1. Abstract

Court cases at the International Criminal Tribunal for the Former Yugoslavia (ICTY) have seen questions raised about the recognition and causes of blast-related trauma and the relationship to human rights abuses or combat. During trials, defence teams argued that trauma was combat related and prosecutors argued that trauma was related to executions. We compared a sample of 81 cases (males between 18 and 75) from a Bosnian mass grave investigation linked to the Kravica warehouse killings to published combat-related blast injury data from World War One, Vietnam, Northern Ireland, the first Gulf War, Operation Iraqi Freedom and Afghanistan. We also compared blast fracture injuries from Bosnia to blast fracture injuries sustained in bombings of buildings in two non-combat 'civilian' examples; the Oklahoma City and Birmingham pub bombings. A Chi-squared statistic with a Holm-Bonferroni correction assessed differences between prevalence of blast-related fractures in various body regions, where data were comparable. We found significant differences between the Bosnian and combat contexts. We noted differences in the prevalence of head, torso, vertebral area, and limbs trauma, with a general trend for higher levels of more widespread trauma in the Bosnian sample. We noted that the pattern of trauma in the Bosnian cases resembled the pattern from the bombing in buildings civilian contexts. Variation in trauma patterns can be attributed to the influence of protective armour; the context of the environment; and the type of munition and its injuring mechanism. Blast fracture injuries sustained in the Bosnian sample showed patterns consistent with a lack of body armour, blast effects on people standing in enclosed buildings and the use of explosive munitions.

Keywords: Bosnia, patterns of blast injury, conflict trauma, blast injury.

2. Introduction

Court cases at the International Criminal Tribunal for the Former Yugoslavia (ICTY) saw arguments based on the autopsy of skeletal remains. Trauma assessments of skeletal remains can determine the manner and cause of death. During trials at the ICTY, prosecution argued that the cause of death was execution related and defence teams argued that the pattern of trauma seen in these cases was combat-related [1–4]. The latter argument was presented most prominently during the trials of the former Bosnian Serb military leaders Radovan Karadžić, Ratko Mladić, and Zdravko Tolimir for war crimes committed during the 1995 civil war in Bosnia. The defence arguments attriuted observed injuries to a confrontation between two armed groups, resulting in combat deaths.

In a previous study, general patterns of gunshot-related trauma and injury were used to indicate forensic differences between remains found in Bosnian mass graves and remains from other combat situations [5]. A review of literature indicates combat-related injuries are often characterised by the presence of shrapnel and blast-related injuries [5,6], but assessments are complicated by the lack of standard classification and description of blast-related fractures in the human skeleton. Previously, most of the available information was presented in a medical management context rather than an osteological one [5], however, a number of publications have now detailed the anthropological aspects of the study of blast injury [7–9]. Blast related injuries are classified in four broad categories [10–12]. Primary blast injuries typically affect the air-filled organs, such as the lungs. Secondary blast injuries, the most commonly encountered injuries, are caused by the impact of materials into the body (such as shrapnel). The injuries resemble ballistic injuries, with blunt or ballistic penetration injuries [13–15]. Tertiary injuries are characterised by the movement of the body and its subsequent impact on structures, resulting in blunt injuries [12,16–18], resembling falls from height or the impact of an object on a bone [19]. Quaternary blast injuries are those which do not fall into the previous categories, such as burns. Injuries of anthropological interest are usually from the secondary and tertiary categories. Using blast-related fractures to discern between combat and human rights abuses requires examination-where possible- of the total body pattern of blast-related fractures in a sample of cases and comparing these to previously published studies on combat trauma.

This study examines the prevalence and distribution of blast-related fractures in a sample from documented Bosnian mass graves and compares the pattern to data from published studies of combat injuries spanning modern conflict. We also investigate if there are differences and similarities in the prevalence and distribution of blast-related fractures between civilian and combat-related casualties. Whilst investigators have presented evidence of human rights abuses in international courts, few studies have assessed if the distribution of injuries differs between victims of combat or human rights abuses. Our study is the first anthropological study attempting to address the question and determine if it is possible to differentiate between blast-related fractures from war crimes victims and combat casualtiesby examining the prevalence of these injuries in known blast-related deaths.

3. Materials and methods

The lead author (MCD) used data collected from autopsy and anthropology reports of known blast-related cases provided heldat the International Commission on Missing Persons, (ICMP)., The ICMP provided ethical approval and with whom the lead author signed a standard research agreement, and additional approval from the ethics committee at xxxx University. . The study compiles data from four mass graves, forensically linked to the Kravica warehouse case [20]. Documented evidence indicates that killings took place inside a building with the use of gunfire and multiple explosives (RPG’s and hand grenades). Men were documented as standing closely-packed together in large numbers in the building, then fired upon with automatic weapons, RPG’s and hand grenades from different directions and killed, after which bodies were moved to graves. We gathered cause and manner of death data from case records compiled by pathologists and forensic investigators. The sample size was 48 cases, all of which were documented as males, aged between 8 and 75 years. No recording of individual case numbers or discussion of identifying features were included in this study.

Cases were included if perimortem blast-related fractures were present as recorded in the pathology and anthropology autopsy documentation and photographs. Perimortem trauma was observed in photographs occurring on wet and dry bone [21,22]. Characteristics examined include the angle, outline, and edge of fractures [23]. The features of perimortem or wet bone fractures were an oblique obtuse or acute angle between the fracture and the cortical bone surface, the fracture outline shape (transverse, curved or V-shaped) and whether the fracture margin was smooth and straight as seen in the photographs and described in the reports. Postmortem or dry bone fractures were observed in the autopsy photographs by characteristics such as a right fracture angle, jagged edges to the texture of the fracture and colour variation between the fracture surface and the internal and external bone surfaces were noted.

Comparative data were collected from a range of previously published papers along with primary data from the Canadian World War One (WW1) death registers, available online from Library and Archives Canada. The cases chosen from this source are available at the Library and Archives Canada website (http://www.bac-lac.gc.ca/eng/discover/mass-digitized-archives/circumstances-death-registers/Pages/circumstances-death-registers.aspx) and were anonymized by excluding the names and service numbers that are available in the source data. The primary author selected cases with associated trauma from mortar blasts as this explosive munition is similar to the fragmentation-type grenades used in the Bosnian cases [24,25]. The sample included 141cases, all were male, over the age of 18.

