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Spatial and contextual factors influencing injury patterns and severity resulting from the 2020 Beirut blast

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This cross-sectional study investigated the factors influencing injury characteristics and outcomes following the 2020 Beirut Blast. Blast victims (n = 310) were identified from hospital registries in Beirut. Soft tissue injuries predominated (N = 276; 88.2%), with most patients struck by objects (N = 261, 84.2%). Minor injuries were common (70.3%), with significant associations noted for eye and internal injuries. Victims were primarily situated 500–1700 m from the blast epicentre (71%), indoors (81%), often in residential dwellings (48%), near windows. Severe injuries, especially musculoskeletal, were more frequent outdoors. Significant associations were found between indoor positioning facing the port and soft tissue injury incidence, and with proximity to windows. A standing posture significantly correlated with musculoskeletal and soft tissue injuries, as well as being struck by objects. A cluster of severe injuries was noted at 600–1400 m radial distance from the blast epicentre. The study underscores the role of spatial and contextual factors in injury patterns post-blast, emphasizing the importance of targeted interventions for disaster preparedness and urban resilience to mitigate the impact of future similar events on affected populations.

Keywords Public health, Forensic analysis, Blast injury, Beirut blast, Disaster

The 2020 Beirut blast created a humanitarian disaster that significantly impacted human lives and the urban environment. The explosion was caused by the detonation of Ammonium Nitrate stored in the port of Beirut, resulting in the loss of more than 200 lives, injuring over 6,000 individuals, and displacing hundreds of thousands of residents[1]. This city-wide, mass-casualty event generated high volumes of casualties that overwhelmed the already resource-limited local health systems. Moreover, it coincided with an unprecedented economic crisis, tense social instability, political unrest, and the COVID-19 pandemic. These overlapping crises further hindered early and effective patient care, critical for improving clinical outcomes[2].

Blast injuries are a complex type of physical trauma caused by different mechanisms, including shock wave exposure, penetrating fragments, and blunt impacts. Traditionally, these mechanisms are classified into primary through quaternary blast injury mechanisms[3,4]. The severity and pattern of injuries depend on several factors, including explosion magnitude, distance from the epicentre, and environmental features[5]. Confined or enclosed urban spaces, for instance, can amplify blast effects and increase injury severity compared to open areas[6,7]. Despite this, limited research has examined how distance and local surroundings affect injury outcomes in civilian urban settings like Beirut.

Existing blast injury research largely stems from military contexts and focuses on young, male military populations that wear protective gear[8–10]. This creates a significant knowledge gap regarding civilian injuries,

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particularly among vulnerable groups. With the increasingly urbanized nature of explosive violence, as seen in the Ukraine invasion and Israel-Gaza conflicts, and the high proportion of casualties being civilian, the Beirut explosion is a significant case study for improving understanding of the consequences and mechanisms of blast injuries sustained by a civilian population in an urban setting[2].

Previous investigations into the injuries caused by the Beirut blast all noted a substantial prevalence of secondary blast injuries, which is attributed to extensive failure of glazing[11–14]. Some prior studies have attempted to estimate victims' distance from the blast based on clinical data collected at the Emergency department level[13,15–17], but often relied on residential addresses rather than actual locations at the time of the explosion. They also lacked details on the victims' immediate environments.

Given the scale of the Beirut explosion, victims' blast injuries are likely to have been influenced by two critical factors at the time of the event: their distance from the epicentre (i.e., blast exposure) and the characteristics of their immediate local surroundings. This study aimed to determine the accurate locations of injured victims at the time of the Beirut explosion to investigate how injury patterns and outcomes were influenced by different spatial and contextual factors such as distance from the blast epicentre, inside or outside spaces, proximity to glazing, posture, and clothing coverage.

Materials and methods

Study design

A cross-sectional study was conducted on individuals who were injured by the 2020 Beirut blast. The current study is a continuation of an initial study that retrospectively reviewed hospital records to assess injury types and disabilities[17], under a previously registered protocol (BIO-2020–0357). This study expands on the initial study by directly engaging with the same patient population and collecting data using structured telephone surveys to investigate the spatial and contextual factors that contributed to patients' blast injuries. Blast victims were selected from the initial study database of patients who sought care at five hospitals in the greater Beirut area: American University of Beirut Medical Center—AUBMC, Lebanese American University Medical Center—LAUMC, Keserwan Medical Center -KMC, Hopital Notre Dame Du Liban—HNDM, and Sahel General Hospital. The surveys were conducted over the telephone by qualified researchers who were trained before data collection to ensure consistent administration of the survey. Before commencing the study, oral informed consent was acquired from all participating patients, and their personal identifying details were anonymized to protect their autonomy and privacy. The study received approval from the American University of Beirut Institutional Review Board (BIO-2022-0152).

Inclusion and exclusion criteria

Patients were eligible for inclusion if they met the following criteria: (1) were aged 18 years or older at the time of the Beirut blast; (2) sustained a physical injury as a direct and immediate result of the explosion on August 4, 2020; and (3) provided oral informed consent to participate in the study. Exclusion criteria included: (1) individuals whose injuries occurred during post-blast activities such as emergency response or clean-up operations; (2) individuals who could not be reached after multiple contact attempts or who declined participation; and (3) individuals who were unable to respond adequately due to reduced mental alertness or memory loss, which prevented reliable data collection.

