Review

Clinical review: The Israeli experience: conventional terrorism and critical care

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Abstract

Over the past four years there have been 93 multiple-casualty terrorist attacks in Israel, 33 of them in Jerusalem. The Hadassah-Hebrew University Medical Center is the only Level I trauma center in Jerusalem and has therefore gained important experience in caring for critically injured patients. To do so we have developed a highly flexible operational system for managing the general intensive care unit (GICU). The focus of this review will be on the organizational steps needed to provide operational flexibility, emphasizing the importance of forward deployment of intensive care unit personnel to the trauma bay and emergency room and the existence of a chain of command to limit chaos. A retrospective review of the hospital's response to multiple-casualty terror incidents occurring between 1 October 2000 and 1 September 2004 was performed. Information was assembled from the medical center's trauma registry and from GICU patient admission and discharge records. Patients are described with regard to the severity and type of injury. The organizational work within intensive care is described. Finally, specific issues related to the diagnosis and management of lung, brain, orthopedic and abdominal injuries, caused by bomb blast events associated with shrapnel, are described. This review emphasizes the importance of a multidisciplinary team approach in caring for these patients.

Introduction

Every hospital should be able to respond to a multiple-casualty terror attack as it can occur anywhere and anytime [1]. Over the past four years there have been 93 multiple-casualty terrorist attacks in Israel, 33 of them in Jerusalem. The Hadassah-Hebrew University Medical Center is the only Level I trauma center in Jerusalem and has therefore gained important experience in caring for the critically injured patients. Despite the violence, all surgical services continued providing all routine services, including our general intensive care unit (GICU). To do so we developed a highly flexible operational system for managing the GICU. The focus of this report will be on the organizational steps needed to provide operational flexibility. In addition, issues related to the

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ARDS = acute respiratory distress syndrome; CT = computed tomography; ED = emergency department; GCS = Glasgow Coma Score; GICU = general intensive care unit; HFJV = high-frequency jet ventilation; ICP = intracranial pressure; ICU = intensive care unit; ISS = injury severity score; MCI = multiple-casualty incident; PACU = post-anesthesia care unit; PEEP = positive end-expiratory pressure; SIRS = systemic inflammatory response syndrome.

diagnosis and management of specific injuries associated with terror events will be discussed.

Numbers and statistics

A retrospective review of the hospital's response to multiple-casualty terror incidents occurring between 1 October 2000 and 1 September 2004 was performed. Information was assembled from the medical center's trauma registry and from GICU patient admission and discharge records. The information we collected included the following: type of attack, number of victims at the location, number of patients treated and admitted to the intensive care unit (ICU), location before admission to the ICU [operating rooms, imaging department or emergency department (ED)], trauma injury severity score (ISS), time for admission to the ED, time to admission to the ICU, length of stay in the ICU and mortality in the ICU.

ICU organization

The hospital intensive care facilities include 29 surgical ICU beds (11 general, 6 pediatric, 6 neurosurgical, and 6 cardio-thoracic). When these ICUs are full, patients are treated in the 14-bed post-anesthesia care unit (PACU), which is adjacent to the GICU. In addition, nine medical intensive care beds are available. The GICU is part of the Department of Anesthesiology and Critical Care Medicine. All ICU attending professionals are board-certified anesthesiologists. All anesthesiology residents have training in intensive care (6 months of an ICU rotation) and are routinely involved in the daily care of patients in the GICU.

Patients

After 33 major terror attacks, 541 victims were admitted to the ED of the Hadassah Hebrew University Medical Center, of whom 208 were hospitalized. Twenty of these attacks involved more than 10 wounded and therefore were defined as a 'multiple-casualty incident' (MCI; Table 1). In preparation for the admission of critically injured terror victims, 40 patients were transferred out of the GICU either to a regular ward (75%) or to another ICU (25%). Additional patients (postoperative) were discharged from the PACU if their condition was deemed stable. This was done to increase the number of GICU beds. One hundred and one (49%) patients were admitted to an ICU (median 4 admissions per event; range 0 to 9), 86 to the GICU, 8 to the neurosurgical ICU and 7 to the pediatric ICU. The age distribution of terror victims was skewed towards the younger generation (80% aged 15 to 44 years, compared with 37% for other traumas). During this period, a total of 2,647 patients were admitted to the GICU, of whom 4% were victims of these terrorist attacks. Twelve patients, who were victims of five different attacks each associated with more than six admissions to the GICU, were initially admitted to the PACU. Fifty-seven patients were admitted from the operating rooms (56%), 11 from the angiography suite (10%) and the rest were admitted directly from the ED (34%).

