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REVIEW ARTICLE

Risk factors associated with mortality from explosions in civilian and military populations

Factores de riesgo asociados a mortalidad por explosiones en poblaciones civil y militar

Patrizio Petrone[1,2], Jordi Marin-García[1], Javier Dagnesses-Fonseca[1], John McNelis[3], and Corrado P. Marini[3]*

[1]Department of Surgery, NYU Grossman Long Island School of Medicine, Mineola; [2]Research Committee, Panamerican Trauma Society; Department of Surgery, [3]Department of Surgery, Albert Einstein College of Medicine, Jacobi Medical Center. Bronx, New York, USA

Abstract

Trauma from explosions is among the most serious injuries faced by healthcare professionals. There are few studies that describe the risk factors for mortality, or the patterns of blast injuries in the civilian compared to the military population. Review of articles extracted from Medline, PubMed, and Scopus published (01/2014-03/2024). Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines were followed. Data on mortality and injury patterns were extracted from the articles that met the inclusion criteria to describe the type of injuries and to identify risk factors for mortality. Sixteen articles were included. Average age of civilians was 40.0 years ± 3.7, with men representing 79.4% compared to a mean age of 24.5 ± 1.4 and 79.0% for the military patients. While there was no difference in the distribution of injuries by body regions, the civilian population was more likely to sustain severe cranial and thoracic injuries (31.9% and 20.4% vs. 18.1% and 9.9%, respectively). Civilian population had a non-statistically significant lower risk of death (odds ratio = 0.96; 95% confidence interval = 0.82, 1.13). The findings of this review indicate that clinical experience derived from explosions occurring in one setting may not be fully generalizable to explosions occurring in other contexts, as demographic, environmental, and contextual factors contribute to distinct injury patterns.

Keywords: *Explosions. Injury patterns. Injury severity. Blast injuries. Mass-casualty incidents. Mortality. Risk factors.*

Resumen

Los traumatismos por explosiones se encuentran entre las lesiones más graves a las que se enfrentan los profesionales sanitarios. Existen pocos estudios que comparen los factores de riesgo de mortalidad o los patrones de lesiones por explosión en la población civil en comparación con la población militar. Se realizó una revisión sistemática de artículos publicados en Medline, PubMed y Scopus, de enero de 2014 a marzo de 2024, siguiendo las directrices PRISMA. Se extrajeron datos sobre mortalidad y tipos de lesiones de los estudios que cumplieron los criterios de inclusión. Se incluyeron 16 artículos. La edad media de los civiles fue de 40.0 ± 3.7 años, con un 79.4% de varones, frente a 24.5 ± 1.4 años y un 79.0% de varones en los militares. No hubo diferencias en la distribución de las lesiones por regiones corporales, pero la población civil presentó una mayor probabilidad de sufrir lesiones craneales y torácicas graves (31.9% y 20.4% frente a 18.1% y 9.9%, respectivamente). La población civil tuvo un riesgo de muerte menor, aunque no estadísticamente significativo (OR: 0.96; IC 95%: 0.82-1.13). Esta revisión sugiere que la experiencia clínica derivada de las explosiones en un entorno específico podría no ser completamente extrapolable a otros contextos, debido a diferencias demográficas, ambientales y operativas que influyen en los patrones de lesión.

Palabras clave: *Explosiones. Patrones de lesiones. Gravedad de las lesiones. Lesiones por explosión. Incidentes con múltiples víctimas. Mortalidad. Factores de riesgo.*

***Correspondence:**
Patrizio Petrone
E-mail: patrizio.petrone@gmail.com

Date of reception: 21-11-2025
Date of acceptance: 14-02-2026
DOI: 10.24875/CIRU.25000541

Cir Cir. 2026;94(3):341-349
Contents available at PubMed
www.cirugiaycirujanos.com