Data collection

The survey comprises two parts. The first part collected victims' demographic data (i.e., age and gender), whereas the second part included a detailed assessment of the victim's exact location at the time of the explosion (i.e., distance, inside or outside a building, etc.) and detailed questions about types of injury sustained. The patients' Injury Severity Score (ISS) was retrieved from the initial study and included in this study[17]. ISS is categorized as follows: minor (ISS 0–8), moderate (ISS 9–15), severe (ISS 16–24), very severe (ISS 25–49), critical (50–74), and not survivable (75).

A key component of the interview involved asking victims to describe their exact location at the time of the blast, including whether they were inside or outside. Locations were identified and recorded with place markers using Google My Maps[15] (Fig. 1). Locations were determined as accurately as possible (≈ 10 m), enabled by interviewers' local knowledge and two-way conversation with victims referencing nearby local landmarks to verify locations.

Following the interviews, all records were verified to ensure that they met the study inclusion criteria. In cases where patients sustained multiple injuries, each injury was considered and analyzed as a separate data point, allowing for individual characterization and assessment irrespective of the number of injuries per patient.

Statistical analysis

Compiled data were coded and analysed using Statistical Package for Social Sciences (SPSS) software version 23.0[18]. For analytical purposes, injuries were grouped into three broad categories: soft tissue injuries, musculoskeletal injuries, and other injuries (including burns, eye injuries, concussion, and internal injuries). This classification was based on clinical relevance and informed by established injury classification systems, including ICD-10 Chapter XIX (S00–T88)[19], which distinguishes between open wounds and musculoskeletal trauma, and the WHO Emergency Care Toolkit[20,21], which supports grouping injuries by functional type to aid triage and clinical decision-making in mass casualty contexts. This approach is also consistent with prior studies of blast-related injury patterns following large-scale urban explosions, such as the Oklahoma City bombing[8] and recent analyses of the Beirut Blast[14,16], which similarly categorised injuries into soft tissue and musculoskeletal domains to support interpretation of severity, mechanism, and clinical response. In this study, continuous variables were represented as mean (M) and standard deviation (STD), while categorical variables were expressed

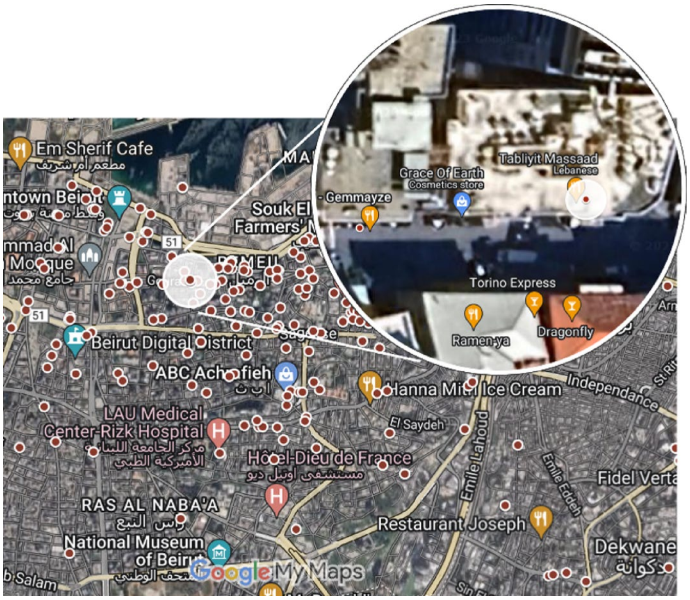

Fig. 1. Victims' locations were recorded in Google My Maps[15] as accurately as possible through interviewers' extensive local knowledge and reference to nearby landmarks.

as frequency (percentage). To account for missing values, the statistical analysis was adjusted by considering the valid percentage in the results. Binary logistic regression was performed to identify the association between the type of injury and location, position, and surroundings. A comparison of proportions was performed using Pearson's Chi-squared test and Fisher's exact test. In addition, the Student's *t*-test was used to compare the means of two groups; for means of three or above, the Analysis of Variance (ANOVA) test was applied. In the case of non-homogeneity, non-parametric tests are substituted for the parametric tests.

Ethics declaration
The University's Institutional Review Board (IRB) approved the study (BIO-2022–0152). Consent was deemed applicable by the committee. All blast victims were above 18 and were carefully briefed about this study. Oral informed consent was obtained from all victims. All methods were performed in accordance with relevant guidelines/regulations as per the ethical standards as laid down in the Declaration of Helsinki and its later amendments or comparable ethical standards.

Results
The study group comprised a total of 310 blast victims, representing a broad civilian demographic that included a similar proportion of males and females (N = 148, 47.7% and N = 162, 52.3% respectively), with a mean age of 45.1 ± 17.3 years, ranging from 18 to 94 years.

A wide range of injuries was reported by study patients, which were subsequently categorized into core blast injury patterns, with their constituent injury types/presentations, detailed in Table 1.

