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Management of Victims in a Mass Casualty Incident Caused by a Terrorist Bombing: Treatment Algorithms for Stable, Unstable, and In Extremis Victims

Guarantor: Ricardo Alfici, MD
Contributors: Ricardo Alfici, MD; Itamar Ashkenazi, MD; Boris Kessel, MD

Bombs aimed at civilian populations are the most common weapon used by terrorists throughout the world. Over the last decade, we have been involved in the management of more than 20 mass casualty incidents, most of which were caused by terrorist bombings. Commonly, in these events, there may be many victims and many deaths. However, only a few of the survivors will suffer from life-threatening injuries. Appropriate and timely treatment may impact their survival. Due to the complex mechanism of injury seen in these scenarios, treatment of victims injured by explosions is somewhat different from that exercised in blunt and penetrating trauma from other causes. The intention of this article was to outline the initial medical treatment of the injured victim arriving at the emergency department during a mass casualty incident caused by a terrorist bombing. Treatment protocols for stable, unstable, and in extremis patients are presented.

Introduction

Hillel Yaffe Medical Center (HYMC) is a level II trauma center with extensive experience in trauma. From 1994 to 2004, the hospital staff of HYMC responded to 20 mass casualty incidents (MCI) caused by terrorist attacks. Of these, 16 were bombing incidents. In these bombings, 467 victims were admitted to the HYMC emergency room averaging 29.2 (±20.5, range, 9–66) victims per incident. Sixty-three (13.9%) were severely wounded, averaging 3.9 (±4.3, range, 0–15) victims per incident. Twelve (2.6%) died in-hospital. We believe that the recommendations presented in this study, drawing on the lessons learned from these incidents, are applicable to any medical center experiencing daily encounter with trauma patients.

The Advanced Trauma Life Support (ATLS) course was developed to allow an organized and consistent approach to the trauma patient with the aim of providing an optimal outcome.[1] Although the physiologic parameters of instability after terrorist bombings are similar to those of other trauma scenarios, the mechanism of injury in explosions is multifactorial (Tables I and 2).[2] It includes a blast component, a penetrating component, a blunt component, and flash burns. Commonly encountered patterns of injury and the problems encountered in their treatment are outlined in Table III.

Treatment of the Stable Victim within the Context of an MCI Caused by a Terrorist Bombing

Stable victims account for as many as 90% of the casualties who arrive at the emergency room after an MCI caused by terrorist bombings. Half of these patients will have acute psychological stress reaction as their main diagnosis. Ten to 15% will have serious injuries that are not immediately life-threatening but will lead to disability, such as limb and ophthalmic injuries. Others will suffer from minor lacerations, minor penetrating wounds, and minor burns.

The main concern with this large group of victims is that some of them will be harboring serious injuries that will not be apparent during the primary evaluation. Our experience is that this rarely happens. Primary and secondary survey in the emergency room did not identify the gravity of the injury in only 2 of the 63 severely injured victims. Both of these patients suffered from distracting injuries. One patient had a completely transected pancreas coupled with a severe upper extremity injury. The other patient suffered from bowel lacerations and intraperitoneal hemorrhage coupled with non-life-threatening facial injuries.

The primary and secondary surveys are the key to the workup of the stable victim population. The main difference between the treatment of the victims of conventional trauma scenarios and the treatment of the victims of an MCI is that laboratory exam-

Surgery B Department, Trauma Unit, Hillel Yaffe Medical Center, POB 169, Hadera 38100, Israel.