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Introduction

Traumatic injuries remain one of the leading causes of morbidity and mortality in the world population.[1] Although trauma and acute care surgeons have experience with more common injury mechanisms, such as motor vehicle accidents and interpersonal violence, they are not as familiar with less frequent, but more lethal, blast-related injuries.[2,3] Blast or explosion-related injuries encompass a wide spectrum of trauma resulting from explosive events and are typically classified by their setting in military (war-related) defined as those occurring in the context of organized armed conflict involving military forces, and civilian (non-war-related) contexts, as those occurring outside active combat zones, including terrorism, industrial accidents, and unintentional explosions; by injury mechanism (primary to quinary); and by the nature of the explosion as accidental blast – such as gas line ruptures, boiler failures, or chemical plant accidents – usually occur in industrial or residential settings and often involve thermal burns, blunt force trauma, and inhalation injuries from structural collapse or fire. In contrast, intentional explosions – such as those from improvised explosive devices (IEDs), car bombs, or suicide attacks – are engineered for maximum lethality, combining multiple mechanisms including blast overpressure, penetrating trauma from shrapnel, and complex polytrauma. Distinguishing between these events is essential not only due to their intent but also due to differing injury patterns: accidental explosions tend to injure bystanders, whereas intentional blasts are often premeditated to affect densely populated or enclosed areas, amplifying casualty severity. Recognizing these distinctions is critical for anticipating injury profiles and guiding effective emergency response and trauma care.

Explosions result in multisystem injuries through a range of mechanisms, including both direct and indirect blast effects. These effects generate shearing and tearing forces that can lead to tissue penetration, organ perforation or rupture, and thermal burns.[4] In addition, blast waves may produce internal injuries that are often occult, difficult to detect due to their non-visible nature and the unique injury mechanisms involved.[5,6] Explosive involve also has the potential to cause mass casualty incidents (MCI) given their non-discriminatory and spreading impact across wide areas.[4] Victims located near the epicenter typically sustain immediate fatal or severe injuries, while those further from the blast radius are more likely to suffer minor to moderate trauma (Fig. 1).[7] As a general rule, for every fatality, at least two individuals sustain injuries.[8]

The global incidence of deaths due to armed conflict and terrorism has been rising, with an estimated 129,700 fatalities reported in 2017 alone.[9] As blast injuries increasingly occur in civilian settings,[10,11] there is a growing need for emergency personnel to be proficient in the assessment, management, and triage of blast-related trauma and potential MCIs.[12-17] Nonetheless, accidental explosions remain a more frequent source of blast injuries among civilians. A notable example is the 2020 Beirut harbor explosion, in which the detonation of stored ammonium nitrate – located adjacent to a fireworks warehouse – resulted in over 200 deaths and tens of thousands of injuries.[18]

The distribution of injuries to the different body regions varies and is often directly related to the mechanism of the explosion and the location of the explosive material.[19] The placement of IEDs at ground level as opposed to a higher level leads to a different distribution of body regions injuries. For example, in the 2013 Boston Marathon bombing, two IEDs were placed at ground level causing predominantly lower extremity injuries.[16] Lung injuries and tympanic membrane perforations were the most common following the 2004 Madrid train bombings from over-pressurization in confined space.[20] In contrast, the Beirut port shock wave occurred in an open-air space, but quickly spread to the densely populated capital, where it was amplified by reflecting off surfaces. The pressure of the blast wave caused extensive damage to buildings and glass windows, resulting in blunt head injuries from falling debris and masonry, and penetrating wounds to the face and extremities.[19]

To date, relatively few studies have systematically investigated the risk factors associated with adult mortality following blast trauma, particularly with respect to differences in injury patterns between civilian and military populations. These distinctions may be critical in anticipating injury severity and guiding appropriate medical response. Within this context, the present study aims to examine and compare the injury profiles and associated mortality risk factors from both accidental and intentional explosions across civilian and military settings.