Soft tissue injuries (Lacerations, abrasions, bruises, hematomas, puncture wounds, degloving) were the most common reported injury pattern (N = 276; 88.2%), followed by musculoskeletal injuries (Fractures, dislocations, sprains, strains, crush injuries, amputations; N = 182; 58.7%). In contrast, a low number (less than 5%) of blast victims reported either burns, concussion, eye, or internal injuries (e.g., internal bleeding or organ rupture) (Table 1). Due to the significantly smaller sample size for these injury types, no further statistical analysis was undertaken for these injuries.

A large proportion of the group (N = 261, 84.2%) reported being hit by an object immediately following the Beirut blast (Table 1). The majority were hit in multiple body areas, including their head (N = 145, 46.8%) or multiple areas without their head (N = 52, 16.8%). Many fewer victims reported being hit by an object in a specific or localized region (i.e., torso only, head only, upper, or lower extremities). Approximately half of the victims (N = 163; 52.6%) reported being propelled against objects because of the Beirut blast.

For the subset of the study group with available injury severity scores (ISS) (N = 187), the majority (N = 130; 70.3%) had 'minor injuries' (ISS < 8), with a total of N = 25 (13%) classified as 'major trauma' (ISS > 15). ISS scores ranged from 4 to a maximum of 34, with a mean ISS = 7.92 ± 6.28 (Table 2). Blast injury patterns were associated with different ISS (Table 2). Mean ISS was higher in victims with musculoskeletal injuries (8.2 ± 6.361, ***p*-value = 0.008**), eye injuries (12.07 ± 7.457, ***p*-value = 0.022**), and internal injuries (12.33 ± 8.201, ***p*-value = 0.03**) (Table 2).

The radial distance of the victims from the Beirut blast epicentre ranged from 472 to 7832 m, with a mean distance of 1494 ± 993 m. Most victims were located 500–1700 m (m) from the blast epicentre, with a generally decreasing number at further distances (Fig. 2a,b). Only four victims were located within a 500 m radius of the

Blast injury patterns and injury mechanism	Frequency of injuries (%)
Soft tissue injuries (Lacerations, abrasions, bruises, hematomas, puncture wounds, degloving)	276 (88.2)
Musculoskeletal injuries (Fractures, dislocations, sprains, strains, crush injuries, amputations)	182 (58.7)
Eye Injuries	16 (5.2)
Internal injuries (e.g. internal bleeding or organ rupture)	11 (3.5)
Concussion	3 (1.0)
Burns	3 (1.0)
Body part/region hit by object(s)	
Head	42 (13.5)
Upper extremities	28 (9.0)
Lower extremities	32 (10.3)
Multiple parts without the head	52 (16.8)
Multiple parts and head	145 (46.8)
Torso	6 (1.9)
Others	5 (1.6)
Hit by object(s)	
No	44 (14.2)
Yes	261 (84.2)
Don't know	5 (1.6)
Blown/propelled against objects	
No	142 (45.8)
Yes	163 (52.6)
Don't know	5 (1.6)

Table 1. Key blast injury patterns and injury mechanisms reported by the study group.

Injury severity score (ISS)	Frequency (%)
Minor (ISS = 0–8)	130 (70.3)
Moderate (ISS = 9–15)	30 (16.2)
Severe (ISS = 16–24)	17 (9.2)
Very severe (ISS = 25–49)	8 (4.3)
Average ISS for each blast injury pattern	**Mean ± STD**
All Injuries	7.92 ± 6.281
Soft Tissue Injuries (Lacerations, abrasions, bruises, hematomas, puncture wounds, degloving)	7.70 ± 6.156
Musculoskeletal Injuries (Fractures, dislocations, sprains, strains, crush injuries, amputations)	8.20 ± 6.361
Eye Injuries	12.07 ± 7.457
Internal Injuries	12.33 ± 8.201

Table 2. Analysis of injury severity scores (ISS) for a subset of the study group (N = 187).

blast due to the large port area surrounding the explosion epicentre, and very few injuries were survivable within this region.

Most of the victims reported being located inside at the time of the blast (N = 250, 81%), with 60 (19%) located outside (Table 3). Those located outside at the time of the blast were predominantly located on the street (N = 37, 61.7%) with some on outdoor balconies or roof terraces (N = 19, 31.7%) (Table 3). For those located inside, nearly half were in residential homes (N = 120, 48%) and nearly a quarter (N = 56, 22.4%) were in restaurants, cafes, shops, or bars (Table 3). Over half of the victims located inside at the time of the explosion described the room's aspect as facing the Beirut port (N = 149, 59.6%), and therefore the site of the explosion.

Frequently, victims were situated near windows, where they were either looking through windows from a distance or with windows directly in front (N = 84, 27.6% and N = 74, 24.3%, respectively) (Table 3). The elevation of the study patients ranged from the basement to the 13th floor (Fig. 2c), reflecting the many high-rise buildings in downtown Beirut. Most of the study group was located at ground level (N = 128; 41.3%) with a generally decreasing number at higher elevations (Fig. 2c).