The average time from the initial trauma to admission to the GICU was 5.5 ± 3.1 hours (mean ±SD) (range 1 to 13 hours). Patients admitted directly from the ED or angiography suite were admitted earlier than those from the operating rooms (means 3.8, 3.7 and 6.3 hours, respectively). The severity of injuries is demonstrated by the fact that 47 of 101 patients (46%) had to be intubated in the ED in addition to those already intubated at the scene. Out of all the 541 MCI terror victims, 12 patients admitted to our center were intubated at the scene and 16 patients were admitted as secondary transfers after initial resuscitation from other hospitals. Furthermore, 116 (56%) of the patients admitted to our Level 1 trauma center needed surgery within the first 8 hours after the attack. Less severely injured patients were diverted by the emergency medical services to other regional trauma centers in the Jerusalem area [2]. The terror victims stayed in the GICU for an average of 9 days (range 1 to 80 days; Table 2), whereas the median length of stay for the entire GICU population was 3 days. More than half of the patients admitted to an ICU had an in-hospital length of stay of two weeks or more (Table 3). The average overall mortality rate for patients in the ICU was 8.5% in 2001 to 2004. Finally, patients hospitalized after terror events had sustained more severe injuries (74% versus 10% in other types of trauma with an ISS of more than 16) and had double the mortality (6.2% versus 3%) [3].

Type of injury

The hallmark of the injuries was a combination of blunt trauma and penetrating injuries due to bolts. The injuries could be divided into three categories. Blunt trauma was diagnosed in 51 patients, burns in 33 and penetrating injuries in 90 patients. Blast injury was registered as blunt injury. Commonly victims suffered injuries originating from more than one mechanism of injury. Moreover, victims commonly had injuries to several parts of the body, the most frequently injured region being the head, neck and facial area (Tables 4 and 5). The ISS in the 101 patients requiring intensive care varied from 5 to 75 with an average score of 24 (Table 6). Four patients with low ISS scores (5 to 8) were admitted to the unit for a 24-hour observation period: two patients for chest and neck burns, one patient after neck exploration and one patient kept intubated after a long surgical intervention. The Glasgow Coma Score (GCS) on admission in these patients was as follows: 29 (28.7%) injured had a GCS of 3 to 8; 6 (5.9%) within the range 9 to 12; and 66 (65.3%) had a GCS of 13 to 15.

Exploring the sequence of events and organizational issues

On 24 May 2001 the floor of Versailles Hall (located on the third floor of a building in the center of Jerusalem) collapsed during a wedding celebration. Over a 2-hour period more than 200 victims were admitted to the Hadassah ED. On the basis of our experience from this incident, we believe that the response to a multiple-casualty terror attack does not differ

Table 1

Data for 20 major bombing attacks with more than 10 wounded

Date	Location	Wounded on scene (*n*)	ED admissions (*n*)	Hospital admissions (*n*)	ICU admissions (*n*)	Ventilated (*n*)	Acute surgery (*n*)	In-hospital deaths (*n*)
Aug 2001	Restaurant	113	18	8	4	2	4	–
Dec 2001	City center	188	65	26	9	6	18	1
Jan 2002	City center	150	32	3	1	1	1	–
Mar 2002	Street	58	8	4	4	3	3	1
Mar 2002	Café	64	35	10	5	3	8	–
Mar 2002	Café	100	17	4	2	2	4	1
Mar 2002	Supermarket	50	33	3	1	1	2	–
Mar 2002	EMS station	10	7	2	2	2	2	–
Apr 2002	City center	66	23	6	4	3	4	–
Jun 2002	Bus	73	25	11	6	7	7	1
Jun 2002	Square	20	9	5	2	2	2	–
Jul 2002	University	93	25	15	8	8	13	2
Nov 2002	Bus	58	44	15	8	8	11	1
May 2003	Bus	27	5	4	4	4	3	–
Jun 2003	Bus	100	21	9	5	5	6	1
Aug 2003	Bus	154	33	16	9	9	7	2
Sep 2003	Café	(missing)	26	6	3	2	5	–
Jan 2004	Bus	60	17	8	6	6	4	1
Feb 2004	Bus	69	26	14	3	2	6	–
Aug 2004	Checkpoint	22	8	7	6	4	3	–
Total		1,475	477	176	92	80	113	11

ED, emergency department; EMS, emergency medical services; ICU, intensive care unit.

Table 2

Length of stay in the intensive care unit for 101 terror victims

Length of stay (days)	No. of patients (%)
0–3	44 (44)
4–7	23 (23)
8–14	20 (20)
15–21	5 (5)
>22	9 (9)

Table 3

Hospital length of stay in 101 terror victims primarily admitted to the intensive care unit

Length of stay (days)	No. of patients (%)
0–6	14 (14)
7–13	34 (34)
14–20	12 (12)
>21	41 (41)

from the response to any other multiple-casualty trauma. Hence, lessons learned during these events should be implemented by others in preparation for catastrophes. A previous publication discussed the in-hospital response to the specific actions that were taken in response to the various time periods of a multiple-casualty terror event:

assessment of incident size and severity; alerting of backup personnel; initial casualty care; and definitive treatment [4].