Methods

Data sources and search strategy

A literature search was performed using Medline, PubMed, Scopus, and through searching citations of

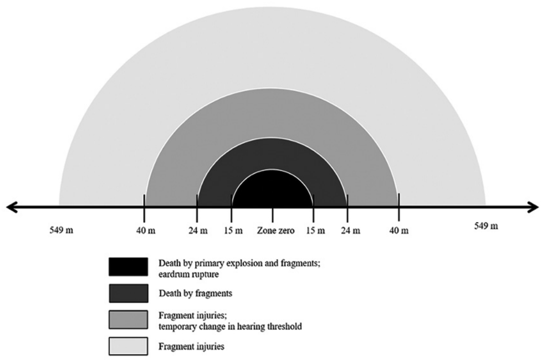

Figure 1. *Type of injuries according to distance from the explosion.*

other original articles. MeSH terms utilized were explosions, blast, blast waves, blast injuries, injury patterns, and mass-casualty incidents. Articles published in English and Spanish were selected from 1/1/2014-3/31/2024 (Fig. 2). The authors attempted to register this systematic literature review in PROSPERO, as it does not currently accept registrations for scoping reviews, literature reviews, or mapping reviews.

Study selection criteria

Only original and human subject research articles were included, encompassing both prospective and retrospective descriptive studies. Eligible studies were required to report injury profiles, defined as the distribution of injuries sustained from explosions stratified by injury severity score (ISS) and abbreviated injury score (AIS) body region. Exclusion criteria included studies involving non-human subjects, clinical case reports, literature reviews, pediatric populations, and publications in languages other than English or Spanish.

Data extraction

The first author (P. Petrone) supervised the entire process, from article selection to data extraction methodology. Data extraction was conducted in two phases: One international research fellow (Jordi Marin-García) independently extracted the first set of data, which was then verified by PP. In turn, PP extracted the second set of data, which was subsequently verified by JMG. For the articles published in Spanish, three of the first three authors are native Spanish speaker, ensuring accurate interpretation. Data were extracted using a standardized table that included the following variables: Author, year of publication, study type, number of patients, age, gender, injury types, and injury severity (as measured by ISS and AIS). To ensure consistency and accuracy, any disagreement between the authors was resolved through a structured consensus process. Initial differences were identified during independent data review and addressed through open discussion. When informal consensus could not be achieved, a third senior investigator was consulted to provide an impartial opinion. This stepwise approach ensured methodological rigor, minimized bias, and maintained alignment with the study's predefined criteria and objectives.

This review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses and Assessing the methodological quality of systematic reviews guidelines to ensure methodological rigor and transparency. A comprehensive literature search was performed to answer the following PICO-formulated research question (Population, Intervention, Comparison, and Outcome):

- Population: Victims of explosion-related injuries (civilian and military).
- Intervention/exposure: Blast exposure in different operational contexts (war-related vs. non-war-related).
- Comparison: Injury pattern differences between groups.
- Outcome: Distribution and severity of injury by anatomical region.

An assessment of risk of bias was performed per individual study, using the Newcastle - Ottawa Quality Assessment Scale for both case control studies and cohort studies as valid evaluation tool.

Given the heterogeneity in study designs, populations, and outcome measures, data from the included studies were synthesized using a narrative synthesis approach. The involved systematic categorization of key themes, patterns, and findings across studies, with specific attention to contextual variables, such as setting, intent of explosion, and injury mechanisms, enabled a comprehensive synthesis of the available evidence and facilitated the identification of recurring trends, knowledge gaps, and clinically relevant associations

To assess the certainty of the overall body of evidence, each outcome was evaluated using established domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. Certainty ratings were assigned as high, moderate, low, or very low, and any decision to downgrade the certainty was explicitly documented and justified to ensure transparency.