The published combat data used for comparison included conflicts from Vietnam (1955-1975), Northern Ireland (late 1960's- 1998), Iraq/Iran (1980-1988), Lebanon (1982), the first Gulf War (1990-1991), Operation Iraqi Freedom (2003-2011), and Afghanistan (2001-2014) [17,26–30]. Additionally, we compared the blast fracture injuries from the Bosnia sample to blast fracture injury patterns sustained in the Oklahoma City (USA) bombing and a series of pub bombings in Birmingham, UK [31,32]. These studies were included to evaluate similarities or differences in blast fracture injuries sustained in a known building context, a characteristic that is absent from most conflict studies. We compared blast injury patterns from the remains from mass graves related to Kravica warehouse, to the following:

- blast injury patterns from known combat situations;
- blast injury patterns due to bombing explosions in buildings;

The data from the published trauma studies were limited by vague descriptions of orthopaedic injuries. Most of the clinical literature has a medical management focus and skeletal injuries are rarely described in detail. Their descriptions also varied in terms of specific regions of the body (i.e., upper arm, lower arm), specific bones or larger body regions such as the thorax, complete limbs, and head. To overcome differences in data quality between different studies, we divided the distribution of trauma by different body regions. We calculated the prevalence of blast related trauma in different body regions in the Bosnian sample to ensure comparability between data sets. The body regions were initially divided into the head, thorax, upper and lower limb. We increased the number of possible comparisons by matching our classification to those in the comparable studies. For example, one study divided the upper limb into its proximal and distal portions and the Bosnia data were analysed in the same manner to permit adequate comparison between those data sets.

Blast-related trauma was recorded as present or absent for each body region and noted using adichotomous classification system of 1 (absent) and 2 (present) for ease of statistical analysis. The data were compiled into a Microsoft Excel ™ spreadsheet and analysed using SPSS 19.0 [33] to compare the prevalence and distribution of blast-related fractures in the Bosnian sample to the different datasets. A Chi-squared statistic, with a Holm-Bonferroni correction to account for multiple comparisons, assessed significant differences between the prevalence of blast-related fractures in a body region, and distribution of trauma in the body region.

4. Results

The prevalence and distribution of blast-related fractures in different body areas differed significantly between various modern combat cases and the Bosnian mass grave cases.

4.1. Bosnia vs. WW1 (1914-1915)

We compared blast injuries from Bosnian casualties to soldiers killed during WW1 (1914-1915) at Ypres, Vimy, Passchendaele and the Somme. The WW1 sample included 141 casualties killed by explosive munitions such as mortars and blast-related shrapnel trauma. Blast injuries were significantly more common in the Bosnian sample in the vertebral column, pelvis, upper and lower limbs. There was no significant difference in the prevalence of trauma to the head and torso (Table 1; Figure 1).

Table 1: Prevalence of trauma and results of χ^2 (1, N= 189) analysis showing significant differences in the prevalence of blast-related fractures in the vertebrae, upper limbs, pelvis and lower limbs between cases from WW1 and Bosnian mass graves. Significant differences shown in bold.

Body Region	***p*-value**	**Prevalence WW1 (N = 141)**	**Prevalence Bosnia (N= 48)**
Upper limb	$\mathbf{p \leq 0.000}$	22.7%	68.8%
Pelvis	$\mathbf{p \leq 0.000}$	7.8%	45.8%
Lower limb	$\mathbf{p = 0.001}$	31.9%	60.4%
Vertebrae	$\mathbf{p = .002}$	14.2%	35.4%
Torso	$p = .056$	31.9%	47.9%
Head	$p = 0.314$	41.1%	50.0%

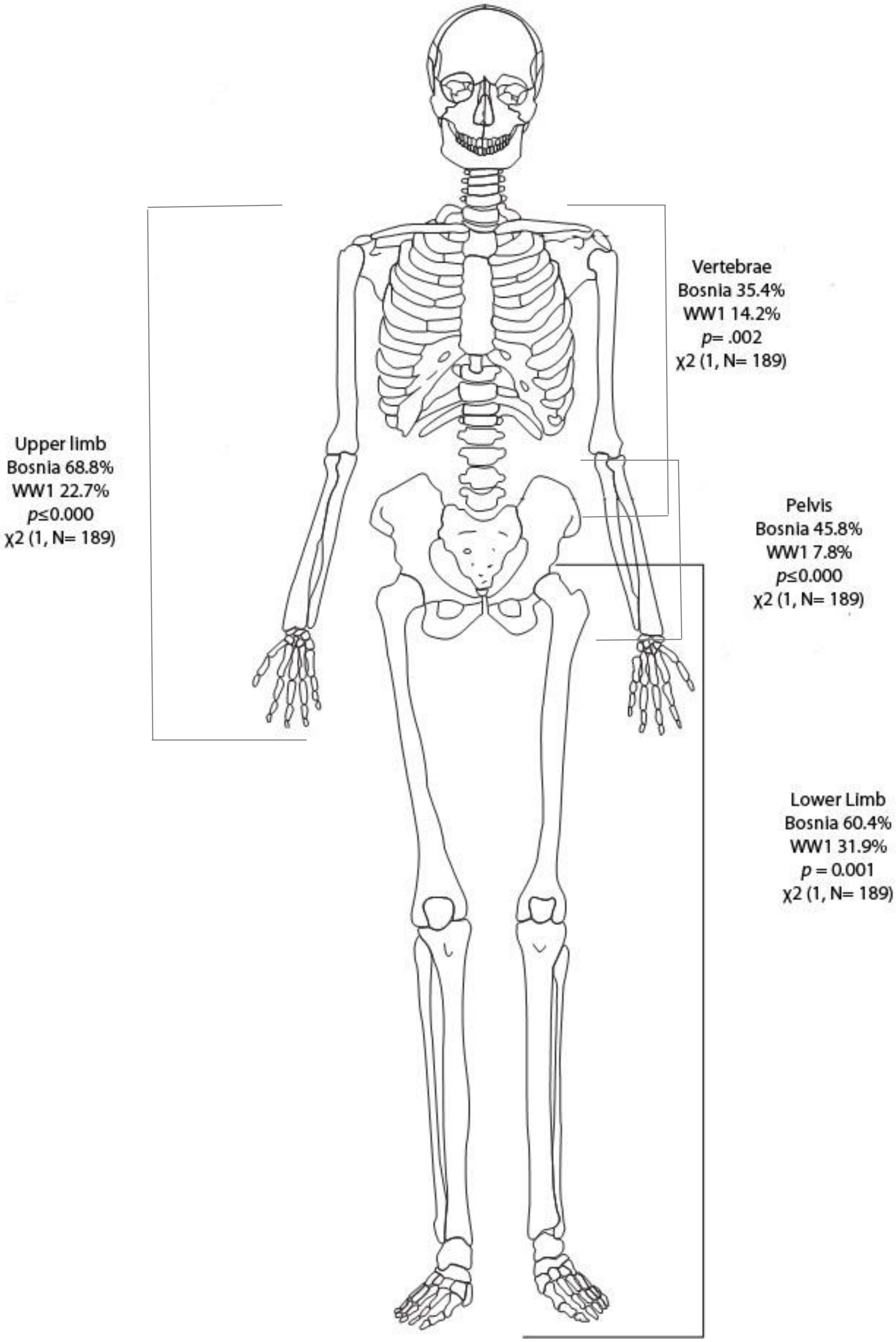

Figure 1: Distribution of areas of the body that are significantly different in prevalence of blast-related fractures between the sample from Bosnia and the sample from WW1.

