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ORIGINAL ARTICLE

Hemodynamic consequences of extremity injuries following a terrorist bombing attack: retrospective cohort study

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Abstract

Background Extremities are commonly injured following bomb explosions. The main objective of this study was to evaluate the prevalence of hemorrhagic shock (HS) in victims of explosion suffering from extremity injuries.
Methods Retrospective study based on a cohort of patient records maintained in one hospital's mass casualty registry.
Results Sixty-six victims of explosion who were hospitalized with extremity injuries were identified and evaluated. Sixteen (24.2%) of these were hemodynamically unstable during the first 24 h of treatment. HS could be attributed to associated injuries in seven of the patients. In the other nine patients, extremity injury was the only injury that could explain HS in seven patients and the extremity injury was a major contributor to HS together with another associated injury in two patients. In those 9 patients, in whom the extremity injury was the sole or major contributor to HS, a median of 10 (range 2–22) pRBC was transfused during the first 24 h of treatment. Six of the nine patients were in need of massive transfusion. Fractures in both upper and lower extremities, Gustilo IIIb-c open fractures and AIS 3–4 were found to be risk factors for HS.
Conclusions Ample consideration should be given to patients with extremity injuries due to explosions, as these may be immediately life threatening. Tourniquet use should be encouraged in the pre-hospital setting. Before undertaking surgery, emergent HS should be considered in these patients and prevented by appropriate resuscitation.

Keywords Hemodynamic instability · Multiple casualty incidents · Blast injuries

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Introduction

Extremity wounds are common following explosions [1]. They are associated with a higher rate of associated injuries, higher Injury Severity Score (ISS), longer hospitalization

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and increased risk of death compared with extremity injuries caused by gunshot wounds and motor vehicle accidents [1, 2].

Victims with extremity injuries may present with hemorrhagic shock (HS) both at primary assessment and during subsequent admission. It is presumed that associated injuries rather than extremity injuries are the cause of this HS. Reports of the July 7, 2005 London and the March 11, 2004 Madrid terrorist bombings described patients with extremity injuries and no truncal injuries who had HS [3, 4]. Guided by HS, negative and non-therapeutic laparotomies were performed in several of these patients. This experience suggests that there is a need to further explore HS in patients with extremity injuries following explosions, a mechanism of trauma with which civilian surgeons are relatively inexperienced.

The objective of this study was to evaluate the prevalence of HS in civilian victims of explosion suffering from extremity injuries and to assess possible risk factors for HS in patients with extremity injuries.

Methods

Hillel Yaffe Medical Center (HYMC) is a Level II trauma center located in Hadera, Israel. Over thirty thousand trauma patients are treated yearly in the emergency department, mostly following motor vehicle accidents and falls. As many as 10% are hospitalized. The hospital responded to 23 mass casualty incidents (MCI) following terrorist attacks between 1994 and 2005. Of these, 19 were bombing incidents. Patients admitted to the ED following a terror-related MCI are assigned unique admission numbers. Information concerning patients treated in HYMC was retrospectively collected and maintained in a MCI registry. The main purpose of this registry was to describe the different types of injuries encountered and their outcome. The registry includes demographic data, details of the hospitalization, clinical data concerning the mechanism of injury, specific injuries, treatment and outcome. This study was authorized by the HYMC's institutional review board.

For the purposes of this study, the registry was reviewed and all patients with extremity injuries following explosion in need of hospitalization were identified. Included in this study were patients with injuries to bone or soft tissue either to the lower extremity, upper extremity or both. Patients with extremity injuries limited to the skin and subcutaneous tissue were excluded.

The patient records were analyzed for demographics, fractures, soft tissue injury, associated injuries and injury severity. Patients were considered to have HS if suffering from either tachycardia (> 100 heart rate per minute) and/or hypotension (< 100 mmHg systolic blood pressure) and in need of blood transfusions to correct these disorders at admission or during the first 24 h of treatment. Injuries were classified according to the Abbreviated Injury Scale (AIS) [5]. Open fractures were further classified according to Gustilo's open fracture classification [6]. Hemoglobin and platelet levels measured during first 24 h were noted. Disseminated Intravascular Coagulopathy (DIC) was considered if consecutive platelet counts deteriorated and prothrombin time were prolonged [7]. The type and number of blood products transfused during first 24 h was assessed. These included packed red blood cells (pRBC), platelets, cryoprecipitate and recombinant Factor VIIa. Following review of the medical files, two authors (IA and RA) determined whether associated injuries could account for HS or death in patients suffering from these adverse events. Relative risk and *p* values according to Fisher's exact probability test were analyzed using dedicated statistical software (GraphPad InStat 3.06; GraphPad Software Inc, San Diego, CA, USA).