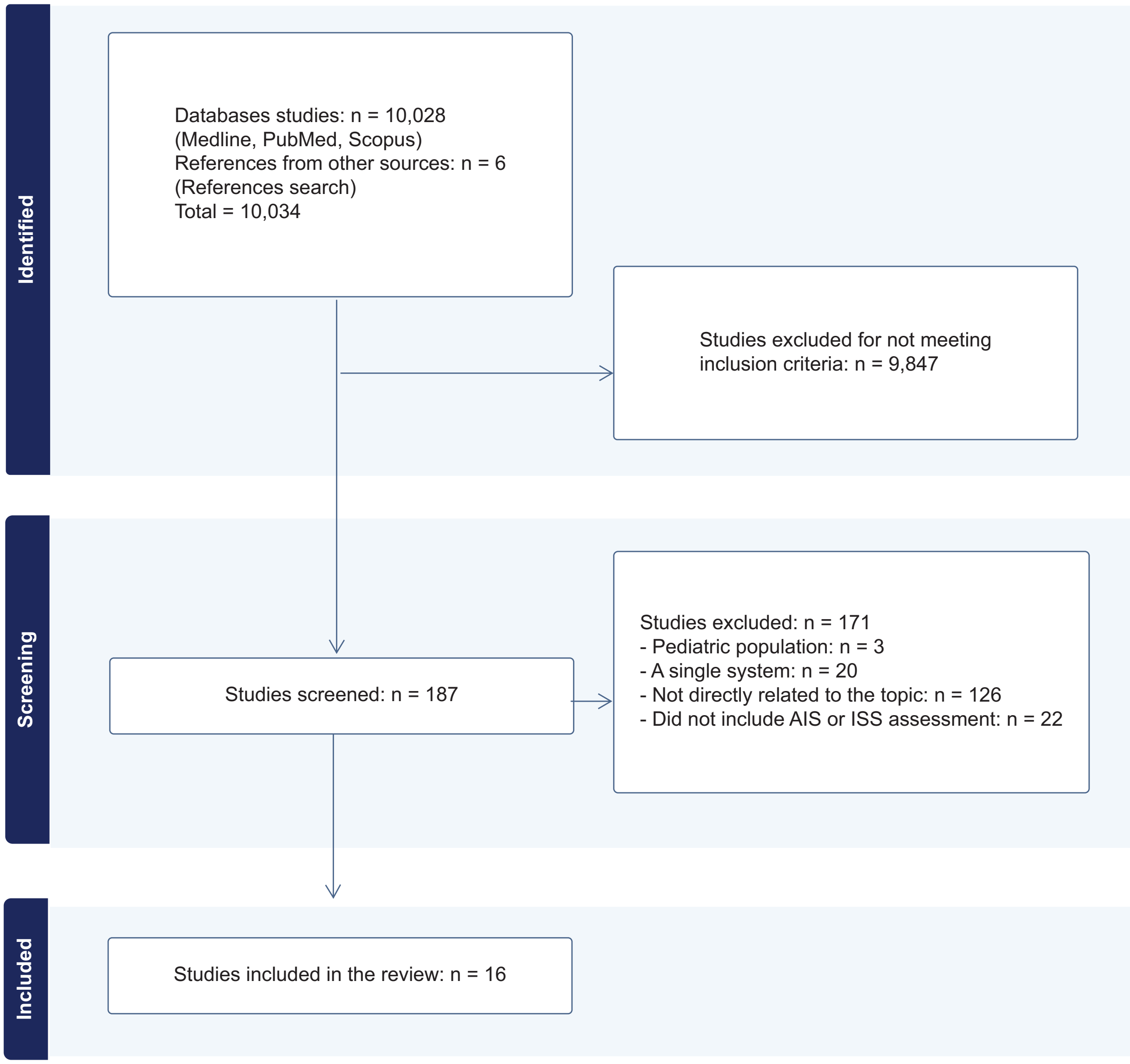

Figure 2. *Preferred reporting items for systematic reviews and meta-analyses flowchart.*

The AIS is an anatomically based injury severity scoring system that rates injury by body region on a six-point scale that provides data to calculate the ISS.[21,22] There are six regions of the body according to the ISS classification to which injuries can be assigned, although the AIS dictionary 2005 – Update 2008 is divided into nine anatomical chapters.[22,23]: head or neck injuries, facial injuries, thoracic injuries, abdominal injuries, pelvic, extremity, or pelvic girdle injuries, external injuries, and other traumatic injuries.

