ORIGINAL ARTICLE

Civilian spinal cord injuries due to terror explosions

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Study design: Retrospective analysis of civilians with spinal cord injuries (SCIs) due to terror explosions.

Objectives: To analyze and describe the clinical characteristics and rehabilitation outcomes of civilians with SCI due to explosions admitted for in-patient rehabilitation from 2000–2004.

Setting: SCI rehabilitation service, Tel Hashomer, Israel.

Methods: Retrospective chart review. Civilians with SCI due to terror-related gunshot wounds (GSWs) served as a control group.

Results: Eleven civilians with SCI caused by penetrating atypical foreign objects (PAFOs) and eight with GSWs were identified. The male-to-female ratio was approximately 2:1. Foreign objects were present within the spinal canal in seven patients, causing bone injury without canal penetration in three, and one patient had both bone injury and canal penetration. The most common level of injury was thoracic. Seven had complete motor SCI. Three individuals improved in American Spinal Injury Association status: one individual improved from B to C (cervical); one from C to D (thoracic); and the third from D to E (lumbar). Despite the similar acute hospital length of stay and functional independence measure (FIM) scores on admission, the PAFO group had a shorter rehabilitation length of stay with higher FIM scores and higher FIM efficiency at discharge.

Conclusions: Although the pathophysiology of PAFO blast injuries is similar to the high-velocity GSWs or the high-energy military munition injuries, better rehabilitation outcomes were seen, with slightly higher FIM efficiency and efficacy at discharge. This result is likely to be caused by less neurological tissue damage at impact.

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Keywords: spinal cord injury; terrorism; blast injuries; rehabilitation outcomes

Introduction

Spinal cord rehabilitation in Israel has years of experience in treating terror-related injuries. Terror attempts to destroy both the body and the spirit.¹ Data from the Israeli defense force shows that 7633 people were injured during the wave of terror in the early years of the 2000s.² In addition, since the start of this new millennium, rehabilitation professionals throughout the world have also become more familiar with these specific types of injuries, including those caused by explosions.

The leading mechanisms in traumatic spinal cord injury (SCI) in Western societies are blunt injury caused by motor vehicle accidents, falls or sport activities, and penetrating trauma, especially gunshot wounds (GSWs).³ The mechanisms of injury in essentially all of these types of injuries have been clearly defined. SCI due to explosions had been relatively uncommon until recently, and the pathophysiol-

ogy of the injury being more complex. The mechanisms of injury following explosions include the blast shock wave, penetrating fragments and thermal injuries. The mechanisms could be further characterized as to whether the blast was in a confined space or in an open area.⁴

Although combat SCIs are widely described,^{5,6} a review of the literature revealed only a few cases of terror-related SCI described and analyzed, and even fewer reports of SCI due to blast injuries.²

The purpose of this study is to analyze and describe the clinical characteristics of civilians with SCIs due to explosions and admitted for in-patient rehabilitation.

Materials and methods

This is a retrospective study of civilians with SCI due to terror-related blast injuries admitted to a national SCI rehabilitation department between the years 2000 and 2004. We collected demographic data, severity of the SCI as reflected by impairment, that is, the neurological level and the American Spinal Injury Association (ASIA) Impair-

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ment Scale,⁷ level of function as per the Functional Independence Measurement (FIM),⁸ imaging studies, outcome measures as expressed by the ASIA and FIM scores at discharge from rehabilitation, and the length of stay in the acute and rehabilitation departments (length of stay). The FIM efficacy was calculated.

Imaging studies were analyzed for the presence or absence of intraspinal canal fragments and for structural spinal injury.

The blast injuries were subdivided into two groups according to whether the blast occurred in an open or closed setting.

Civilians with SCI due to terror-related GSWs during the same time interval were used as a control group.

Results

Eleven civilians with SCI caused by blast injuries were identified. All had secondary blast injuries caused by penetrating atypical foreign objects (PAFOs). An additional group of eight civilians with SCI due to GSWs in terror attacks were admitted during the same period of time. The data regarding age, gender, marital status and employment are presented in Table 1. The age of the patients in both groups was filtered by the admission criteria of our rehabilitation center, as there are separate rehabilitation facilities for the pediatric and the geriatric populations, and is similar to the age of others with SCI treated in our facility. The male-to-female ratio was approximately 2:1, a much higher percentage of female SCIs than that seen because of other etiologies.⁹ All of the patients in both groups were either employed or students, despite a relatively high unemployment rate (>10%) in the country at that time.

The imaging studies showed various types of metallic hardware that were converted to agents of warfare to maximize the effects of the explosions. These included screws, nails, ball bearings, bolt nuts and other metal fragments (Figure 1).

Computed tomography scanning of the spine was the primary imaging technique used in all of our patients. The

findings were classified as to location of the foreign objects and structural bone injuries. PAFOs were present within the spinal canal in seven patients, causing bone injury without canal penetration in three, and one patient had both bone injury and canal penetration. Three of the patients underwent surgery for removal of the PAFOs.

In the group with SCI due to GSW, all had bone injury, five of the eight had either bullet or bone fragments within the spinal canal, and two had surgical removal of the bullet from the canal.