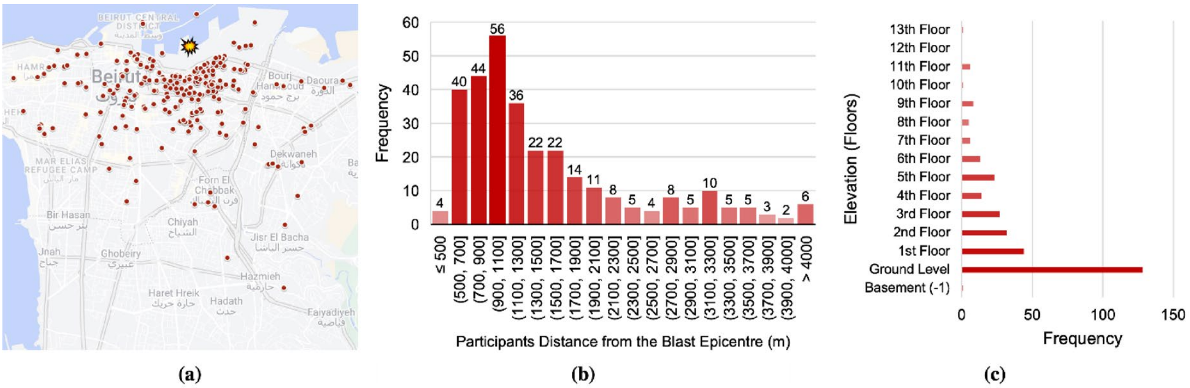

Fig. 2. **(a)** Mapped locations of the study group in Beirut at the time of the explosion, **(b)** radial distance of victims from the Beirut blast epicentre, and **(c)** elevation of victims at the time of the 2020 Beirut blast.

Most victims were standing at the time of the blast (N = 229, 73.9%), followed by approximately a fifth who were sitting (N = 63, 20.3%) (Table 3). Additionally, 33.2% of the victims had their entire bodies covered (N = 103) at the time of the blast, followed by those wearing either summer clothing (i.e., shorts and T-shirts, dresses) (N = 89, 28.7%) or clothing that fully covered their legs (N = 84, 27.1%) (Table 3).

The incidence of soft tissue injuries (Lacerations, abrasions, bruises, hematomas, puncture wounds, degloving) was similar for both outside and inside spaces (86.7% vs. 89.6%; Fig. 3a). However, a relatively higher proportion of musculoskeletal injuries (fractures, dislocations, sprains, strains, crush injuries, amputations) occurred in outside spaces in comparison to inside spaces (78.3% vs. 54%; Fig. 3a). A higher proportion of the most severe injuries (major trauma ISS > 15) occurred in victims located outside (21%) compared to those inside (11%) (Fig. 3b).

Soft tissue injuries were significantly more likely to occur in individuals who were hit by an object during the blast, with 93.9% of those hit sustaining soft tissue trauma, compared to only 59.1% of those who were not hit ($p < 0.001$). Additionally, proximity to windows played a major role: individuals surrounded by glazing (98.1%), inside vehicles (91.7%), or near outside glazing (86.7%) had significantly higher soft tissue injury rates compared to those with no nearby glass (33.3%) ($p < 0.001$) (Table 5).

The bivariate analysis revealed a significant association between indoor rooms facing the port and an increased incidence of soft tissue injuries (N = 141, 94.6%, p-value = 0.002) (Table 5). No correlation was observed between the elevation of the participant at the time of the blast and their injury patterns (Table 5) or injury severities (Table 4). A significant correlation was observed between the occurrence of soft tissue injuries with victims' proximity to glazing or windows. Specifically, victims exhibited a high likelihood of lacerations and penetrating injuries if they were either surrounded by glazing (N = 53, 98.1%), had windows directly in front of them (N = 70, 94.6%), or were indoors with nearby glazing (N = 105, 92.1%), as illustrated in Table 5 (p-value < 0.001).

For musculoskeletal injuries, individuals in indoor settings had significantly higher rates of injury (78.3%) compared to those outdoors (54.0%) ($p = 0.001$). Being blown or propelled by an object was also strongly associated with musculoskeletal injuries, with 76.1% of affected individuals sustaining such injuries versus 37.3% of those who were not ($p < 0.001$). Proximity to windows was again significant ($p = 0.008$), with higher injury rates among those with no glass nearby (86.7%) and those surrounded by glazing (64.8%).

The victims' posture at the time of the blast was observed to influence the likelihood of certain injury patterns. A standing position was significantly associated with musculoskeletal (N = 149, 65.1%, p-value = 0.005) (Table 5). Similarly, a standing position was significantly associated with being propelled by the blast against objects (N = 132, 81.5%, p-value = 0.007) (Table 4). No correlation was observed between clothing coverage and different blast injury patterns (Table 1).

While a relatively higher proportion of severe injuries (ISS > 15) occurred in blast victims located outside, statistical analysis revealed no significant correlation between ISS and indoor or outdoor spaces (Table 4). No correlation was observed between ISS and blast victims' elevation or posture at the time (Table 4).