To streamline the administration of a multiple-casualty event, two important administrative concepts have been adopted: first, peri-incident intensive care management ('forward

Table 4

Numbers of patients with injuries to specified parts of the body out of 101 terror victims treated in the intensive care unit

Injured part of the body	No. of patients
Face	56
Chest	51
Lower extremities	46
Head	44
Upper extremities	39
Abdomen	32
Neck	17
Spine	7

Note: several patients had more than one injury.

Table 5

Isolated versus combined injuries in 101 terror victims admitted to the intensive care unit

Injured part of the body	No. of patients
Isolated injury	15
Combined injuries	86
With head injury	40
Head, chest, abdomen	5
Head, chest	21
Head, abdomen	3
Without head injury	46
Chest, abdomen	11
Combined injuries including extremities	55

Table 6

Injury severity score (ISS) in the 101 terror victims admitted to the intensive care unit

ISS	No. of patients (%)
5–8	4 (4)
9–14	22 (22)
16–24	29 (29)
>25	46 (46)

deployment') and second, maintaining a 'chain of command' [4]. Forward deployment of anesthesiology and surgical personnel is the procedure used at Hadassah for responding to all traumas. When severe injuries occur, an anesthesiology resident with ICU training or a critical-care fellow continuously

cares for a severely injured patient from admission to the ED, through imaging studies in the radiology department and during surgery. Continuity of care is guaranteed and vital information is collected by one dedicated team and the complete medical picture of the specific patient is maintained. This is especially important in severe multiple-trauma patients for whom surgical teams often change during several multi-disciplinary interventions.

A chain of command should be established by the institution and the departments as soon as possible. This is essential to control the chaos that will ensue as victims arrive en masse. Command rests with the most senior personnel available on site from general surgery, orthopedic surgery and anesthesiology/ critical care medicine and hospital administration. As events evolve and more senior personnel arrive they will take charge. A senior general surgeon performs triage at the door of the ED. Another experienced general surgeon acts as the 'surgical command officer' who guides the trauma teams. The command team maintains a log of the most severely injured victims. They consult frequently in the ED as to the disposition of these patients (operating room, radiology suite, ICU or recovery room). The GICU attending professional is present in the ED trauma area to evaluate those wounded who may need intensive care. This early evaluation is of utmost importance to help direct the placement of each of these patients in the ICU or in a less intensive area such as the PACU. Early knowledge of the type and magnitude of injuries gives an immediate estimate of the number of ICU beds required. In addition, it is helpful in planning the exact ICU bed for each patient. It is important to prevent clustering of the most complicated patients in one location, treated by few nurses, while other areas are left out. Furthermore, providing early information to the ICU team on the injuries their patient has suffered allows time to organize special equipment such as ventilators, rapid infusion and blood-warming devices.

Sequence of events
Assessment of incident size and severity
After a terror attack there is a latent period, lasting at least 20 minutes, in which events are taking place outside the hospital [4]. During this period, estimating the number of victims and the possible severity of their injuries is crucial for proportional 'department wakeup'. Estimations depend on the day of the week, time of day, location and nature of the incident. It is important to realize that an explosion in a confined space will result in a large number of severely injured victims [5]. Early information may best be obtained from the media, the Internet or emergency medical services' radio communications. Estimates of casualties must be updated frequently because information changes with time. During this latent phase, lower-intensity care areas of the ED should be cleared of patients. Patients in the ED should be quickly triaged, admitted to a ward or discharged. The attending professional in the ICU can use this period to