The SCI neurological characteristics as to level and completeness are shown in Tables 2 and 3. In both groups, thoracic level injuries predominated.

These penetrating injuries resulted in an unusually high rate of flaccid paralysis, even in those who would have been presumed to have upper motor neuron injuries based on the level of the trauma (7 of 17). The flaccid paralysis was present in six of the eight GSWs (including the two with lumbar injuries) and 3 of the 11 PAFOs.

Among the PAFO group, 3 of 11 showed neurological improvement as expressed by their ASIA classification: one individual improved from B to C (cervical); one from C to D (thoracic); and the third from D to E (lumbar) (Table 3). The PAFO group consisted of eight patients (73%) injured while indoors, and three patients (27%) who were injured outdoors. Of those who improved, two were open space injuries and one was an enclosed space injury. In the GSW group, no neurological improvement as indicated by the ASIA classification was noted (Table 4).

The majority of the patients in both groups suffered injuries at multiple sites of the body. In the GSW group, the additional sites were most frequently the abdomen and the limbs, whereas the PAFO group had injuries in the thorax and face, as well as burns. In addition, two of the PAFO patients also had associated brain injuries.

The GSW group had a higher incidence of infections (primarily pneumonia and urinary tract infection). Neuropathic pain requiring medication was more common in the GSW group (4 vs 1).

The groups had comparable FIM scores on admission to the rehabilitation facility. Length of the acute hospital stay was not significantly different between the two groups.

Despite the similar acute hospital length of stay and FIM scores on admission, the PAFO group had shorter acute rehabilitation length of stay with higher FIM scores and higher FIM efficiency at discharge. However, the differences were not statistically significant (Table 5).

One patient (GSW) died during the rehabilitation hospitalization. Another patient (PAFO) died during long-term follow-up. One patient was transferred to a nursing home and all of the others returned home.

In addition to our 19 civilian SCI patients, five other patients with SCI due to terror were described in an article by Schwartz *et al*.² Of these, four were caused by blast injuries and one was due to GSW. Thus, among the patients we were able to identify with SCI due to terror during the years 2000–2004, 62.5% were the result of blast injuries and 37.5% the result of GSWs. This closely reflects a 70 to 30% breakdown of blasts vs GSWs for all diagnoses

Table 1 Participants demographic characteristics

Characteristics	N = 19	Group GSW = 8	Group PAFO = 11
Gender			
Males (%)	13 (68.4)	8 (75)	7 (63.6)
Age (mean years)	34.5	36.5	33.0
Range (years)	15–77	15–77	22–63
Marital status			
Single (%)	7 (36.8)	2 (25)	5 (45.5)
Married (%)	12 (63.2)	6 (75)	6 (75)
Divorced (%)	0	0	0
Employment status			
Working (%)	13 (68.4)	6 (75)	7 (36.8)
Unemployed (%)	0	0	0
Student (%)	5 (26.2)	2 (25)	3 (27.3)
Retired (%)	1 (5.3)	0	1 (9.1)

Abbreviations: GSW, gunshot wound; PAFO, penetrating atypical foreign objects.

Figure 1 Weaponized metallic hardware.

Table 2 Neurological spinal cord injury characteristics

Characteristics	N = 19	Group GSW = 8	Group PAFO = 11
<i>Level of injury</i>			
Cervical (%)	4 (21.1)	1 (12.5)	3 (27.3)
Thoracic (%)	12 (63.2)	5 (62.5)	7 (63.6)
Lumbal (%)	3 (15.8)	2 (25)	1 (9.1)
Tetraplegia (%)	4 (21.1)	1 (12.5)	3 (27.3)
Paraplegia (%)	15 (78.9)	7 (87.5)	8 (72.7)

Abbreviations: GSW, gunshot wound; PAFO, penetrating atypical foreign objects.

of injuries in terror attacks as reported in a previous article.² These 24 patients comprise 0.3% of the total terror injuries in Israel.

Discussion

SCIs in civilian terror victims during the years 2000–2004 were caused by blast injuries or GSWs. Although penetrating injuries are often divided into high and low velocity, other factors such as bullet/fragment size, the presenting area of

Table 3 ASIA impairment on admission

Characteristics	N = 19	Group GSW = 8	Group PAFO = 11
<i>ASIA admission</i>			
A (%)	12 (63.2)	6 (75)	6 (54.5)
B (%)	2 (10.5)	1 (12.5)	1 (9.1)
C (%)	2 (10.5)	0	2 (18.2)
D (%)	1 (5.3)	0	1 (9.1)
E (%)	1 (5.3)	0	1 (9.1)
Cauda Equina (%)	1 (5.3)	1 (12.5)	0

Abbreviations: ASIA, American Spinal Injury Association; GSW, gunshot wound; PAFO, penetrating atypical foreign objects.

the fragment and the mechanical properties of the tissues involved all have a significant role. These factors take part in determining the amount of kinetic energy transferred from the bullet/fragment to the tissues. The effects of bullets and other penetrating fragments may be either direct or indirect.¹⁰ The direct effects are related to the bullet/fragment tract.