The two most common blast injury patterns (soft tissue injuries and musculoskeletal injuries) are plotted as a function of distance from the blast epicentre in Fig. 4. Soft tissue injuries had a high prevalence at all distances from the blast epicentre (Fig. 4a). Musculoskeletal injuries had notably increased prevalence at distances closer to the blast epicentre (< 1.5 km), with relatively few reported further afield. Despite these visible patterns, no statistical significance was observed between injury patterns and distance from the blast epicentre (Table 4).

ISS within the study group clearly shows a correlation with victims' distance from the blast (Fig. 4). Generally, the most severe injuries (higher ISS) occurred closer to the blast epicentre, with a notable cluster of 'severe' and 'very severe' injuries at radial distances 600–1400 m (Fig. 4). Minor injuries occurred at all distances from the blast epicentre, with some isolated cases of severe injuries further from the blast. While higher ISS appears to be distributed closer to the blast epicentre (Fig. 4b), no statistical significance was observed between ISS and distance from the blast (Table 4).

Variables	Frequency (%)
Indoor or outdoor spaces	
Indoor	250 (80.6)
Outdoor	60 (19.4)
Outside spaces	
Street	37 (61.7)
Balcony/roof terrace	19 (31.7)
Outside-other	4 (6.7)
Inside spaces	
Office	34 (13.6)
House/apartment	120 (48.0)
Restaurant/café/shop/bar	56 (22.4)
Building stairs	9 (3.6)
Hospital	11 (4.4)
Vehicle	12 (4.8)
Indoor-other	8 (3.2)
Aspect of the room	
Facing the port	149 (59.6)
The port on the right	38 (15.2)
The port on the left	27 (10.8)
Port behind the room	30 (12.0)
N/A	6 (2.4)
Proximity to windows	
No glass nearby	15 (5.0)
Surrounded by glazing	54 (18.1)
Windows directly in front	74 (24.7)
Glazing nearby (inside)	114 (38.1)
In a vehicle	12 (4.0)
Glazing nearby (outside)	30 (10.0)
Posture	
Standing	229 (73.9)
Sitting	63 (20.3)
Other	15 (4.8)
Unknown	3 (1.0)
Clothing coverage	
Summer clothes	89 (28.7)
Body fully covered	103 (33.2)
Legs fully covered	84 (27.1)
Arms fully covered	3 (1.0)
N/A	31 (10.0)

Table 3. Characteristics of the study group's surrounding environment and other contextual factors at the time of the Beirut blast (Number of patients; N = 310).

Discussion

Distance from the blast epicentre

Protective strategies and preparedness for explosive events rely on an understanding of the potential injury patterns and their extent for a particular explosive threat. When explosions occur in open spaces, the risk of mortality and severity of injuries typically decreases with increasing distance from the detonation, particularly for primary blast injuries. This concept is the basis of multiple predictive blast injury criteria and confirmed by experimental studies such as that by Zhao-Xia et al., which explores the survival rate among goats placed at various distances from an explosive detonation[12,22]. This is because blast wave overpressure is inversely proportional to the distance cubed from the point of detonation[6,13]. This explains the nearly 100% mortality rate among victims located closest to the explosion within the port of Beirut.

However, secondary blast injuries from fragmentation and tertiary blast injuries from blunt traumas or crush injuries remain highly possible over greater distances[6]. In this study, a high prevalence of laceration and penetrating injuries reported at all distances from the blast epicentre suggests that blast loading was sufficient to cause secondary blast injuries from projectiles, including glazing fragments and other debris, even at large distances from the epicentre (> 4 km).