Statistical analysis

The data set was assessed for normality using the Shapiro-Wilk test, and continuous data were analyzed using Welch's t-test.[24,25] The Welch's t-test was selected instead of the Student's t-test because it provides better control for type I errors when homoscedasticity (the assumption that the variance of the data is homogeneous) is violated, while performing the Student's t-test when homoscedasticity is maintained.[26,27] Discrete variables were compiled into contingency tables to determine the odds ratio (OR). Fisher's exact test was used instead of the chi-square for greater reliability.[28] Continuous variables are reported as mean with standard deviation (SD). Statistical significance was conferred if $p < 0.05$.

Results

Of the 10,028 articles initially identified through searches of Medline, PubMed, and Scopus, ten met the predefined inclusion criteria. An additional six eligible articles were identified through citation tracking of original studies, resulting in a total of 16 articles included in the final review (Fig. 2). Duplicate publications were identified and removed using automated software (Covidence; Melbourne VIC 3000, Australia). All reviewers independently evaluated these 16 studies and agreed on their inclusion following a detailed assessment. Notably, only one of the included articles directly compared outcomes between civilian and military populations (Table 1).[7,19,29-42]

Study demographics

Of the 16 studies included, 9 (56%) investigated the effects of explosions in the military populations, while the remaining seven focused on civilian populations. Across all studies, a total of 14,942 patients were affected by explosions – 9,240 civilians and 5,702 military personnel. Collectively, 27,270 injuries were reported: 17,620 in the civilian population resulting from both terrorist and accidental explosions, and 9,650 in the military population. Demographic characteristics of the study populations are summarized in table 2. The average age of victims in the civilian population was significantly higher than that of victims of military casualties (40 ± 3.7 vs. 24.5 ± 1.4; $p < 0.05$). However, there was no statistically significant difference in sex distribution, with a predominance of male victims in both groups (79.4% vs. 79.0%; $p > 0.05$). Mortality rates were also comparable between the two populations (4.6% vs. 4.7%; $p > 0.05$). No independent risk factors for mortality were identified that distinguished civilian from military outcomes (OR = 0.96, 95% confidence interval [CI] = 0.82, 1.13; p = 0.659), nor were there significant predictors for the occurrence of severe injuries, defined as ISS ≥ 15 (OR = 1, 95% CI = 0.82, 1.23; p = 0.952).

Table 1. Studies included by author and by type of population

Author (year of publication)	Study period	Type of population	n = 14,942
Rozenfeld et al.[29]	2004-2011	Military	474
Rozenfeld et al.[2]	2012-2013	Military	19
Shakargy et al.[46]	2003-2014	Military	844
Heldenberg et al.[7]	2000-2005	Civilian	1261
Yu et al.[32]	2015	Civilian	75
Sharrock et al.[33]	2003-2014	Military	80
Ashkenazi et al.[34]	1994-2005	Civilian	66
Rozenfeld et al.[35]	1997-2016	Civilian	1025
Schweizer et al.[36]	2001-2018	Military	739
Maddry et al.[37]	2011-2014	Military	915
Nunziato et al.[38]	2015	Civilian	2682
Al-Hajj et al.[39]	2020	Civilian	791
Tapia et al.[40]	2007-2020	Military	1526
Gebran et al.[19]	2020	Civilian	315
Rozenfeld et al.[41]	1997-2018	Civilian-Military	3908
Shakargy et al.[46]	1982-2021	Military	222

Table 2. Demographics of the study population

Variable	Civilian events	Military events
Age	40 years (SD ± 3.65)	24.5 years (SD ± 1.41)
Sex, n (%)		
Male	7366 (79.4)	4505 (79.0)
Female	1742 (20.6)	1197 (21.0)
Mortality, n (%)	421 (4.6)	267 (4.7)
ISS	8 (IQR = 2)	9 (IQR = 10.5)

SD: standard deviation; ISS: injury severity score; IQR: interquartile range.