Results

Sixty-six victims of explosion suffering from extremity injuries were identified following review of 439 medical files. Average hospital length of stay was 18 days (95% CI 11–26 days). Other demographic and clinical data are shown in Table 1.

Nineteen patients were assessed as hemodynamically unstable upon admission (Fig. 1). Two patients with evidence of multiple injuries were admitted without signs of life and did not respond to immediate resuscitative efforts. In one other patient, no significant bleeding was found and hemodynamic instability was probably secondary to a severe head injury. The remaining sixteen patients had evidence of HS during the first 24 h of treatment. Twelve had HS on admission while four others developed HS during treatment.

HS was attributed to associated injuries in 7 of the patients. All of these patients were assessed as having HS on admission. Three patients died due to severe intra-abdominal injuries, two within 24 h and one due to multiple organ failure, 9 days after admission.

In seven patients, extremity injury was the only injury that could explain HS. In two other patients, the extremity injury could be considered a major contributor of HS together with another associated injury. One of these patients had open tibia-fibula fractures with bleeding, closed humeral fracture and associated burn, most of which was second degree and few areas which were third degree involving 45% of total body surface area. The second patient suffered from a penetrating injury to the globe of the eye, facial fractures, small bowel lacerations, intra-abdominal bleeding and an open fracture of the humerus with laceration of the brachial

Table 1 Demographic and clinical data in 66 patients

Characteristics	Number of patients
Age	
6–17 years	6
18–64 years	47
≥65 years	13
Hospitalized in ICU	15
Mortality	8
	(5 early; 3 late)[a]
Injury severity score	
1–8	26
9–14	17
16–24	9
25–75	14
Extremity abbreviated injury scale	
1	21
2	22
3	21
4	2
5	0
Patients operated (any operations)	54
Extremity injury	
Upper limb fractures	15
Lower limb fractures	24
Upper and lower limb fractures	4
Severe soft tissue only	22
Severe contusion only	1
Associated neurovascular injury	12
Associated injuries	
Intracranial haemorrhage	7
Spine	1
Chest injury	22
Abdominal injury	12
Tympanic membrane perforation	21
Eye injury	15

[a]Early deaths—within 24 h; late deaths—> 24 h

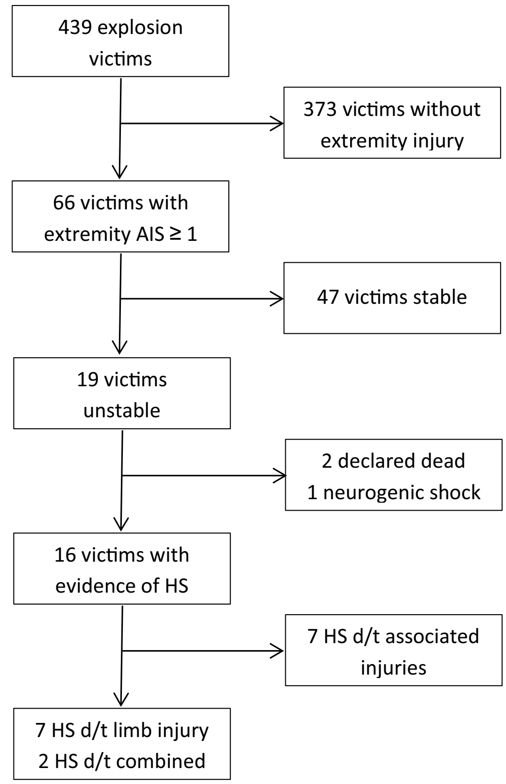

Fig. 1 Patient schema. *AIS* abbreviated injury score, *HS* hemorrhagic shock

artery which bled profusely until the bleeding was controlled by a tourniquet.

Of the 9 patients in whom the extremity injury was either the sole or a major contributor to HS, 6 were assessed as having HS on admission while 3 developed HS during treatment. A median of 10 (range 2–22) pRBC was transfused during the first 24 h of treatment. Six of the patients were in need of 10 or more pRBC during this time period. In two patients the hemorrhage could be ascribed to a major vessel bleeding. Only one of these, the patient with an eye injury described above, had a combined injury in which major bleeding also occurred from a non-extremity injury. Seven patients developed thrombocytopenia. In six patients platelet count decreased to below 100,000/microl. In three of these, platelet count decreased to below 50,000/µL. Seven patients developed laboratory evidence of DIC. Grading of DIC could not be achieved in most of patients due to lack of data concerning fibrinogen and fibrin degradation products. However, in four patients, platelet counts decreased within the first 24 h to 65,000/µL and less, coupled with PT prolongation of more than 6 s. Four patients received platelet transfusions. None received cryoprecipitate or recombinant factor VIIa. Two of the 9 unstable patients died of their injuries. One patient died from cardiac insufficiency within 24 h while the other died from multiple organ failure, 15 days after admission.