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Figure 1
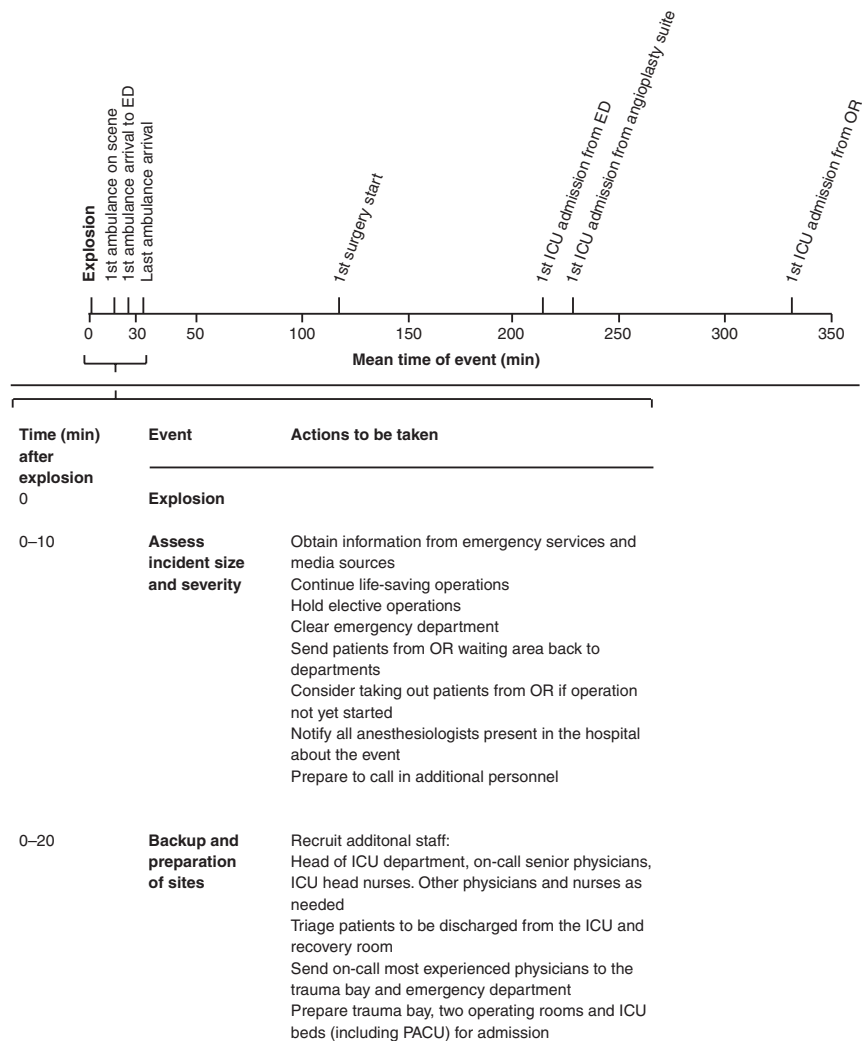
Timeline of events after an incident and actions to be taken. ED, emergency department; ICU, intensive care unit; OR, operating room; PACU, post-anesthesia care unit.

quickly review the patients in the ICU, thus identifying the potential vacant beds. A list of actions to be taken by the on-call chief resident has been placed at the anesthesiology control office. Figure 1 summarizes these actions in context with the time frame of events.

Meanwhile, lower-intensity care areas in the ED or PACU should be quickly equipped to care for patients with major injuries. Equipment available in all high-intensity care areas should include oxygen, airway equipment (laryngoscope, endotracheal tubes, bag/mask and suction devices), intravenous supplies, drugs (ketamine, ethomidate, succinylcholine and a non-depolarizing muscle relaxant) and monitors. Mobile 'multiple-casualty carts' containing these supplies can save valuable time. It is of importance to check the availability of rapid infusion devices and body heaters for these patients.

Backup

Recruiting additional staff is essential. We used an average of 16 anesthesiologists, attending and resident staff, per event to manage all the department's activities. Naturally, at the beginning personnel are used for resuscitation of the injured in the ED. An up-to-date list of all staff members, permanently posted in a prominent place, is crucial for efficient personnel recruitment. Staff are called according to residential distance rather than professional status. On hearing of an event, the in-house on-call ICU physician should call the at-home on-call attending professional for the ICU, the department chair, and a few other senior physicians with trauma expertise. Our hospital is equipped with cellular phones that act as an extension of the hospital telephone system (a virtual private network). However, cellular networks tend to fail immediately after an MCI and cannot be relied on, mandating the use of

beepers and cable telephone systems [6]. There is also a computerized call-in system that delivers a recorded message using regular telephone lines. Cellular networks usually resume normal function after some time and become invaluable communication tools between physicians spread in various locations throughout the hospital.

During our study period, a median of four patients per event were admitted to the GICU, 5.5 ± 3.2 hours (mean ± SD) after the event. Some patients, however, arrived in the ICU soon after the event, either because they did not require surgery or because they needed extensive stabilization before surgery. The ICU must not be a limiting factor in clearing the ED. One should also anticipate a second wave of wounded referred from smaller hospitals. Finding vacant beds and negotiating with the appropriate services should be done with extensive help from nursing and hospital administrators. In contrast to routine transfers, requests for patient transfer in these circumstances are dealt with instantaneously and with acceptance as part of the entire hospital's response. The transfer of a patient and preparation of the vacant bed for a new admission consumes time and must therefore begin as early as possible. The ICU attending professional present on site decides which patients can be transferred to a ward and which to another ICU and arranges their transfer. Shortly thereafter, as additional personnel arrive, at least two to four physicians are diverted to the ICU to help in the care of the ICU patients and transfers. The ICU attending professional then moves to help with triaging and managing patients in the ED.