Injury profile and severity of injuries

The overall distribution of injuries among civilians did not differ significantly from that observed in the military population. Injuries involving the head–face–neck, thoracic, and abdominal regions occurred in 29.8% vs. 34%, 8.8% vs. 7.7%, and 7.3% vs. 6.5% of cases, respectively. However, extremity injuries were significantly more frequent among military casualties than among civilians (39.8% vs. 30.8%; $p < 0.05$). Conversely, head and thoracic injuries were more prevalent in the civilian population (31.9% vs. 18.1% and 20.4% vs. 9.9%, respectively), while severe extremity injuries occurred more commonly in military personnel (51.8% vs. 30.9%). None of the included studies specified whether the explosive devices involved were high-order or low-order explosives.

Discussion

The objective of this review was to compare the risk factors associated with mortality among patients injured by different types of explosions across civilian and military settings. Interestingly, the finding data suggests that, despite clear differences in the context and underlying causes of explosions between these populations, there are several similarities in injury patterns and outcomes. These commonalities may indicate the degree of transferability in treatment strategies and clinical management approaches across both settings.

As one would expect, the victims of war-related explosions were young adults with a mean age of 24.5 years, while civilian victims had a mean age of 40.0 years. The patterns of injuries in the civilian population showed a greater proportion of severe injuries to the head and thoracic body regions and a lower incidence of severe injuries to the pelvic and extremities compared to the military population. These differences can be ascribed to the types of explosive devices responsible for the explosions in the civilian and military environment and the universal use of protective equipment by the military personnel. IEDs and landmines, also known as antipersonnel mines, are among the most common causes of localized military explosions aimed at increasing the logistic burden for caring for the victims by causing either traumatic amputations of the lower extremities or massive lower extremities and pelvic injuries, as opposed to the civilian explosions that predispose the victims to head and thoracic injuries.[41,43] Some degree of similarity between intentional and terrorism explosions is observed when high explosives are placed in maximum proximity to potential victims; in this setting, a massive amount of the explosive energy is transferred to victims.[41,43]

The placement of an explosive device in enclosed environments, such as within a vehicle during assassination attempts, or in confined public spaces like buses, bars, or coffee shops during terrorist attacks, amplifies the impact of the blast by redirecting and concentrating the pressure wave toward victims inside the space.[44,45] In contrast, unintentional outdoor explosions, like the one mentioned in Beirut, tend to produce a more heterogenous injury pattern due to the dissipation of the blast wave in open air.[29]

Explosions typically occur in one of four primary contexts: Domestic settings (e.g., gas leaks or residential fires), industrial environments involving occupational hazards (e.g., mining, demolition, or the production of chemical products and fuels), armed conflict zones, and acts of terrorism. An additional critical factor influencing the resulting injury patterns is the physical environment in which the explosion takes place, as factors such as confinement, proximity, and structural surroundings significantly affect the blast's impact. Underwater blast waves cause greater damage due to the water's incompressibility.[30,31] These waves travel faster and farther than in the air, leading to more severe injuries over longer distances.[32] Personnel floating in water are more prone to abdominal than thoracic injuries, while fully submerged victims face equal risk of both, even at 3 times the blast distance.[46]

Explosion-related injuries are classified into four categories based on the mechanism of injury (Table 3 and Fig. 3) and by distance from the blast epicenter (Fig. 1):

