimating the number of casualties and their injuries [47].

4. Conclusion

Explosive events can be natural or man-made, accidental or intentional, and caused by various reasons. In addition to financial damages, explosive events can result in deaths, injuries, and disabilities. Nowadays, terroristic use of explosives has turned such events to the main cause of death and injury among man-made explosive events [1]. As it was discussed, the wide-range consequences of explosions on individual and social health deems it crucial that the health system personnel, besides being familiar with how to treat casualties, be cognizant of the preventive principles, protection, and management of explosion sites. In this regard, it is recommended that training courses and specific maneuvers be designed and held by healthcare sectors. As for Iran, we recommend that future studies be conducted on accidental and intentional explosions. In addition, training and educating the public on explosive events can reduce damages incurred by possible events.

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