4.2. Bosnia vs. Vietnam (1964-1972)

We compared the Bosnian sample to combat casualties from Vietnam killed between 1964 and 1972. In the Vietnamese sample, trauma was predominantly related to landmines, improvised explosive devices, grenades, RPG's and mortars [26,34]. Blast injuries in the Bosnian sample were significantly more prevalent in all body regions (Table 2; Figure 2).

Table 2: Prevalence of trauma and results of χ^2 (1, N=36788) analysis showing significant differences in the prevalence of blast-related fractures in: head, neck, and face; thorax and back; upper limb; and lower limb between cases from Vietnam and Bosnian mass graves. Significant differences shown in bold.

Body Region	*p*-value	Prevalence Vietnam (N = 36740)	Prevalence Bosnia (N= 48)
Head, neck, and face	**$p \leq 0.000$**	20.6%	50%
Thorax and back	**$p \leq 0.000$**	8.8%	47.9%
Upper limb	**$p \leq 0.000$**	27.2%	68.8%
Lower limb	**$p = 0.008$**	40.9%	60.4%

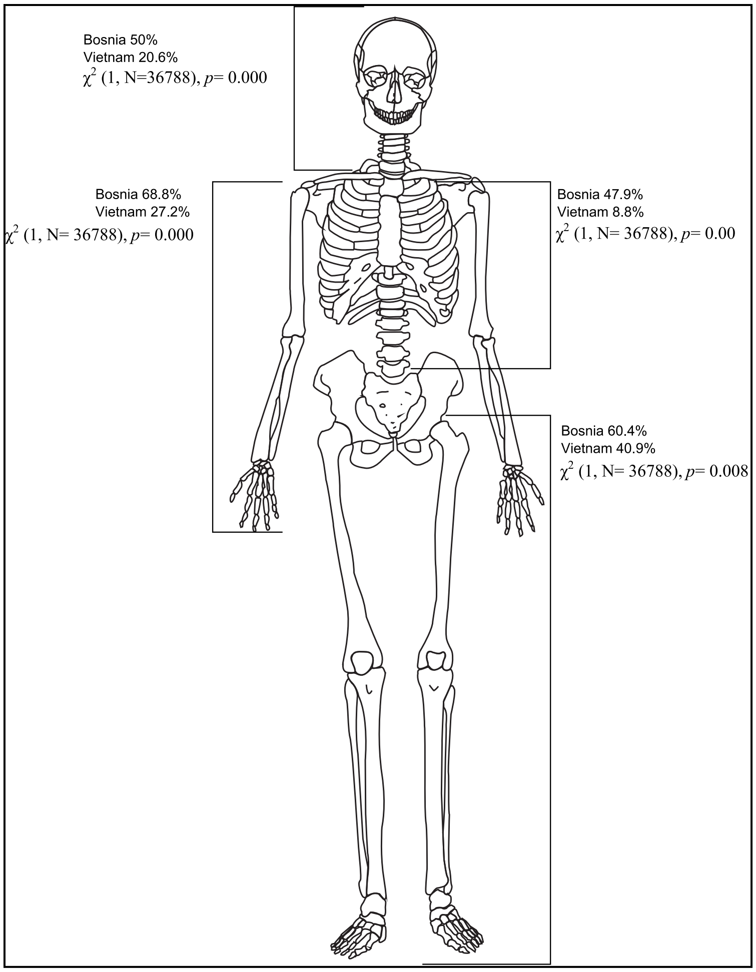

Figure 2: Comparison of the prevalence of trauma in a sample from Bosnia and a sample from Vietnam [22]. Areas of significant difference were the head, neck and face, the thorax and back, as well as the upper and lower limbs. Prevalence of trauma was also higher in the Bosnia sample, for all body regions.

4.3. Bosnia vs. Northern Ireland (1970-1974)

Data of casualties killed by mortars and artillery in Northern Ireland (1972-1974) were obtained from a military surgical unit [35] and compared to the Bosnian sample, focusing on three areas: the head, neck and face; the thorax and back and the upper limbs. We found significant differences in the head; neck and face; and the thorax and back, with the prevalence of blast injuries being higher in the Bosnian sample (Table 3; Figure 3). We compared the Bosnian sample to a second data set from Belfast, Northern Ireland [17] which included casualties from 1970 to 1984 that had been injured or killed by various explosions. Most of these casualties (90%) were wearing body armour but not head protection (20%) (11). Trauma in the upper and lower limb was significantly higher in the Bosnian sample compared to the Belfast, Northern Ireland sample (Table 3; Figure 3).

Table 3: Prevalence of trauma and results of χ^2 analyses showing significant differences in the prevalence of blast-related fractures in: head, neck, and face; thorax and back; upper limb; and lower limb between cases from Northern Ireland and Bosnian mass graves. Significant differences shown in bold.

Body Region	*p*-value	Prevalence Northern Ireland (1972-1974) (N= 669)	Prevalence Bosnia (N= 48)	Prevalence Belfast, Northern Ireland (1970-1984) (N= 298)
Head, neck, and face	***p*≤0.000**	13.2%	50%	--
Thorax and back	***p*≤0.000**	16.6%	47.9%	--
Upper limb	***p*≤0.000**	--	68.8%	29.9%
Lower limb	***p*≤0.000**	--	60.4%	35.6%
Upper limb	*p*= 0.361	61.9%	68.8%	--