- Primary blast injuries result from the direct interaction of the blast shock wave with the body. Gas-containing organs, such as the middle ear, lungs, and gastrointestinal tract, are at particular risk. In contrast, solid organs, including the skin, are more resistant to the blast wave. Notably, patients with isolated primary blast injury may present with minimal signs of trauma despite significant internal damage.
- Secondary blast injuries are caused by energized fragments propelled by the blast. These include both *primary fragments* (components of the explosive device itself) and *secondary fragments* (environmental debris such as glass, metal, or building materials). These injuries often result in penetrating trauma, lacerations, traumatic amputations, and traumatic brain injury, and can affect any part of the body.
- Tertiary blast injuries occur when the victim is physically displaced by the blast wind and thrown against a hard surface or when heavy objects are propelled into the body. These injuries are commonly associated with blunt trauma, crush injuries, and structural collapse. The combination of primary and tertiary forces may lead to complex injuries such as limb avulsion, crush syndrome, and compartment syndrome.
- Quaternary blast injuries result from the thermal effects of the blast, combustion gases, and chemical or environmental contaminants. Victims may present with thermal burns, asphyxiation, and toxic syndromes secondary to fuel, metal exposure, or environmental contamination.

Limitations of the evidence and review process

Several limitations were identified in the available body of evidence. First, there was substantial heterogeneity

Table 3. Classification of trauma explosion

Mechanism	Cause	Organs affected	Typical injuries
Primary	Increased pressure	Predominates in organs with air: lungs, middle ear, gastrointestinal tract	Tympanic rupture
			Lung injuries
			Intestinal perforation
			TBI
			Eye injury
Secondary	Splinters/shrapnel	Whole body	Penetrating injuries
			Lacerations
			Compartment syndrome
Tertiary	The victim is thrown against a stationary object, or objects are thrown towards people	Whole body	Blunt trauma (contusions, fractures, crush injuries)
			Polytrauma
			Amputations
			Compartment syndrome
			Crush syndrome
			TBI
Quaternary	Other explosion-related injuries (e.g., heat)	Whole body Burns: unprotected skin (face, neck, hands)	Burns
			Inhalation
			Smoke poisoning
			Infections
Quinary	Bacteria, chemicals, radiologic materials	Hyperinflammatory or hypermetabolic responses	Shock, fever, coagulopathy without clear trauma mechanisms

TBI: traumatic brain injury.

across studies in terms of study design, populations examined, injury classification systems, and outcome measures, which limited direct comparability and precluded pooled analysis. Many of the included studies were retrospective or descriptive, often with small sample sizes and limited external validity. In addition, methodological details were frequently underreported, reducing the ability to assess study quality and risk of bias comprehensively.

Contextual factors – such as the type of explosive device used, the environmental setting of the incident (e.g., open vs. confined spaces), and the use of personal protective equipment – were inconsistently reported, further complicating interpretation of findings. Notably, within the civilian population, most studies did not differentiate between injuries resulting from accidental explosions and those related to acts of terrorism, limiting the specificity of conclusions drawn for this subgroup.

Regarding the review process itself, several limitations must also be acknowledged. Although a comprehensive and systematic search strategy was employed, it is possible that relevant studies published in non-English languages or non-Spanish languages, as well as those in the grey literature, were inadvertently excluded. Screening and data extraction were conducted independently by the authors, with discrepancies resolved through consensus or third-party adjudication. Nonetheless, the potential for subjectivity in data interpretation remains and may have influenced the synthesis of findings. The authors emphasize that this review provides a descriptive synthesis rather than a meta-analytic comparison.