In blast injuries, the mechanisms of injury include the shock wave of the blast (primary injury) and the accelerated penetrating fragments (secondary injury). Secondary injuries may be further classified as to primary fragments that are

Table 4 ASIA impairment at discharge

Characteristics	N = 19	Group GSW = 8	Group PAFO = 11
ASIA discharge			
A (%)	12 (63.2)	6 (75)	6 (54.5)
B (%)	1 (5.3)	1 (12.5)	0
C (%)	2 (10.5)	0	2 (18.2)
D (%)	1 (5.3)	0	1 (9.1)
E (%)	2 (10.5)	0	2 (18.2)
Cauda Equina (%)	1 (5.3)	1 (12.5)	0

Abbreviations: ASIA, American Spinal Injury Association; GSW, gunshot wound; PAFO, penetrating atypical foreign objects.

Table 5 Rehabilitation outcomes

Characteristics	Group GSW = 8	Group PAFO = 11
LOS acute care		
Mean (days) $\pm$ s.d.	26.4 $\pm$ 26.4	24.7 $\pm$ 20.5
Range	5–75	8–64
LOS rehabilitation		
Mean (days) $\pm$ s.d.	177.1 $\pm$ 68.3	150.7 $\pm$ 126.7
Range	102–291	20–401
		$P = 0.317$
FIM admission		
Mean (days) $\pm$ s.d.	66 $\pm$ 14.3	65.8 $\pm$ 15.0
Range	48–84	48–90
FIM discharge		
Mean (days) $\pm$ s.d.	100.2 $\pm$ 29.8	105.8 $\pm$ 24.4
Range	48–116	49–126
FIM gain (efficiency)	34.2	40
Relative efficiency	0.441	0.322

Abbreviations: FIM, functional independence measure; GSW, gunshot wound; LOS, length of stay; PAFO, penetrating atypical foreign objects.

parts of the weapon, and secondary environmental fragments accelerated by the explosion. In addition, there are tertiary injuries due to structure collapse with crush injuries, and quaternary injuries due to thermal, chemical or infective agents.^{11,12}

In the PAFO group of our study, imaging showed the presence of fragments at the anatomical level, which correlated with the neurological findings. Therefore, we assume that all were secondary injuries, due to primary fragments, that often included metallic hardware placed in the 'homemade' bombs, that is, PAFOs. In a previous report, penetrating injuries from primary and secondary fragments were noted to be the leading cause of morbidity and mortality in both military and civilian terrorist attacks.⁹

SCIs due to GSWs are widely recognized as resulting from both the direct effects of the bullet, including secondary bone injuries, as well as the high-energy component. In the presence of a high-energy component, the indirect effects may be more significant in determining the severity of the injury. The indirect effects include contusions and lacerations removed from the tract of the bullet. As the bullet travels through the tissues, a wave of compressive energy is

followed by negative pressure that can both disrupt tissues not directly traumatized as well as suck environmental contaminants into the wound cavity. Radial forces perpendicular to the tract may result in cavitation, and can cause indirect bone fractures.^{8,13–15}

Our study was undertaken to analyze and describe the clinical characteristics of civilians with SCIs due to explosions and admitted for inpatient rehabilitation. It was expected that, owing to the differing mechanisms of tissue damage, there would be an observable effect on the clinical course and functional outcomes.

Despite the relatively small number of patients, there were some relevant clinical findings. In all of those with explosion-related SCI, the spinal cord damage was due to foreign body tissue penetration, and there was a higher rate of neurological recovery in this group compared with the GSW group. Our assumption is that this latter finding is probably related to a lesser degree of neurological tissue injury and thus may explain the slightly higher FIM efficiency and efficacy at discharge.

The unusually high rate of flaccid paralysis (7 of 17) in the total group of those with presumed upper motor neuron injuries occurred more frequently in the GSW than the PAFO group. This presentation may well be the result of the kinetic energy from the bullet or fragments, longitudinally disrupting the gray matter, including the possibility of cavitations. The overall implication is that the PAFO injuries may in fact be similar to the high velocity, high-energy military munition injuries, but the lesser level of velocity and energy is likely to cause less neurological tissue damage.

The study population was specifically limited to civilians, as their injuries would likely differ from military blast injuries where the use of protective clothing modifies the effects of the potential PAFO. The distribution of the anatomic sites of injuries in fact showed that both the control GSW and study PAFO groups suffered a high proportion of thoracic level injuries, whereas a report on PAFO injuries in the current USA military conflicts describes the injuries as being most frequently at the cervical level.¹⁶ Furthermore, attacks on unprotected civilians may not involve the same level of high-grade explosives used against protected military targets.

In conclusion, our assumption that there will be a clinical differentiation between the two groups of terror-related SCI was only partially supported by the data. There were small but statistically significant differences in the neurological outcome with greater improvement in the PAFO group. Functional improvement did not reach statistical significance, although it was slightly better in the PAFO group.

There would be value combining our data with data from other countries that have also suffered significant terror-related injuries to the civilian population. Such a meta-analysis may indeed provide important diagnostic and prognostic information.

Conflict of interest

The authors declare no conflict of interest.

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