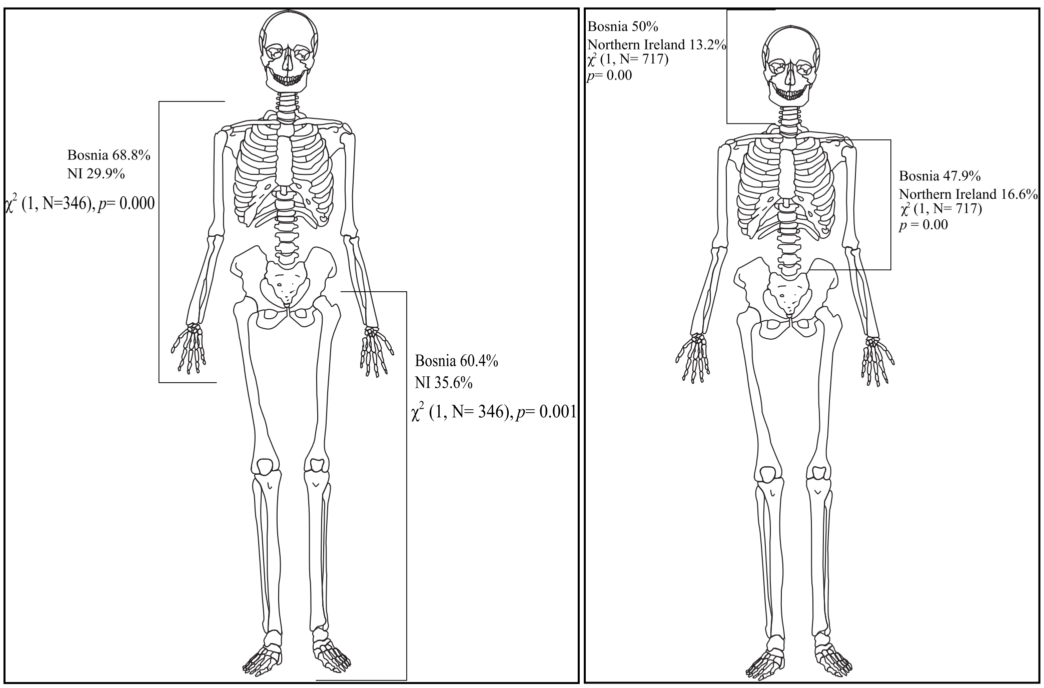

Figure 3: Prevalence of blast fracture injuries by body region. Panel A contrasts blast injury patterns in the Bosnian and Irish (1970 – 1984) samples. Panel B contrasts blast injury patterns in the Bosnian and Irish, Belfast (1972-1974) samples. Prevalence is higher in the Bosnia sample and significantly different in the head, neck and face and the thorax and back region (Panel A). In the second comparison, the prevalence of trauma in the upper limb, and the lower limb, is higher in the Bosnia sample, and both are significantly different.

4.4. Bosnia vs. Iraq and Iran (1980-1988)

We compared maxillofacial injuries sustained in Bosnia to those recorded during the Iraq and Iran war between 1980 and 1988 [27]. Sadda examined injuries to the lower third of the face and the mandible in 300 cases from the Basra Republic Hospital, none of whom died and most were wounded by low-velocity shrapnel. We found a significant difference in blast-related fractures of the mandible between the Iraq and Iran war and the cases from Bosnia (χ^2 (1, N= 348), *p*= 0.006). The cases from the Iraq and Iran War presented with a higher prevalence of trauma than the Bosnian sample (40.3% and 18.8% respectively) (Table 4; Figure 4).

Table 4: Prevalence of trauma and results of χ2 analyses showing significant differences in the prevalence of blast-related fractures to the mandible between cases from the Iraq Iran war and Bosnian mass graves. Significant differences shown in bold.

Body Region	*p*-value	Prevalence Iraq and Iran (N= 300)	Prevalence Bosnia (N= 48)
Mandible	***p*= 0.006**	40.3%	18.8%
Lower third of face	*p* = 0.591	24.3%	29.2%

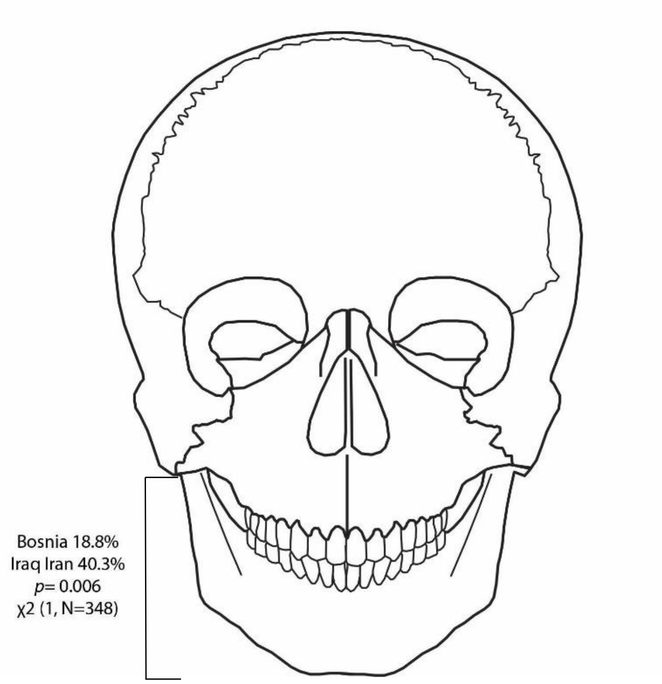

Figure 4: Prevalence of trauma to the mandible and lower third of the face in a sample from the Iraq/Iran War (12) and Bosnia. Prevalence is significantly higher in the mandible in Iraq/Iran than in the Bosnian sample.

4.5. Bosnia vs. Lebanese war (1982)

We compared injuries to the face, head and neck, torso and extremities incurred in the Lebanese war [29] to the Bosnian sample. Lebanese cases include casualties from June to September 1982 and includes cases of penetrating shrapnel injury. During this time, combat was characterised by artillery and aircraft bombing. We found significant differences in all regions of the body examined (χ^2 (1, N= 212), $p \leq 0.000$). Prevalence of trauma was higher in the face; head and neck; and extremities in the Bosnian sample but blast fracture injuries to the torso were more prevalent in the Lebanese sample (Table 5; Figure 5).

Table 5: Prevalence of trauma and results of χ^2 analyses showing significant differences in the prevalence of blast-related fractures in the head and neck, face, torso, and extremities between cases from Lebanon and Bosnian mass graves. Significant differences shown in bold.

Body Region	***p*-value**	**Prevalence Lebanon (N= 164)**	**Prevalence Bosnia (N= 48)**
Head and Neck	***p*≤0.000**	11.6%	50%
Face	***p*≤0.000**	34.8%	70.8%
Torso	***p*≤0.000**	84.1%	47.9%
Extremities	***p*≤0.000**	40.2%	60.4%

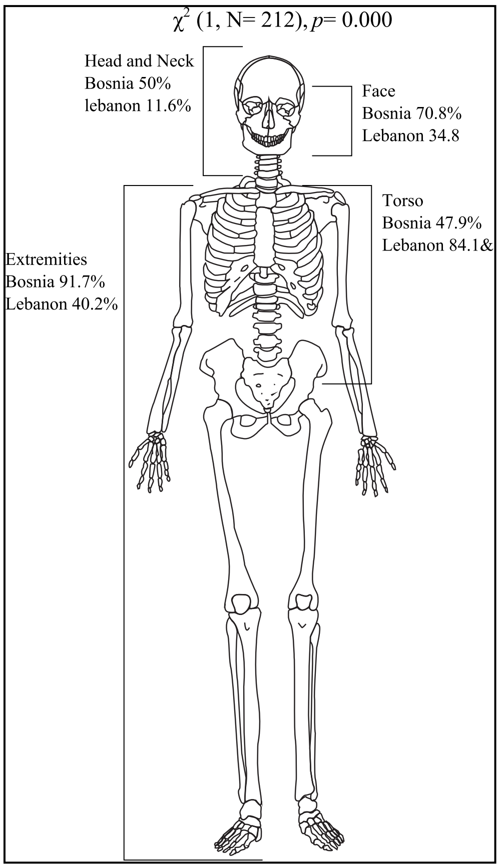

Figure 5: Prevalence of blast fracture injuries by body region for the Bosnia sample and a sample from Lebanon in 1982 [29]. Prevalence of injuries differed significantly in different body regions between the two samples, except for the torso.