Comparing the nine patients in whom extremity injuries were either the sole or major contributors to HS to the 47 patients with extremity injuries without HS, three risk factors for HS stand out: fractures in both the upper and lower extremities; Gustilo III b or c fractures; and AIS (Table 2). Four of nine patients, aged 65 years and older, had HS. However, differences in age observed between patients with HS and patients without HS did not reach statistical significance. One patient, 84 years old, suffered from extensive soft tissue injury without any associated fracture. This patient probably bled from his wounds during the pre-hospital phase. He had HS on admission that responded to intravenous fluids. His wounds started bleeding profusely during treatment. Though

Table 2 Possible risk factors for Hemorrhagic Shock (HS)

Risk factors	HS ($n=9$)	No HS ($n=47$)	Relative risk (95% CI)	P value
Age				
<65	5	40	3.3 (1.1, 10.2)	0.0632
≥ 65	4	7		
Fracture location				
Other[a]	2	20	10.4 (4.5, 23.9)	0.0003[b]
Upper limb fractures	0	11		
Lower limb fractures	3	16		
Both upper and lower fractures	4	0		
Type of injury				
Other	2	42	12.8 (3.1, 54.0)	0.0001
Gustilo IIIb–IIIc	7	5		
AIS				
AIS 1–2	0	38	Infinite	<0.0001
AIS 3–4	9	9		

[a]Patients with severe contusion or soft tissue injury only with no fractures

[b]Fractures in both and upper limbs compared to all others

he responded to resuscitation with both crystalloids and blood products, he developed cardiac arrhythmias and died of cardiac failure.

Discussion

Extremity injuries requiring hospitalization are common following explosions [8–10]. In this study, almost one out of four patients with extremity injuries developed HS. In over half of these, extremity injury proved to be the main cause of HS. Six of nine patients were treated with massive blood transfusion.

Victims of explosion are not commonly encountered in the civilian setting. Rather, injuries in the civilian setting are predominantly blunt or penetrating secondary to motor vehicle accidents, falls, stab wounds and gunshot wounds. Following these mechanisms of injury, victims whose major injuries are located in the extremities are commonly considered moderately injured unless a major artery is severed. The AIS of most extremity injuries ranges from 1 to 3 yielding a maximum score of 9 on the ISS [5]. One of the patients, for example, with bilateral below knee amputation who was admitted with hemodynamic shock, would have only scored an AIS of three points. AIS underscores the life threatening potential of limb injuries caused by explosion.

Unlike the civilian setting, appreciation of the potential lethality of extremity bleeding is common in the armed forces whose physicians have been exposed to injuries resulting from explosions [11]. Tourniquets are now issued to all coalition soldiers and studies have validated their efficacy in saving lives [12, 13]. Following the extensive use by the military, some authors have advocated the use of tourniquets in the civilian pre-hospital setting as well [14–16]. In this setting, however, extremity injury as a source of exsanguinating hemorrhage is considered uncommon [17]. The extent of blood loss seen in some of the patients described in this study, and in other patients seen after the London, Madrid and Boston terror attacks demands a change of attitude towards extremity injuries seen following bombing incidents in the civilian setting [3, 4, 18]. Improvised tourniquets were applied on scene in most of the limb-injured victims of the Boston Marathon bombing [18]. This may have lowered mortality [19, 20]. However, bleeding control may be inadequate if the tourniquet is of suboptimal design [21]. In London, physiological decompensation during surgery for the extremities led to the performance of non-therapeutic laparotomies. In this study hemodynamic decompensation during treatment contributed to the death of two patients.

We assume that some of the patients suffering from extremity injuries bleed significantly from these injuries during the pre-hospital phase. The majority of the HS patients in this study were bleeding from the bone and soft tissue rather than from large named arteries. In these injuries, bleeding may not be overt on admission due to vasoconstriction and low blood pressure, leading to underestimation of the extremity as a source of significant hemorrhage. Bleeding from extremities may readily be controlled with pressure bandages or tourniquets applied either prehospital or immediately upon admission to the emergency department. Insufficient resuscitation before proceeding with operation in these patients may lead to hemodynamic decompensation during surgery. This decompensation may be exacerbated by the vasodilatatory and cardio-depressant effects of anesthesia and profuse bleeding from the wound may be aggravated by soft tissue debridement and local vasodilatation.