Casualty care – chaotic phase

The arrival of the first ambulance, about 20 minutes after the attack, signifies the beginning of the chaotic phase during which the center of activity is the ED. There is a continual flow of ambulances from the scene for about 30 minutes. Patients can arrive via various transportation modes; mostly, but not exclusively, by emergency medical service ambulances. In addition, the Israeli emergency medical service has adopted the 'scoop and run' approach [2]. This may explain the finding that nearly 47 patients had to be intubated in the ED. Hence, adequate pre-hospital triage is not guaranteed. However, this may explain the survival to hospital admission of some severely injured patients. Patients receive the same initial evaluation as non-terror-related trauma victims. An important task of the surgical command officer is to coordinate patient evaluations according to injury severity. The victim's initial care requires the efforts of many health care professionals and support staff, creating unavoidable, but ideally controlled, chaos. Only surgeons and anesthesiologists care for major trauma victims in our institution, whereas emergency physicians treat minor injuries and medical patients.

At times the trauma admitting area was full and severely injured patients had to be admitted to lower-intensity care areas in the ED. At other times, patients were initially under-triaged to lower-intensity care areas in the ED. Several of

these patients required intubation, mechanical ventilation or urgent procedures (for example chest decompression, volume resuscitation or surgery). Timely assessment of patients admitted to such areas is important to identify deteriorating or under-triaged victims. Anesthesiologists and ICU physicians were therefore assigned to all areas of the ED to help assess patients and perform timely intubations and resuscitations.

The observation that a median of 3.7 patients were initially treated in the trauma admitting area (which has only three bays) meant that patients were transferred from the trauma admitting area rapidly enough to accommodate new patients. This is in line with the expectation that a Level I trauma center should rapidly prepare for new arrivals referred from secondary trauma centers. We have adopted an approach of unidirectional flow of patients. Patients who have gone for radiological studies are not brought back to the ED.

Definitive treatment

During the definitive care phase, activities concentrate in and around the ICU. The PACU was found to be an excellent location for the care of unstable or ventilated patients awaiting surgery or an ICU bed. Hence, sufficient staff should be assigned to the additional high-intensity care areas. In emergencies, additional staff were recruited to help the PACU staff. Additional nurses may be recruited from other ICUs or departments in the hospital. These nurses were well acquainted with our ICU's routines by having previously worked additional hours in the recovery room. The staff may also be expanded by nursing students, who have to undergo strict selection. The students are carefully instructed in advance regarding the tasks they are expected to perform. The senior nursing staff are instructed how to manage these inexperienced students during an unusually heavy workload. Finally, volunteer workers, supervised by a senior nurse, may help in preparing treatment carts and in undressing and washing the victims. These volunteer workers may assist in administrative activities: preparing forms and files, answering telephone calls, and by being the contact person with the families and the public.

Patient assessment is a detailed and lengthy process, as a combination of many injury mechanisms (blunt, penetrating, thermal and blast injuries) should be suspected [7]. Only patients arriving in uncontrollable shock were operated on immediately.

Despite meticulous preparations and previous experience, no system is perfect and errors occur. For example, we have learned that because of the large number of severely injured patients the risk of missed injuries is high. We have consequently called the surgeons for tertiary survey the day after the event, to re-evaluate the patients.

Working in the ICU soon after a terror incident is difficult, both emotionally and physically. It is therefore important to

provide relief after 8 to 12 hours of work. The activities surrounding a multiple-casualty event have repercussions for the ICU for up to 48 hours and even longer. It is important to add both nurses and physicians to the subsequent shifts to provide adequate care for a large number of severely and sometimes unstable patients. This is highlighted by the relatively large proportion of patients needing ICU admission, together with their substantially longer ICU stays, again demonstrating the severity of injuries in terror events. Debriefing as soon as possible after the event, sometimes on the same day, proves useful for improving procedures. Furthermore, it contributes to inter-service communication and cooperation as well as to identifying a lack of needed equipment.

Diagnosis and management of specific injuries

Bombing injuries are caused by a combination of mechanisms: blast (from changes in atmospheric pressure), blunt (consequence of body displacement caused by expanding gases), penetrating injuries (caused by shrapnel) and burns [3]. The extent of injury will depend on several factors, including the explosive power of the bomb, the distance of the injured patient from the site of detonation, the nature of the space in which the explosion occurred (closed or open), and the nature of the shrapnel within the bomb. In this section we will describe important issues for the diagnosis and management of victims.