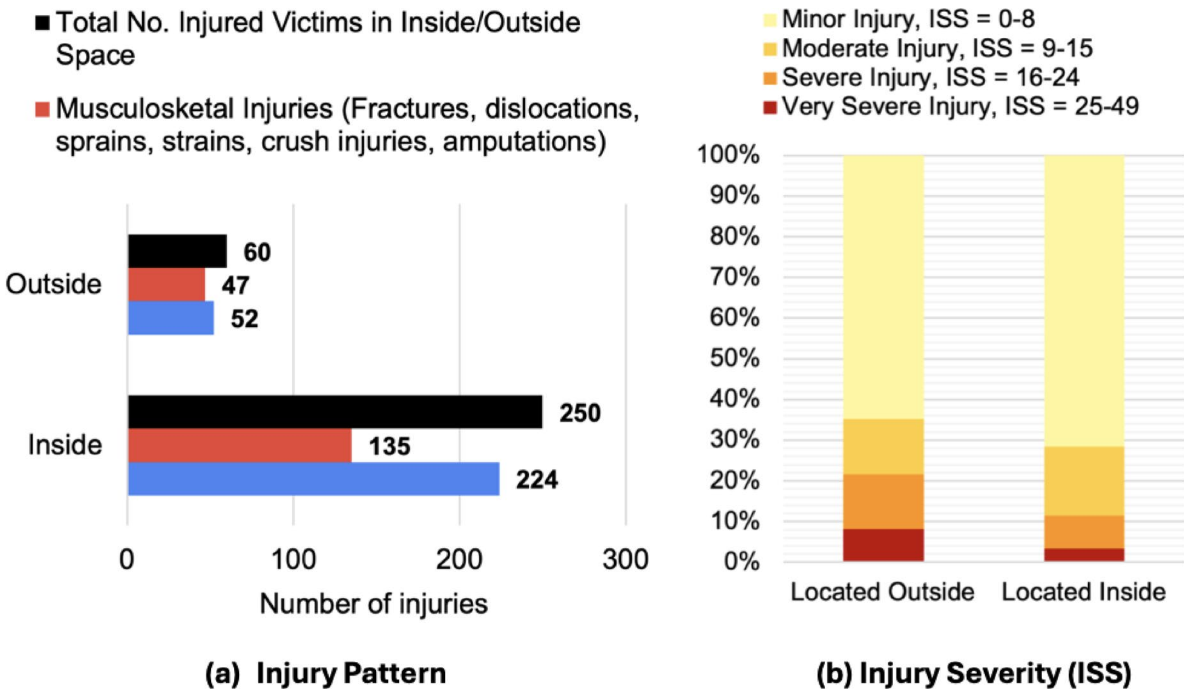

Fig. 3. **(a)** Injury patterns and **(b)** injury severities (ISS) for inside and outside spaces.

This study found that the prevalence of some injury patterns (i.e., musculoskeletal and soft tissue injuries) and higher ISS scores correlated with increasing distance to the blast epicentre, which is likely to be caused by stronger blast loading conditions. The study findings confirm that distance to the blast epicentre influenced the prevalence and severity of injuries, aligning with previous studies[13,23,24].

Inside versus outside spaces

Whether victims were located inside or outside at the time of the blast was observed to influence injury outcomes. This study showed a relatively higher proportion of musculoskeletal injuries, soft tissue injuries, and a relatively larger proportion of higher ISS scores for blast victims located outside (in comparison to inside spaces). This may suggest that higher exposure to blast winds and other hazards found in outdoor spaces results in an increased likelihood of forcible displacement, falls, and impacts with surfaces, causing blunt force trauma, fractures, and other soft tissue injuries.

Findings from this study confirmed a high incidence of laceration and penetrating injuries, aligning with previous studies on the Beirut blast injuries[1,11,14,16], mostly attributed to people being close to their windows to watch or film the initial fire before the blast[23]. Unsurprisingly, this study confirmed a significant correlation between victims near windows with lacerations, penetrating wounds, and bleeding. This underscores the strong influence of one's immediate surroundings on the nature and extent of injuries sustained.

Other location factors

This study found that victims located in rooms facing the port suffered a higher incidence of laceration and bleeding injuries compared to other room aspects. This suggests that being in a room that faced the port increased the likelihood of these injury types, highlighting the effect of room orientation and the multidimensional nature of blast-related injuries. The elevation of blast victims was not found to influence the injury patterns or severity (ISS), which contrasts findings from previous injury studies, which show that lower air density at higher elevations can increase the injurious effects of blast waves. Due to the large distances of most victims from the blast epicentre (typically $R > 500$ m), near-uniform blast wave conditions can be expected at all elevations, which may explain the absence of correlation with injury outcomes.

Other contextual factors

Understanding how posture affects vulnerability to blast injuries is critical for developing sheltering guidance and other protective strategies. This study indicated that a standing posture at the time of the explosion was significantly associated with a higher incidence of soft tissue and musculoskeletal injuries, with the latter also associated with higher ISS scores. Findings also showed that a standing posture was associated with being propelled by the blast against objects. These findings suggest that the powerful blast winds, in combination with a standing posture, increased the likelihood of being thrown against or falling on hard surfaces, leading to fractures, blunt trauma, and other soft tissue injuries. Several studies suggest that some injury mechanisms are posture-dependent[25,26]. For example, a study evaluating the effects of blast winds from underground explosions showed that changing posture from standing to kneeling or lying down may improve survivability[25]. These

Variable	Blown/propelled by blast against objects				*P*-value
	No		Yes		
Posture					
Standing	93 (66.0)		132 (81.5)		0.007
Sitting	38 (27.0)		25 (15.4)		
Other	10 (7.1)		5 (3.1)		
Variable	**Injury severity score (ISS)**				***P*-value**
	Minor	**Moderate**	**Severe**	**Very severe**	
Indoor or outdoor spaces					
Indoor	105 (81.4)	23 (79.3)	12 (70.6)	5 (62.5)	0.389
Outdoor	24 (18.6)	6 (20.7)	5 (29.4)	3 (37.5)	
Mean floor elevation $\pm STD$	2.077 ± 2.613	2.100 ± 2.682	2.250 ± 3.336	3.500 ± 2.138	0.253
Posture					
Standing	87 (68.0)	24 (82.8)	13 (76.5)	6 (75.0)	0.165
Sitting	34 (26.6)	2 (6.9)	4 (23.5)	1 (12.5)	
Other	7 (5.5)	3 (10.3)	0 (0)	1 (12.5)	
Variable	**Distance from explosion (m)**				***P*-value**
	0–1000	**1001–2000**	**> 2000**		
Injury severity score					
Minor	53 (67.9)	51 (71.8)	26 (72.2)		0.298
Moderate	18 (23.1)	8 (11.3)	4 (11.1)		
Severe	5 (6.4)	7 (9.9)	5 (13.9)		
Very severe	2 (2.6)	5 (7.0)	1 (2.8)		
Soft tissue injuries (Lacerations, abrasions, bruises, hematomas, puncture wounds, degloving)					
No	17 (13.5)	10 (8.5)	7 (10.4)		0.463
Yes	109 (86.5)	107 (91.5)	60 (89.6)		
Musculoskeletal injuries (Fractures, dislocations, sprains, strains, crush injuries, amputations)					
No	49 (38.9)	50 (42.7)	29 (43.3)		0.776
Yes	77 (61.1)	67 (57.3)	38 (56.7)		