Patients with open limb fractures require early wound debridement and fracture stabilization. However, if the extremity injury is not profusely bleeding, resuscitation takes preference over debridement and operative fracture stabilization. Hypothermia, coagulopathy and metabolic acidosis should be assessed and corrected before proceeding with surgery. Initial treatment of extremity injuries in patients in whom surgery is delayed should include irrigation of gross contamination, bandaging, splinting, intravenous antibiotics and administration of tetanus toxoid. Early debridement is not an independent predictor of decreased risk of infection [22]. We, therefore, recommend that debridement should be delayed until the patient has been fully resuscitated.

The use of a pneumatic tourniquet may be considered for the debridement of limb injuries resulting from explosions. However the effectiveness of this may be limited. Adequate debridement entails excision of non-viable muscle [23]. The assessment of viability may be impaired if a tourniquet is applied. Furthermore, the major objective of surgery is to secure bleeding vessels which can only be identified if pressure from the tourniquet is released.

Limitations

A major limitation of this study is that it relies on data from over a decade ago on patients treated between 1994 and 2005. In these years, hypotensive resuscitation and blood transfusion protocols in trauma were not fully established. One could assume that some of the patients included in this study would not have bled as extensively if treated according to current resuscitation guidelines, thus avoiding HS. However, the basis for such an assumption is weak. Five of the nine limb-injured patients with HS suffered from instability on admission. The Israeli prehospital transport system does not carry blood. Extremely short transport times to the hospital in the different events would not allow any significant infusion of crystalloid, even if this was attempted [24]. Two patients developing HS during treatment were taken within less than 1 h to the operating theater. It was during their operation that it became clear they were suffering from HS. The first hemoglobin level in one patient was 5.6 and 10.7 g% in the second. It is uncommon to see similar deterioration in patients with limb injuries from any other scenario except for crush injury.

Another limitation concerns our primary intent to grade DIC according to the International Society on Thrombosis and Hemostasis (ISTH) criteria that includes measurements of PT, platelets, fibrinogen and fibrin degradation products [7]. Information concerning PT and platelets was available for all patients but fibrinogen and fibrin degradation product levels were not measured. We assume that patients who revealed prolongation of PT and decrease in platelet levels suffered from DIC which is why we presented these data, even if we could not grade the severity of the impaired coagulation. Thromboelastometry was not available during the years of the study.

Conclusion

Fifteen percent of bombing victims surveyed suffered from extremity injuries. One quarter of patients with these injuries presented with HS during the first 24 h of treatment. Half of the patients in shock were bleeding primarily from extremity injuries. The major risk factors for HS due to extremity injuries include fractures in both the upper and lower extremities, Gustilo III b or c fractures; and AIS 3–4. Patients with extremity injuries after explosions are at significant risk for HS. The use of tourniquets should be considered during pre-hospital treatment. HS should be considered and prevented by appropriate resuscitation before surgery.

Author contributions IA: substantial contribution to the conception and design of the work; acquisition, analysis and interpretation of data, drafting the manuscript and final approval. RS: substantial contribution to the conception and design of the work, critical revision for important intellectual content and final approval. FT: substantial contribution to the conception and design of the work, critical revision for important intellectual content and final approval. MSW: substantial contribution to the conception and design of the work, critical revision for important intellectual content and final approval. OO: substantial contribution to the conception and design of the work, critical revision for important intellectual content and final approval. WPS: substantial contribution to the conception and design of the work, critical revision for important intellectual content and final approval. RA: substantial contribution to the conception of the work and design, critical revision for important intellectual content and final approval.

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Compliance with ethical standards

Conflict of interest Itamar Ashkenazi, Roger Sevi, Fernando Turégano-Fuentes, Michael S. Walsh, Oded Olsha, William P. Schecter, Ricardo Alfici declare no conflict of interest concerning the contents of this manuscript.

Research involving animal and human participants This study inolved human subjects and was compliant with the 1964 Helsinki Declaration and its later amendments. This study was compliant with the Institutional Review Board of the Hillel Yaffe Medical Center.

Ethical approval This study was approved by the Institutional Review Board of the Hillel Yaffe Medical Center, Hadera, Israel.

Informed consent This was a retrospective observational study based on patient files, for which formal consent was not required.

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