Acute lung injuries
Incidence and prevalence
Fifty-one (52%) of the injured in the bombings had some type of acute lung injury. We and others have noted significantly worse injuries after closed-space versus open-air explosions [5]. The lung injuries observed after bombings include lung contusion, penetrating injuries, barotrauma, hemorrhage, acute lung injury, acute respiratory distress syndrome (ARDS) and superimposed pneumonia. Several patients presented with significant bronchopleural fistulae. Although our opinion is not based on a review of the data, but as noted by others, we believe that there is a correlation between the severity of injuries by explosion in closed spaces and the distance of the victim from the explosion's epicenter [8].

Diagnosis
The diagnosis of acute lung injury is made by considering the mechanism of injury and the patient's oxygenation state. The diagnosis is confirmed by chest X-ray or computed tomography (CT). The chest CT scan is highly sensitive in identifying acute lung injury and can help to predict the severity and need for mechanical ventilation [9]. Others have suggested that after lung trauma, hypoxemia and hypercarbia are greatest over the first 72 hours after injury [9]. However, as previously noted by us and others, patients with severe blast injuries often develop symptoms compatible with acute lung injury as early as several minutes to a few hours after the injury [10].

Management and therapy
Respiratory support
The respiratory management of patients with severe blast lung injury is challenging because of the combination of lung contusion and extensive barotrauma, complicated by severe secondary lung injury. In addition, these patients may present with bronchopleural fistulae, penetrating injuries and burns. Each of these entities may require somewhat contradictory therapies. For example, managing acute lung injury may require the application of high positive end-expiratory pressure (PEEP) levels for lung recruitment, which may exacerbate the leak from a bronchopleural fistula. Furthermore, management of these patients may be complicated by the presence of shock from hypovolemia, systemic inflammatory response syndrome (SIRS) or sepsis as well as head injuries. We have adopted a set of ventilatory guidelines, published in a previous review [11].

A lung protective ventilatory strategy is started as soon as the patient demonstrates the first signs of acute lung injury [12]. Hence, all patients admitted to our unit with blast injuries, or with a combination of blast and penetrating injuries, are ventilated with low tidal volumes (5 to 7 mL/kg) that keep peak inspiratory pressures no higher than about 35 cmH$_2$O and plateau pressures of about 25 cmH$_2$O, usually using pressure-controlled ventilation, combined with a PEEP of 10 to 20 cmH$_2$O [13,14]. The lowest F$_i$O$_2$ (fraction of inspired oxygen) to maintain an oxygen hemoglobin saturation of about 90% is used and, if necessary, permissive hypercapnia is allowed [15-18]. The use of a low tidal volume for lung protection has been accepted as mainstay therapy in patients with ARDS, following publication of the article by the ARDS Network group [19]. We preferentially use pressure-controlled ventilation in patients with significant acute lung injury/ARDS. To our knowledge, however, few well-designed studies have compared the difference between using volume-controlled ventilation and pressure-controlled ventilation in this setting.

Relative contraindications to the application of high levels of PEEP are the presence, in addition to acute lung injury, of a significant bronchopleural fistula, evidence of head injury supported by CT findings, or measurement of an increased intracranial pressure (ICP). A decision to apply higher PEEP pressures (more than 10 mmHg) in a patient with even a small bronchopleural leak may require the placement of bilateral chest tubes to prevent the development of a tension pneumothorax. Two of our patients with severe hypoxemia not responsive to regular increments in PEEP were successfully treated with recruitment manoeuvres: 40 cmH$_2$O of continuous positive airway pressure for 40 s [20]. When using permissive hypercapnia, P$_a$CO$_2$ (arterial CO$_2$ partial pressure) was allowed to increase above normal values [18]. Permissive hypercapnia is relatively contraindicated in head-injured patients; when used, it requires ICP monitoring. Intermittent prone positioning was successfully applied in one patient who was not responsive to any other therapy [21].

Additional therapies such as independent lung ventilation, high-frequency jet ventilation (HFJV) [22] and nitric oxide [23,24] are described in the literature as adjuncts for the management of severe acute lung injury/ARDS. In those patients with severe acute lung injury/ARDS we have used nitric oxide to overcome severe hypoxemia, thereby reducing the high oxygen concentrations and preventing secondary lung injury. We have used HFJV only in one patient for a short period. We do not use extracorporeal membrane oxygenation on blast-injured patients because of the increased risk of intra-pulmonary bleeding.