Table 4. Bivariate analysis of whether victims were blown/propelled by the blast against objects with posture; injury severity (ISS) with surrounding environment characteristics and posture; and injury patterns and severities with distance from the Beirut blast epicenter.

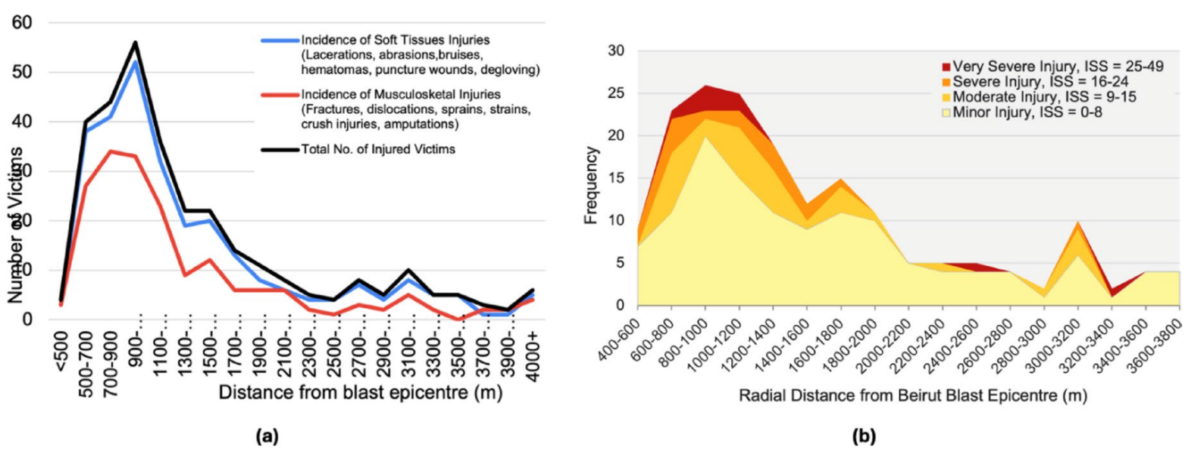

Fig. 4. Distribution of **(a)** injury patterns and **(b)** injury severity (ISS) with distance from the Beirut blast epicentre.

findings highlight the non-trivial effect of posture on blast survivability and the importance of protection and effective sheltering guidance to improve safety.

Clothing

Prior research has shown that textile materials can modify and amplify blast pressures depending on different properties[27]. This may suggest that clothing can potentially influence the pressures exerted on the body, and

Variables	Soft tissue injuries (Lacerations, abrasions, bruises, hematomas, puncture wounds, degloving) No N (%)	Yes N (%)	*P* value	Musculoskeletal injuries (Fractures, dislocations, sprains, strains, crush injuries, amputations) No N (%)	Yes N (%)	*P* value
Indoor or outdoor spaces						
Outdoor	8 (10.4)	52 (89.6)	0.646	115 (46.0)	135 (54.0)	0.001
Indoor	26 (13.3)	224 (86.7)		13 (21.7)	47 (78.3)	
Hit by an object						
No	18 (40.9)	26 (59.1)	< 0.001	14 (31.8)	30 (68.2)	0.058
Yes	16 (6.1)	245 (93.9)		114 (43.7)	147 (56.3)	
Don't know	0 (0)	5 (100)		0 (0.0)	5 (100)	
Blown/propelled by an object						
No	16 (11.3)	126 (88.7)	1.00	89 (62.7)	53 (37.3)	< 0.001
Yes	18 (11.0)	145 (89.0)		39 (23.9)	124 (76.1)	
Don't know	0 (0)	5 (100)		0 (0.0)	5 (100)	
Aspect of the room						
Facing the port	8 (5.4)	141 (94.6)	0.002	70 (47.0)	79 (53.0)	0.989
Port on the right	10 (26.3)	28 (73.7)		16 (42.1)	22 (57.9)	
Port on the left	2 (7.4)	25 (92.6)		12 (44.4)	15 (55.6)	
Port behind the participant	5 (16.7)	25 (83.3)		14 (46.7)	16 (53.3)	
NA	1 (16.7)	5 (83.3)		3 (50.0)	3 (50.0)	
Proximity to windows						
No glass nearby	10 (66.7)	5 (33.3)	< 0.001	2 (13.3)	13 (86.7)	0.008
Surrounded by glazing	1 (1.9)	53 (98.1)		19 (35.2)	35 (64.8)	
Windows directly in front	4 (5.4)	70 (94.6)		34 (45.9)	40 (54.1)	
Glazing nearby (inside)	9 (7.9)	105 (92.1)		52 (45.6)	62 (54.4)	
In a vehicle	1 (8.3)	11 (91.7)		9 (75.0)	3 (25.0)	
Glazing nearby (outside)	4 (13.3)	26 (86.7)		8 (26.7)	22 (73.3)	
Posture						
Standing	28 (12.2)	201 (87.8)	0.220	80 (34.9)	149 (65.1)	< 0.001
Sitting	5 (7.9)	58 (92.1)		37 (58.7)	26 (41.3)	
Others	0 (0)	15 (100)		10 (66.7)	5 (33.3)	
Clothing coverage						
Summer clothes	8 (9.0)	81 (91.0)	0.443	41 (46.1)	48 (53.9)	0.640
Body fully covered	15 (14.6)	88 (85.4)		40 (38.8)	63 (61.2)	
Legs fully covered	10 (11.9)	74 (88.1)		31 (36.9)	53 (63.1)	
Arms fully covered	0 (0.0)	3 (100)		1 (33.3)	2 (66.7)	
NA	1 (3.2)	30 (96.8)		15 (48.4)	16 (51.6)	
Mean floor elevation	2.206 ± 2.507	2.200 ± 2.856	0.991	2.320 ± 2.910	2.116 ± 2.753	0.531