4.6. Bosnia vs the first Gulf War (1991)

A study of trauma from the first Gulf War examined five body regions [26,36]: thorax and back; upper limbs; pelvis; head, neck, and face; and lower limbs. The cases included casualties treated in Army Corps Hospitals during Operation Desert Storm (February 20 to March 10, 1991) and included ballistic injuries from fragmenting munitions. Prevalence of blast injury trauma differed significantly between the Bosnian sample and the first Gulf War sample for all regions of the body (Table 6; Figure 6). Prevalence of blast fracture injuries was higher in the Bosnian sample in all body regions except the head, neck, and face regions and the thorax and back.

Table 6: Significance level and prevalence of trauma in Bosnian and first Gulf War samples [36]. All comparisons were significantly different [χ^2 (1, N= 203)]. Significant differences shown in bold.

Variable	***p*- value**	**Prevalence first Gulf War (N= 155)**	**Prevalence Bosnia (N= 48)**
Thorax and back	**$p \leq 0.000$**	5.8%	47.9%
Upper limbs	**$p \leq 0.000$**	30.3%	68.8%
Pelvis	**$p \leq 0.000$**	0.6%	45.8%
Head, neck and face	**$p = 0.001$**	76.1%	50.0%
Lower limbs	**$p = 0.007$**	37.4%	60.4%

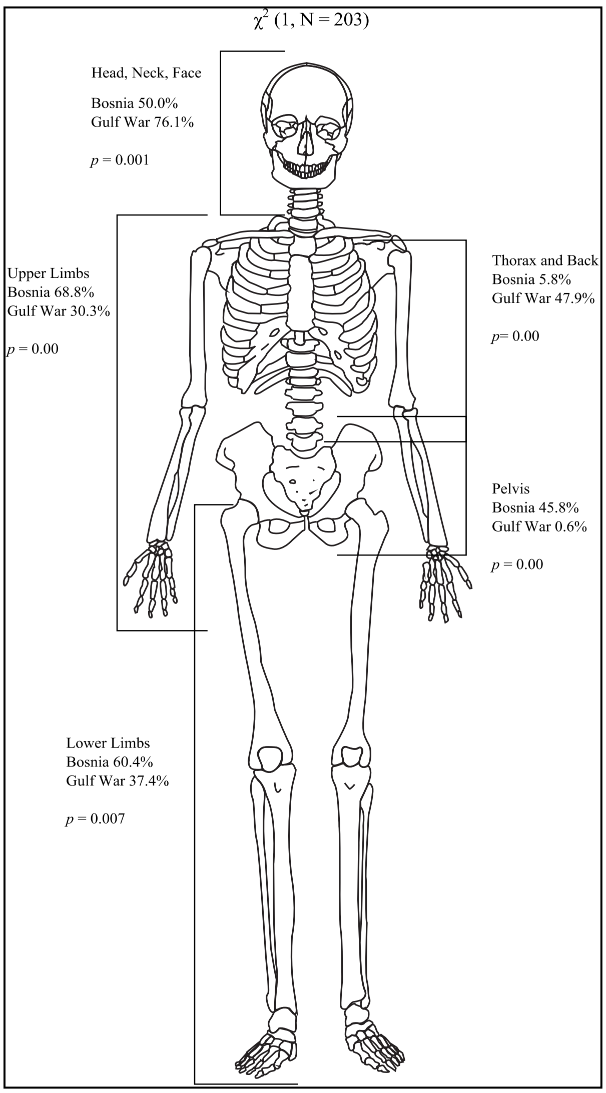

Figure 6: Prevalence of blast fracture injuries by body region for the Bosnia sample and a sample from the first Gulf War [36]. The prevalence of injuries sustained in the two conflicts varied significantly in different body regions except the torso.

4.7. Bosnia vs. Operation Iraqi Freedom (2003)

In a study of trauma sustained during Operation Iraqi Freedom (OIF), the prevalence of blast-injuries were recorded for five body regions: chest and back; lower limb; upper limb; head and neck; and the face [26]. Date were collected from wounded soldiers presenting in hospitals during March and April 2003. The cases included those wounded by explosive munitions such as IED's, land mines, rocket-propelled grenades, mortars and shrapnel. The prevalence of blast injuries was significantly greater in the lower limb in the OIF sample, but significantly less in the chest and upper back compared to the Bosnian sample (χ^2 (1, N= 90), p= 0.001 and χ^2 (1, N= 90), p= 0.004 respectively) (Table 7; Figure 7).

Table 7: Prevalence of trauma and results of χ^2 analyses showing the prevalence of blast-related fractures in the upper limb, lower limb, face, head and neck, and chest and back between cases from Operation Iraqi Freedom [26] and Bosnian mass graves. Significant differences shown in bold.

Variable	***p*- value**	**Prevalence Operation Iraqi Freedom (N= 42)**	**Prevalence Bosnia (N= 48)**
Lower limb	***p*=0.004**	88.1%	60.4%
Chest and back	***p*=0.001**	14.3%	47.9%
Upper Limb	*p*=0.041	88.1%	68.8%
Head and neck	*p*=0.136	66.7%	50%
Face	*p*=1.00	31.0%	29.2%