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TABLE I

MASS CASUALTY EVENTS CAUSED BY TERRORIST BOMBING ATTACKS

Description	No. of Victims Killed[a]	No. of Victims Wounded	No. of Victims Treated in HYMC
13.9.1994—A suicide bomber detonated a bomb inside a bus in Hadera's bus station.	6	33	33[b]
322.1.1995—A suicide bomber detonated a bomb in a bus terminal at Beit Lid junction. A second suicide bomber detonated his bomb during rescue attempts.	22	65	35
17.1.2000—A pipe bomb exploded in a bank in Hadera.	0	26	26[b]
22.1.2000—A car bomb exploded near a bus in the center of Hadera.	3	62	65[b]
01.01.2001—A car bomb containing 10 kg of explosives attached to a gas container exploded in the center of Netanya.	0	60	16
04.03.2001—A suicide bomber failed to board a bus in the center of Netanya and detonated his bomb causing an open air explosion.	3	60	19
18.05.2001—A suicide bomber failed to enter Netanya's mall and detonated the bomb in open air. The bomb contained metal fragments.	5	100	32
25.05.2001—Two suicide bombers detonated a car bomb next to a bus full with passengers.	0	66	66[b]
16.07.2002—A suicide bomber detonated a bomb with 20 kg of explosives in a bus station after failing to enter Benyamina's train station.	2	13	13[b]
29.11.2001—A suicide bomber detonated a bomb in the middle of a bus full with passengers at "Camp 80" junction.	3	10	10[b]
20.03.2002—A suicide bomber detonated a bomb in the middle of a bus at Musmus junction. The explosive contained nails and other metal fragments.	7	30	10
27.03.2002—A suicide bomber detonated a bomb containing 10 kg of explosives and 0.5-cm metallic spheres in Park Hotel's dining room in the middle of Passover Seder meal.	29	140	44
19.05.2002—A suicide bomber detonated a bomb containing nails in the middle of Netanya's market.	3	59	16
05.06.2002—A suicide bomber detonated a car bomb containing over 10 kg of explosives, next to the rear of a bus at Megido's junction causing the bus to overturn and set on fire. Victims who did not get out of the bus got burned.	17	38	9
21.10.2002—The suicide bomber detonated a car containing 80–100 kg of explosives next to the rear of a bus at Karkur junction causing the bus to be set on fire.	14	62	63[b]
30.03.2003. A suicide bomber detonated a bomb at the entrance to a café in Netanya.	0	40	10

[a] Includes both victims killed on site and victims dying in hospitals.
[b] MCIs in which all immediate survivors were transferred to HYMC.

inations and radiology examinations will not be freely available during the first hours of the event. These ancillary services should be kept free to service victims with serious injuries.

History and physical examination are the most important tools for evaluating the patient during the initial evaluation and follow-up (Fig. 1). Patients with clinically significant lung blast injury will suffer from dyspnea and/or hemoptysis. Respiratory rate and oxygen saturation are more reliable and readily available than chest X-ray to evaluate possible lung blast injury. Rupture of tympanic membranes has been quoted as a reliable sign of blast exposure, but this injury is neither very sensitive nor very specific.[3]

TABLE II

CRITERIA OF INSTABILITY

Criteria	
Combative, GCS[a]	<15
Compromised airway	
Pulse	<60, >120
Systolic blood pressure	<100
Respiratory rate	<12, >24
SaO_2[b]	<90%

[a] GCS, Glasgow coma score.
[b] SaO_2, oxygen saturation measured by pulse oxymetry.

The importance of performing screening chest X-rays has evolved from the perception that lung blast injury evolves over a period of many hours.[4] There are no data in the literature to support this statement in airborne blast injuries. More important, there is no evidence that chest X-ray will anticipate respiratory failure in asymptomatic patients. Up to the experience accumulated in Israel, serious blast lung injuries were rare in survivors of explosions since most of the victims sustaining these injuries probably died at the site of the explosion.[5,6] We did