Bronchopleural air leaks present a major problem in the ventilatory management of these patients. Although many patients had bronchopleural leakage, few complications related to this were noted in this group of patients, because of adequate management. A high level of awareness is required. Reducing plateau pressure and mean airway pressure can be as important. This can be coupled with the use of permissive hypercapnia. The use of the lowest PEEP possible has been advocated. Finally, the placement of large enough chest tubes to evacuate a pleural air leak is extremely important in the prevention of tension pneumothoraces. Several case reports have recommended the use of HFJV and independent lung ventilation for ventilating patients with severe bronchopleural fistulae.

The severely injured lung is prone to the development of superimposed infections. Many of these patients develop severe pneumonias within a few days, which may significantly prolong their recovery.

Hemodynamic support
Patients with severe blast injuries can also present with injuries to the abdominal cavity as well as to soft tissues due to penetrating injuries by shrapnel. These patients frequently develop shock as a result of hypovolemia, SIRS or sepsis with significant hemodynamic perturbations and a propensity to develop multiorgan failure. Shock therapy is primarily adequate fluid resuscitation to maintain adequate cardiac filling pressures and blood pressure.

Patients with SIRS or septic shock can develop significant third spacing that requires massive fluid resuscitation, which, in the presence of acute lung injury, can result in significant respiratory deterioration. These patients therefore benefit from invasive monitoring to optimize fluid management with either central venous pressure (CVP) or pulmonary-artery catheters and transthoracic or transesophageal echocardiography, or both. A CVP catheter is routinely placed in all patients with life-threatening injuries. Pulmonary artery catheters are placed only in those patients showing significant hemodynamic instability. Hence, only 10% of injured patients were monitored with a pulmonary artery catheter. Because of increased peak inspiratory pressure transmitted through the lung parenchyma, these patients can present with a relatively high pulmonary artery occlusion pressure (PAOP) despite being hypovolemic [25]. Therefore, after initial fluid resuscitation to adequate filling pressures, we started vasopressor therapy with, preferentially, norepinephrine (noradrenaline) [26,27].

Brain injuries
Bomb blast injuries combine aspects of closed-head injury due to blast effect with penetrating injuries from shrapnel [28]. During our study period, 44 patients sustained head injuries from bombs, of whom three died. The initial presentation of the patients was widely varied. Three patients presented with a GCS of 3 to 5, six with a GCS of 6 to 9, five with a GCS of 10 to 12, and 30 with a GCS of 13 to 15.

Diagnosis
We consider CT to be the examination of choice. Three-dimensional reconstruction CT of the skull is particularly important if penetrating skull and brain injury is suspected. It conveys a better understanding of the mechanism of injury and tract definition, especially if surgery is considered. If the patient is hemodynamically unstable and must be taken urgently to the operating room by the trauma team without a prior CT scan, the neurosurgeon's clinical judgment and experience must help to dictate further actions. X-rays of the skull may help to define the projectile tract, the extent of bony injury, and the presence of intracranial air. In these cases placement of an ICP monitor is warranted until the patient is stabilized to proceed to CT. In case of anisocoria, burr hole placement or an exploratory craniotomy may be undertaken. Intra-operative ultrasound is useful in localizing an intracerebral clot in such cases.

Initial assessment and management
The patient's neurological status at the scene should be clearly defined in terms of GCS and lateralizing signs, and should be communicated to the trauma team on arrival to the trauma unit.

Monitoring of the ICP is an important part of the management of patients with blast injury. The mean ICP at insertion in our patients was 22.5 mmHg, and peak ICP ranged from 12 to 70 mmHg. Higher ICP values were seen in patients with intraventricular blood, brain edema and large hematomas. We believe that patients with penetrating brain injury presenting with a GCS of 8 or less, intraventricular hemorrhage, significant brain edema or significant intracerebral hematomas require ICP monitoring. Ventriculostomy remains the method of choice because this allows therapeutic drainage of cerebrospinal fluid. When significant brain edema and small ventricular size are present, parenchymal ICP monitor placement is preferred. It is appropriate to administer a loading dose of anticonvulsant medication intravenously to all patients with penetrating brain injury [29]. Furthermore, in these patients, initiation of prophylactic antibiotic therapy is recommended. We use broad-spectrum (second to fourth

generation) cephalosporins with blood–brain barrier penetration. For combined cranial sinuses and brain injuries with suspected skull-base defect an anti-anaerobic preparation should be considered. We generally treat patients for 5 days after injury, but vary our practice depending on the nature of the wound [30].

Surgical management
In our series, two patients had documented migration of a metallic fragment. Two patients developed a traumatic intracranial aneurysm. In the two patients with documented migration, as well as in two others in which a large metallic fragment was accessible and considered to pose a potential risk, we removed these with the aid of an image-guided neurosurgical navigation system. In the four patients who underwent this operation, outcome was excellent without new neurological deficit or other complications.