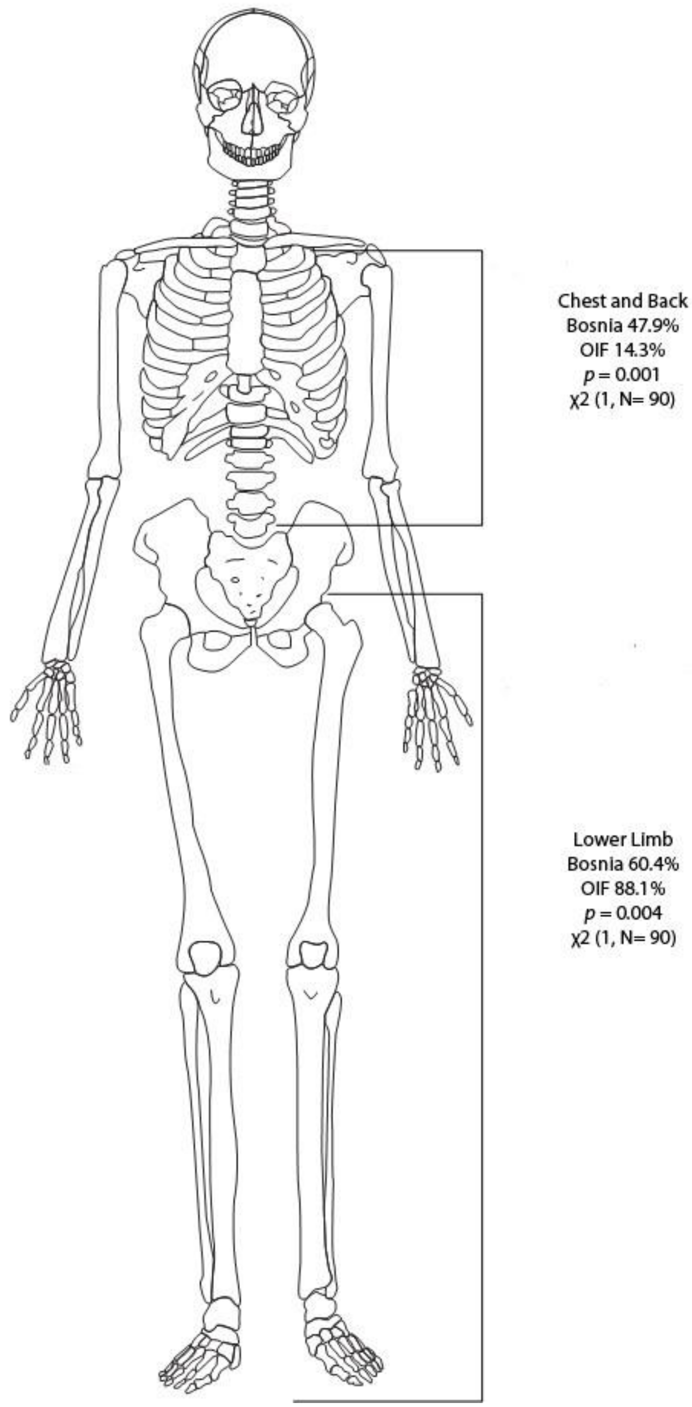

Figure 7: Comparison of prevalence of blast trauma in the Bosnia sample and a sample from Operation Iraqi Freedom [26]. Areas of significant difference were the chest and back and the lower limb.

4.8. Bosnia vs. Afghanistan (2008)

We compared the Bosnia samples to blast injuries to extremities incurred in an in-vehicle context in the Afghanistan conflict [30]. Casualties were admitted to a Field Hospital in Southern

Afghanistan between April 2008 and September 2008. In the Afghanistan sample, blast injuries were more common in the feet and femur but less in the humerus compared to the Bosnian sample (Table 8 and Figure 8).

Table 8: Prevalence of trauma and results of χ^2 analyses showing the prevalence of blast-related fractures in the feet, femur, tibia and fibula, humerus, and hand between cases from Afghanistan [30] and Bosnian mass graves. Significant differences shown in bold.

Variable	***p*- value**	**Prevalence Afghanistan (N=28)**	**Prevalence Bosnia (N= 48)**
Feet	**$p \leq 0.000$**	35.7%	2.1%
Femur	**$p=0.004$**	39.6%	10.7%
Tibia and Fibula	$p=0.023$	46.4%	20.8%
Humerus	$p=0.047$	3.6%	20.8%
Hand	$p=0.646$	3.6%	8.3%

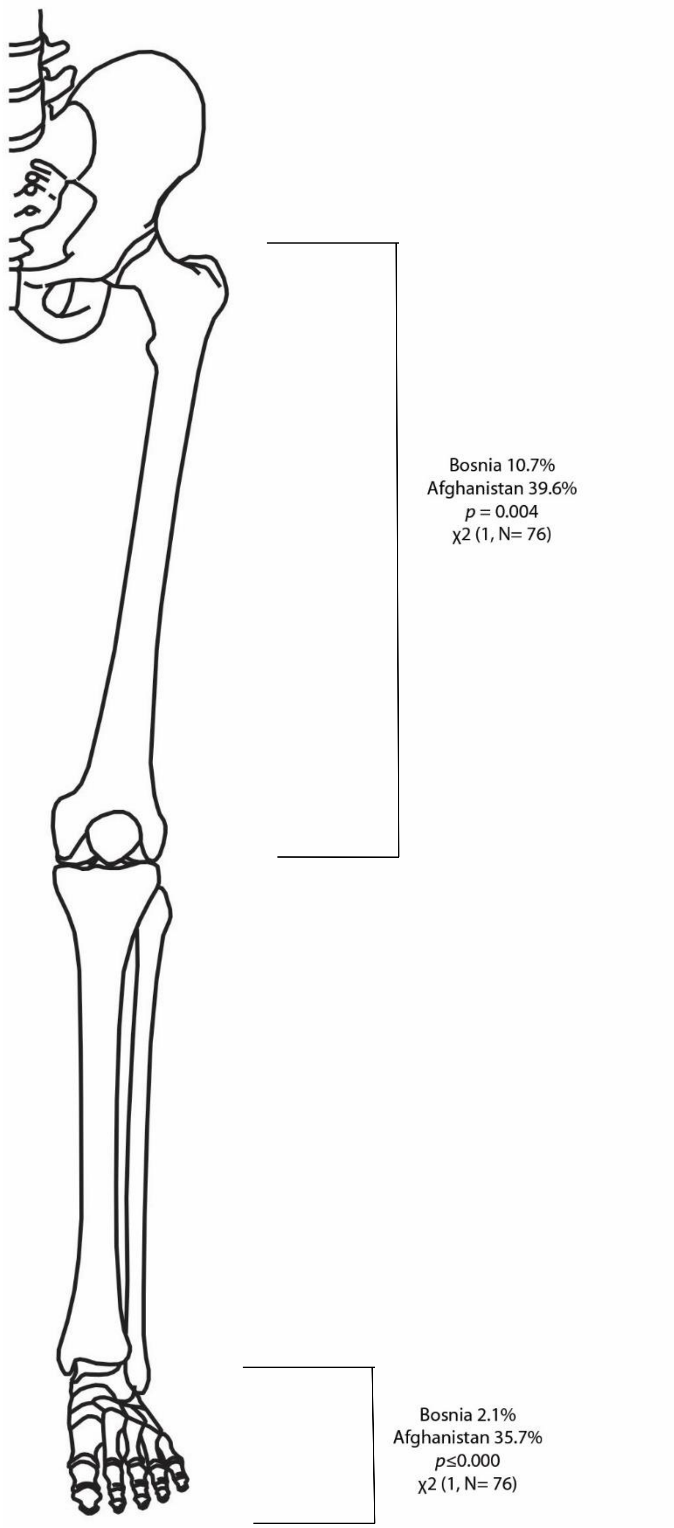

Figure 8: Prevalence of trauma to the feet and femur in a sample from Afghanistan [30] and Bosnia. Prevalence is significantly higher in the femur in Bosnia and significantly higher in the feet in Afghanistan.

4.9. Bosnia vs. bombings in buildings

Examining the Birmingham pub and Oklahoma City federal building bombings [31,32] permited a comparison of two civilian contexts with similar environmental factors. The Birmingham pub [31]bombings occurred on 21 November 1974 in two public houses, simultaneously. Twenty-one cases were analysed by Waterworth and Carr, who found that all cases were associated with injuries from a powerful close-proximity explosion within a confined space. Comparing the prevalence of blast fracture injuries the pub bombings with the prevalence of blast fracture injuries in the Bosnian mass graves, only the Bosnian sample had significantly more injuries to the lower limb (Table 9; Figure 9).

Table 9: Comparison of trauma prevalence in enclosed bombings in Birmingham [31].Table 3 shows a significant difference in the lower limb. Significant differences shown in bold.