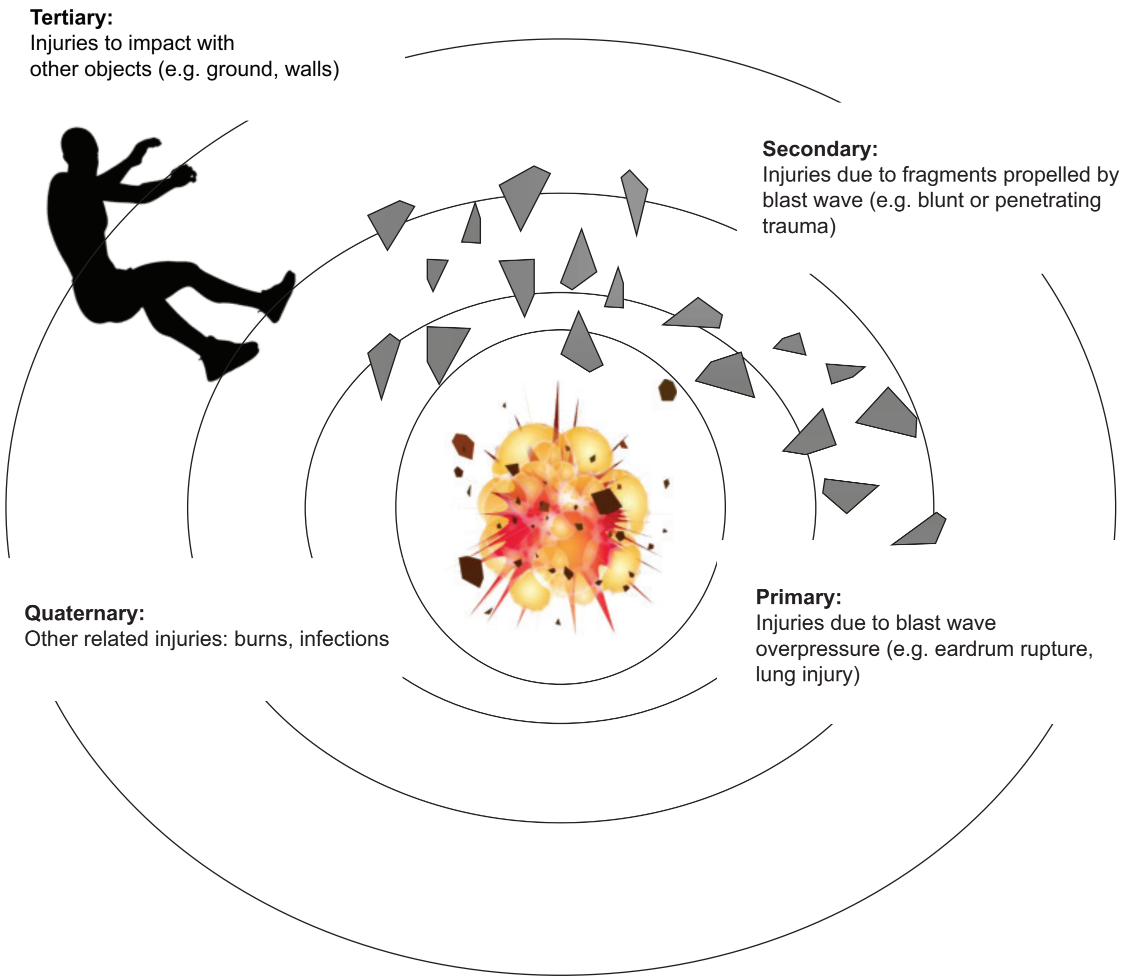

Figure 3. *Type of explosion injuries.*

Conclusions

The findings of this review indicate that clinical experience derived from explosions occurring in one setting – such as military or combat zones – may not be fully generalizable to explosions occurring in other contexts, such as civilian or accidental events, as demographic, environmental, and contextual factors contribute to distinct injury patterns.

Funding

The authors declare that they have not received funding.

Conflicts of interest

The authors declare no conflicts of interest.

Ethical considerations

Protection of human subjects and animals. The authors declare that no experiments on humans or animals were performed for this research.

Confidentiality, informed consent, and ethical approval. This study does not involve personal patient data, medical records, or biological samples, and does not require ethical approval. SAGER guidelines do not apply.

Declaration on the use of artificial intelligence. The authors declare that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

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