Post-traumatic cerebrovascular lesions
In cases where the projectile crosses two dural compartments, or involves the facial, orbital or pterional regions, a higher rate of traumatic intracranial aneurysm has been reported [31]. Today, we consider endovascular therapy an excellent first-line therapeutic option.

Orthopedic injuries
Incidence
Gunshot wounds and multiple shrapnel injuries due to terror attacks may differ in injury pattern and severity. The surge of violence in our region has produced penetrating long bone injuries with increased severity, often associated with multiple trauma. During the review period, 85 patients suffering from 113 long bone fractures due to penetrating gunshot and shrapnel injuries were treated. There were 36 femoral fractures, 50 tibial fractures, 5 humeral fractures and 24 forearm fractures. Thirty-six percent of the patients had multiple fractures. Forty-three percent of the patients suffered from associated injuries, mainly vascular damage and/or nerve injury to the fractured extremity. Fifty-eight percent of these patients had an ISS in the range 9 to 14, and 21% had an ISS of greater than 25. Seven (6.9%) patients had spinal injuries (Petrov K, Weil Y, Mintz A, Peyser A, Mosheiff R, Liebergall M, unpublished data).

Management
Controversy exists for protocols applied for the management of these serious injuries. In the present experience, 77% of the fractures were primarily fixated and 23% were splinted or put in a cast. Limb amputation had to be performed in only 3%. A significant number of fractures needed arterial repair (28%), nerve repair was required in 18%, and soft tissue coverage procedures were necessary in 14% (Petrov K, Weil Y, Mintz A, Peyser A, Mosheiff R, Liebergall M, unpublished data). Many of these injuries became infected, requiring repeated debridement and therapy with local and systemic antibiotics.

When the injury consisted of an isolated fracture, the victim could usually return to normal day-to-day life after treatment. Patients with multiple limb injuries and/or multiple fractures were in a more complicated situation, needing several operative procedures and a long rehabilitation period.

In summary, the aggressive primary surgical approach, using multidisciplinary teams, can result in favorable results in this unique group of patients.

Abdominal blast injuries
Thirty-two (32%) of the trauma victims in our series suffered abdominal injuries and required surgical workup and intervention. Abdominal injuries may occur as a result of the three phases of blast injury. In primary blast injury, gas-containing organs are affected [32,33]. Bowel perforations are the result of this mechanism and have been described in up to 14% of all casualties suffering from primary blast injuries [8]. It is not unusual to diagnose bowel perforations in these casualties after a significant delay because of their multiple injuries and minimal abdominal symptoms, partly owing to the sedation provided to the ventilated patients [34]. It is believed that these small perforations are due to hematomas in the bowel wall, causing ischemia and delayed perforation, rather than missed injuries. Indications for laparotomy include hemodynamic instability, positive imaging studies and/or peritoneal irritation. Because of the possibility of delayed bowel perforation, these patients were closely followed for the first 48 hours in anticipation of abdominal emergency.

Secondary blast injury entails the penetration of shrapnel into the abdominal cavity, causing solid-organ, major vascular or bowel-penetrating injuries. Most often these casualties have multiple abdominal injuries including the stomach, small bowel, colon, rectum, spleen and liver [32]. The presence of penetrating torso injury or injury to four or more body regions serves as an independent predictor of intra-abdominal injury.

The mechanism of tertiary blast injury is similar to blunt abdominal trauma, which mostly affects the solid organs. The probability of being injured as a result of each of these mechanisms is determined by the distance of the casualty from the epicenter of the explosion and whether it was in a confined or an open space. The presence of penetrating shrapnel injury signifies the proximity of the casualty to the epicenter of the explosion. The finding of shrapnel injury to one body region should alert the treating physicians to the possibility of multiple body regions being injured. Penetrating thoracic, abdominal and pelvic injuries frequently coincide and one should also be aware that the trajectory of these asymmetrical missiles is unpredictable. Therefore, a thorough evaluation should be performed, mainly involving complete exposure and liberal use of imaging studies such as CT scans.

The treating physicians should keep in mind that casualties with blast abdominal injuries do not necessarily have external

signs of abdominal trauma. Hence, being injured in a explosion in a confined space should by itself serve as a high index of suspicion for abdominal blast injuries.

Conclusion

In this paper we have presented our approach to multiple-casualty events. We have attempted to highlight the most important issues relevant to patients with blunt and penetrating injuries resulting from bombs containing shrapnel. The paper emphasizes the importance of an aggressive primary medical and surgical approach, using multi-disciplinary teams, to care for this unique group of trauma victims and resulting in a favorable outcome. We hope that this information will not be needed in any other part of the world. It is also our hope that our experience gained through these events shall not be needed in the future.

Competing interests

The author(s) declare that they have no competing interests.

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