Variable	*p*- value	Prevalence Birmingham (N= 21)	Prevalence Bosnia (N= 48)
Lower limb	***p*=0.002**	19.0%	60.4%
Extremities	0.027	66.7%	91.7%
Torso	0.6	38.1%	47.9%
Head and neck	1	47.6%	50.4%

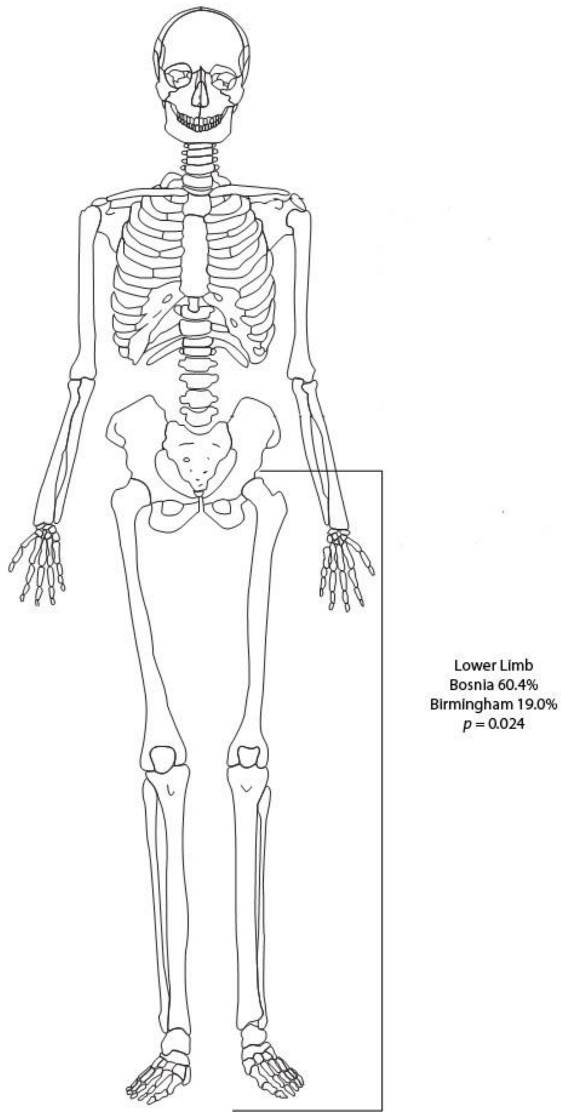

Figure 9: Comparison of trauma prevalence in enclosed bombings in Birmingham [31]. Significant difference is shown in the lower limb between Birmingham and Bosnia.

The Oklahoma City bombing took place on April 19, 1995 and is considered an in-building explosion, with a powerful improvised ammonium nitrate based explosive. The prevalence of blast fracture injuries in the lower limbs and, the head and neck, was similar in the Oklahoma City bombing data and the Bosnian sample. The prevalence of blast fracture injuries in the upper limbs and torso was significantly higher in the Bosnian sample than in the Oklahoma City sample (Table 10; Figure 10).

Table 10: Prevalence of trauma in Bosnia and the Oklahoma City bombing. Significant differences were found in the upper limb and torso [χ^2 (1, N= 108)].

Variable	***p*-value**	**Prevalence Oklahoma (N= 60)**	**Prevalence Bosnia (N= 48)**
Upper limb	0.002	38.3%	68.8%
Torso	0.016	25%	47.9%
Lower limb	0.052	40%	60.4%
Head and neck	0.177	36.7%	50%

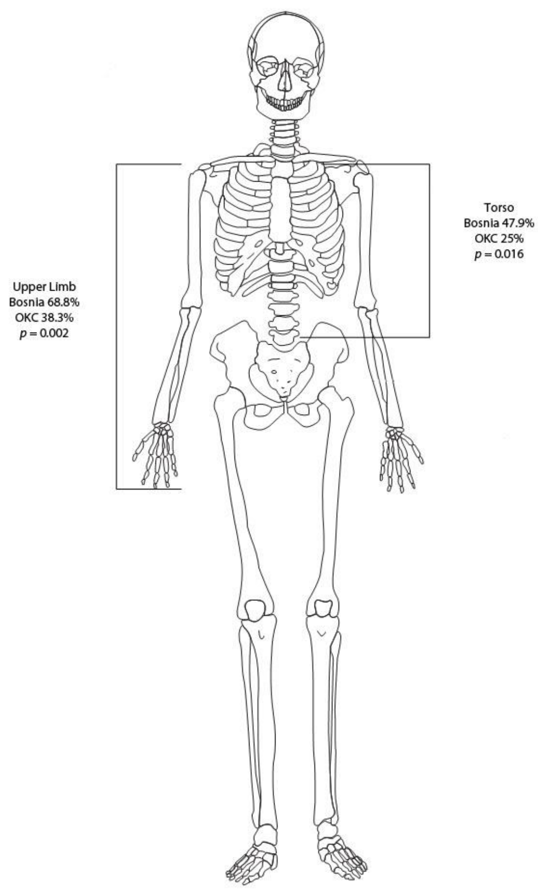

Figure 10: Prevalence of blast fracture injuries in the Bosnian sample and those sustained in the Oklahoma City bombings [32]. There were significantly more injuries to the upper limbs and torso in the Bosnian sample.

5. Discussion

We examined the prevalence and distribution of blast-related fractures in a Bosnian sample and compared these to combat injuries documented in historical and modern cases. We also compared the Bosnian sample with cases from explosions in buildings. The analysis assessed if the injuries seen in the Bosnian sample are consistent with those recorded from combat contexts, or are indicative of explosions in buildings. This study found significant differences in the prevalence and distribution of blast-related fractures in the Bosnian assemblages compared to various combat contexts, including the First World War, Vietnam, the first and second Gulf wars, Lebanon and Afghanistan. Most of our comparisons between contexts revealed a higher prevalence of blast injuries in multiple body regions in the Bosnian sample. The results indicate differences in the prevalence and distribution of blast trauma in different contexts which may reflect use of protective armour, the environment and the type of munition and its injuring mechanism.

We noted a significantly higher prevalence of trauma to the torso, particularly the pelvis and the vertebral column, in the Bosnian sample compared to the combat contexts. This trauma may be due to the effects of a reflected blast wave cause by explosions in enclosed contexts [10]. Explosions in enclosed environments result in blast waves that are reflected from walls causing amplification of the explosion [13,18,37]. The victims in the Bosnia cases were reportedly in a room, tightly packed, and exposed to multiple blasts from different directions. Amplified blast waves result in unique injuries, not often seen in outdoor combat situations. An exception is vehicles hit by explosions, where injuries to the exposed back and posterior portion of the pelvis are caused by blast waves reflecting from behind and below.

We might expect a similar prevalence and distribution of blast fracture injuries in the Bosnian sample and other combat contexts if body armour were worn in all situations. A lack of body armour in the Bosnian sample may have led to the observed increase in trauma to the torso compared to other combat contexts. Military issue protective armour may reduce the impact of the blast waves and shrapnel, leading to fewer injuries. The higher prevalence of blast fracture injuries to the torso in the Lebanese and Gulf War casualties (this study) may be due to failure of protective gear against fragmenting munitions and artillery bombings.