TABLE III

COMMONLY ENCOUNTERED MECHANISMS OF INJURY AND PROBLEMS ENCOUNTERED IN TREATMENT OF VICTIMS OF EXPLOSION

	Mechanism of Injury	Problems with Treatment
Airway	(1) Severe blast lung may be complicated by airway hemorrhage.	(1) Frequent suction is needed
Breathing	(1) Both hemithoraces are injured in the blast. (2) Mechanism of hypoxia is multifactorial, composed of one or a combination of the following etiologies: (a) severe lung contusions, (b) decreased lung compliance, (c) pneumothorax, (d) air embolism.	(1) Diagnosing main etiology of hypoxemia is difficult. (2) High pressures of ventilation may lead to pneumothorax, air emoblism, and bronchopleural fistula. (3) Thoracic interventions (chest tube insertion, thoracotomy) can become complicated with hemorrhage from contused lung parenchyma.
Circulation	(1) Mechanism of hemodynamic instability is multifactorial: (a) hypoxemia, (b) tension pneumothorax, (c) air embolism, (d) external bleeding, (e) penetrating injury, (f) blunt injury, (g) neurogenic shock.	(1) Diagnosing the main et iology of hemodynamic instability is difficult. (2) Due to multiplicity of penetrating skin wounds from shrapnel, delineating trajectory is complicated. (3) There are no guidelines of treatment for victims of explosions (current guidelines of treatment exist only for patients with either penetrating or blunt injury). (4) Fluid administration may worsen lung contusions.
Disability	(1) Penetrating injuries and blunt trauma resulting in central and/or peripheral neurological injuries are common.	(1) Commonly overlooked as reasons for instability in victims suffering from blast and penetrating injuries.

encounter several survivors with clinically significant blast lung injuries. In one of the MCIs, one of us experienced seven such survivors with blast lung injury being their main injury. All except one were either intubated during the prehospital phase or had to be intubated immediately during the initial resuscitation. Only one of the victims developed protracted respiratory failure. Nevertheless, this patient did complain of shortness of breath and hemoptysis during his primary evaluation. Gradual deterioration in oxygenation led to intubation and positive pressure ventilation 3 hours after the explosion. It has been our experience that recurrent physical examination over the course of a few hours is reliable to rule out a clinically significant lung blast injury and this is more practical than relying on chest radiography as a screening tool.

Penetrating injury in explosions may create a diagnostic problem. Terrorists have learned that adding nuts, bolts, and/or nails to the bomb will lead to added morbidity and mortality. Victims often suffer from multiple penetrating fragments. In the case of the trunk, most of these will end up in the superficial layers due to the low energy of penetration. However, few fragments may penetrate deeply and cause life-threatening injuries. The multiplicity of penetrating wounds makes it difficult to assess the tract of penetrating fragments. Most of the wounds caused by these fragments are small and relatively inconspicuous. Due to their large number, it is not practical to perform exploration of all of the wounds to assess penetration. Hemodynamically stable victims with evidence of fragment penetration are best hospitalized for observation. Repeat physical examination is a reliable tool to assess this group of patients, as it is in other scenarios of penetrating trauma.[7-10] Patients with evidence of penetrating wounds in the head, neck, or trunk should undergo chest X-ray and computerized tomography (CT). CT is very useful in detecting foreign bodies and may sometimes delineate the tract that the foreign body traversed to reach its current position.[11] Asymptomatic foreign bodies have been found in practically every body compartment, including the heart and the brain.

Treatment of the Unstable Victim within the Context of an MCI Caused by a Terrorist Bombing

Unstable patients in MCIs secondary to bombings should receive treatment meant to deal with the most common treatable causes of instability (Fig. 2). This is especially important in MCIs where the expertise in trauma of those treating the individual patient is variable and may differ from that seen in other trauma scenarios.

The protocol for treatment of unstable victims differentiates between those with blast lung injury and those without. The presence of blood in the airways is a reliable indicator of blast lung injury. If there is no blood in the airways, one must assume that penetrating trauma is the cause of instability rather than blast injury. Terrorists commonly attach metallic objects such as nails, bolts, and metal spheres to the explosives to increase the destructive potential of their bombs.

Lung contusions, lung lacerations, pneumothorax and hemopneumothorax are commonly encountered after explosions. In blast lung injury, pathology is more often bilateral than not. This is in contrast to penetrating injury were pathology may be unilateral.