Table 5. Associations between types of injury and details about the place and position of the participant at the time of the blast.

therefore injury when subjected to blast. In this study, different levels of clothing coverage were not found to influence injury outcomes. This suggests that increased clothing coverage did not amplify pressures as found in, nor offer any relative protection from fragmentation injuries. This study further highlights the vulnerability of unprotected civilian populations in comparison to military personnel, particularly to secondary (penetrating) blast injuries.

The relatively low incidence of burns, concussion, eye, and internal injuries observed in this study may reflect both the characteristics of the explosion and the location of the study population. All participants were located at distances where the thermal effects of the blast would have been negligible; consequently, any burns sustained were likely due to secondary fires caused by structural damage at the site of injury, rather than exposure to the explosion's thermal output. In addition, the low incidence of reported concussions may reflect under recognition or underreporting of mild traumatic brain injuries in the immediate aftermath. It is also important to note that, as the study relied on patients who survived the blast and were able to participate in follow-up interviews, there may be survivor bias. More severe or fatal injuries, including extensive burns, traumatic brain injuries, and major internal trauma, are likely to be underrepresented in this sample.

Study limitations and future work

A large limitation of this study is the reliance on victims' self-reporting bias, which can introduce potential recall bias, particularly as victims were interviewed two years post-blast.

Also, this study primarily addressed physical injuries with limited investigation of victims' mental health, although many were profoundly affected by the disaster, and many experienced trauma and emotional distress. Mental health is of paramount importance, and given its significant impact on individuals' well-being, further research into the psychological consequences of such catastrophic events would be a valuable field of study. Moreover, this study did not specifically examine the relationship between age, gender, and injury severity. Vulnerable populations, such as children and the elderly, may have different injury patterns and outcomes, and these factors were not sufficiently explored in our analysis.

The study findings should be interpreted with caution when evaluating the health impacts of explosions on individuals in urban settings. Although this study suggests decreasing injury severity with distance and no injury correlation with elevation, further work should seek to accurately model the blast loading at the location of victims in the interest of refining city-level disaster preparedness models.

Finally, this study did not consider structural damage in proximity to the blast victims. Most victims (N = 285, 91.9%) reported that nearby windows broke; however, other potentially more serious structural damage, such as localized building collapse, may have significantly contributed to the injuries sustained. Further work could examine the correlation between injury patterns and structural damage resulting from blasts.

Conclusion

This study provides a comprehensive examination of spatial and contextual factors that contributed to injury patterns and severities resulting from the 2020 Beirut Blast. This follow-up study identified the exact locations of the blast victims, allowing for the first time, accurate calculation of their distance from the blast epicentre. The findings of this study provide valuable insights into how the surrounding urban environment and various contextual factors influence blast injury outcomes in a diverse and unprotected civilian population.

Our findings highlight the vulnerability of individuals in urban settings, particularly to soft tissue injuries, mainly lacerations and penetrating injuries. Risk factors such as room orientation, posture, proximity to glazing, and distance from the blast epicentre (particularly within the 600-1400 m range) had a significant influence on injury outcomes. Specifically, individuals situated inside rooms facing the port near windows and glazing demonstrated heightened susceptibility to laceration and penetrating injuries. Conversely, those outdoors faced an increased risk of sustaining severe injuries, particularly musculoskeletal and soft tissue injuries.

Synthesized knowledge and a new understanding of the influence of the urban environment on blast injury risk are essential for informing practical mitigation strategies and sheltering guidance to reduce harm in both military and civilian settings. Future studies should aim to comprehensively estimate blast loading conditions at the location of blast victims, accounting for complex blast wave interaction, to explore any correlation between blast loading and injury outcomes. Continued research into this domain will be useful for informing disaster preparedness, response, and protection from future blast threats in urban settings.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Declarations

Competing interests
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