Protective gear also includes helmets. Regular use of helmets, e.g. Iraq/Iran and Operation Iraqi Freedom conflicts, possibly contributed to the reduced prevalence of head trauma compared to the Bosnian sample. Despite the use of helmets, blast fracture injuries to the head were more commonly reported in the Gulf War study than in the Bosnian sample. Our comparison of blast fracture injuries to the head sustained in the Bosnian sample to those sustained in other conflicts is consistent with head protection not being used by the victims in the Bosnian case. Documented accounts of the Kravica warehouse incident describe captives being forced into the warehouse before they were executed and dumped in multiple graves [29] and do not describe presence or use of body armour or helmets.

A second important aspect to consider when comparing civilian and combat injuries is the environment in which the blast occurs. In the Bosnian sample, explosions occurred in a building with many individuals standing close together when they were killed [29]. Aside from more injuries to the torso and extremities, reflected blast waves also cause diffuse trauma and a higher prevalence of trauma to multiple body regions [24]. In combat contexts, the enclosed effect does not always occur, unless conflict occurs in-building or in-vehicle rather than in open areas. The enclosed effect may have increased the severity of trench-related deaths in WW1. Compared to the WWI cases, there were more blast fracture injuries in the Bosnian sample in all areas of the postcrania, except the torso. The similar prevalence of torso trauma indicates that trenches may reflect blast waves causing a similar blast injury pattern to the Bosnian victims.

Blast injury type and distribution are influenced by the type of munition used in modern combat. The explosions in the Bosnian cases were reportedly caused by grenades and RPG's. Most of the combat cases studied predominantly list anti-personnel and fragmenting munition types as the injuring agent. Examining specific trauma in uncovered areas such as the limbs and comparing prevalence may provide clues to the context. In Northern Ireland, where roadside and pipe bombs were used, a similar injury distribution to RPG's and grenades was reported [13,14,30, 31]. Operation Iraqi Freedom and the Afghanistan conflict have a significantly higher prevalence of lower limb fractures compared to the Bosnian sample. This reflects the use of antipersonnel type munitions and improvised explosive devices fashioned as land mines. The use of landmines, booby traps and rocket-propelled grenades in Vietnam is reflected in the relatively higher prevalence of limb injuries compared to other body regions. Compared to all combat situations, the collective prevalence of blast fracture injuries was much higher in the Bosnian sample [29].

To examine blast injuries in an enclosed civilian context, we compared the prevalence of blast fracture injuries in the Bosnian case to injuries sustained in the Birmingham city pub bombings. The prevalence of blast fracture injuries in the different body regions was similar, except for more lower-limb injuries in the Bosnian sample. Fewer lower-limb fractures, seen in the Birmingham city pub bombings, may be attributed to the type of munitions used, furniture obstacles such as chairs and the seated position of the victims in the bombings. In the Bosnian sample, the victims were standing tightly packed in the warehouse. We also compared the Oklahoma City bombing and found no significant difference in the head and lower limb blast-related fracture prevalence. Compared to the Oklahoma City bombings, victims in the Bosnian sample had significantly more fractures in the upper limbs and torso, which could possibly be attributed to the reflection of blast waves or effects of multiple explosions in a small, enclosed space in the Kravica warehouse. However, this may also be due to the victims being seated in some cases in the Oaklahoma City Bombings, which may have afforded them protection from the blast.

Similarities and differences were seen between conflicts. In older conflicts, a diffuse pattern of injury with trauma to all areas of the body was more typical, with the more recent conflicts demonstrating a pattern of trauma focusing on the extremities. Concentration of trauma in the extremities may reflect the use of body armour in modern conflicts and the absence of trench warfare as seen in the First and Second World Wars. Injuries sustained due to explosions in buildings are diffuse, or occur throughout the body, compared to modern combat examples, which typically occur in the open. Although the blast fracture injury patterns observed in the Bosnian sample were similar to those observed in WW1 trenches, the Bosnian victims also had a high prevalence of extremity injury, similar to modern combat injuries.

We recognise that comparisons between the different conflicts may be limited due to the many variables that can cause similarities and differences in the whole body patterns of blast trauma observed, and the variation in the documentation of trauma in different studies. The selection of documented blast trauma only for this study, excluding documented gunshot trauma is also noteworthy. However, to gain insight into variation in blast trauma, we have included various contexts to expand the comparisons from available data. Further study will be necessary to compare additional aspects of thesecases and determine how the uniqueness of context impacts interpretation .

6. Conclusion

Several general conclusions can be made from the comparisons undertaken. There were more blast fracture injuries across all body regions in the Bosnian cases than in combat-related cases. Blast fracture injury patterns in combat situations are influenced by the use of body armour and the type of munitions used. The high prevalence of blast fracture injuries, in all body regions, in the Bosnian sample was not observed in any other single combat situation.

We documented multiple significant indicators from a range of conflicts that typify blast-related combat injuries. Older conflicts are typified by a diffuse pattern of injuries, when trench warfare and bombardment was common. Modern conflicts are typified by widespread use of helmets and body armour, leading to more injuries in the extremities, and more lower-limb injuries from in-vehicle contexts which resemble those seen in landmine cases. It should be noted however, that the range of equipment used and level of protection afforded y armour varies greatly.

‘In-building’ explosions cause a diffuse pattern of injury not seen in combat examples. Blast fracture injury patterns caused by explosions in buildings are consistent with fragmenting munitions, a reflective blast wave and a lack of body armour. The diffuse pattern of injuries in the Bosnian sample are similar to those seen in the explosions in buildings.

The interpretation of our results is limited by case specific information, knowledge of context and environment and focus on blast related trauma only. For example, if combatants without body armour were killed by explosions whilst fighting in buildings, their injury patterns may have been similar to those seen in the Bosnian sample. The possibilities thus need to be assessed in context and with knowledge of the crime or death scene. This puts an onus on investigations to comprehensively record the events and evidence around cause and manner of death to assist interpretation and indrawing conclusions.

Complex human rights or criminal investigations require a multidisciplinary investigation [40], which integrates all event data and evidence, including witness statements (providing context to the events), crime scene and forensic archaeology recovery and survey strategies (e.g. informing the recovery to take into account diffuse fragmentation of skeletal elements subjected to a blast wave) and physical anthropology examinations (e.g. incorporating clinical knowledge of injury causation and the pattern of blast trauma to the skeleton). Our study provides investigators, pathologists and anthropologists with summary information on the range of injuries that can be expected from scenarios with blasts from combat munitions and explosions in enclosed spaces. The study provides considerations that may aid in planning the undertaking of investigations and crime scene examinations, such as appropriate examination organization and techniques. The results provide considerations to aid in assessing victim and witness statements or historical accounts against victim examinations data. This may assist in assessing and classifying unidentified remains by helping determine the context of death and by contributing to the recognition of the causes and patterns of trauma.

The comparison of documented blast injury patterns from the Bosnian sample to combat and civilian examples are consistent with blast fracture injuries that are not typical of the reviewed combat situations and are typical of explosions inside buildings.

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