Immediate airway control is achieved by orotracheal intubation. This is executed using rapid sequence induction. Once the airway is secure, blood commonly encountered in lung blast injuries is suctioned. Recurrent suction is needed to clear the airways of blood. As is true in other trauma scenarios, protection of the spine and spinal cord is an important principle during orotracheal intubation. Following explosions, victims' instability may be secondary to multiple mechanisms, including

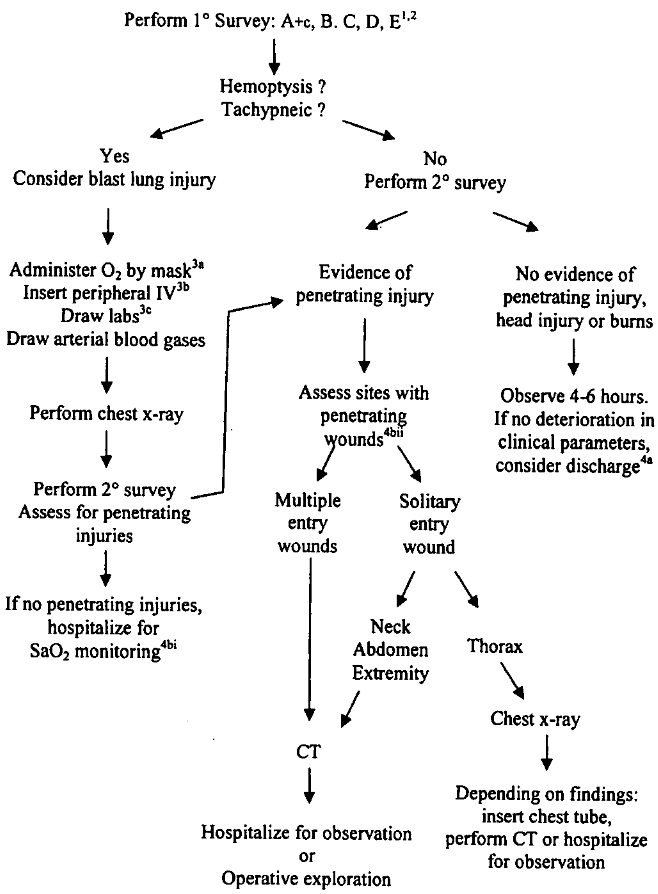

Fig. 1. Protocol: management of the stable patient in an MCI caused by terrorist bombing: (1) perform primary survey according to ATLS guidelines: assess airway, breathing, circulation, and neurological disability. (2) Presence of spinal pain, quadriplegia, paraplegia, sensory loss mandates continuous immobilization of the spine until proper imaging evaluation is done. (3) If patient has hemoptysis, or is mildly tachypneic: (a) administer O_2 by mask; (b) insert one peripheral intravenous line; (c) draw blood for hemoglobin, blood screen without cross-match, human chorionic gonadotrophin in women of childbearing age, and baseline arterial blood gases. (4) Perform secondary survey: (a) if primary survey and secondary survey do not demonstrate any significant injury, consider discharge after 4 to 6 hours of observation if vital signs are stable. Patients with tympanic membrane perforation as a solitary finding can be discharged after observation. Laboratory studies and chest X-ray are unnecessary. (b) Stable patients with hemoptysis, mild tachypnea, burns, or penetrating injuries to either trunk or limbs are hospitalized for further workup and observation: (i) patients suffering from hemoptysis and mild tachypnea should have a baseline chest X-ray and arterial blood gas analysis performed. Patients are hospitalized, SaO_2 is monitored, and respiratory rate is repeatedly assessed. Deterioration is usually manifested by the gradual development of hypoxic respiratory failure. Repeat chest X-ray as a method of monitoring is not indicated. Repeat arterial blood gas analysis and chest X-ray are only indicated in those patients demonstrating clinical evidence of respiratory deterioration. (ii) Stable patients with evidence of penetrating injury from fragments are treated according to ATLS guidelines for penetrating trauma. Once stability is established, the trajectory of fragments is determined. This may be complicated by multiplicity of entry sites. Assessment of individual body areas is as follows: head: computer tomography (CT) scan without contrast; neck: assess for signs of vascular, airway, and esophageal injury. Perform CT scan with intravenous and oral contrast. If an injury to any of these organs is suspected, perform angiography, bronchoscopy, or esophagoscopy/esophagogram; chest: perform chest X-ray. Perform CT chest with intravenous and oral contrast in patient with multiple shrapnel wounds and in any patient suspected to harbor a penetrating injury with a transmediastinal trajectory. Angiography, bronchoscopy, and esophagoscopy complement CT of the chest as necessary. Patients with penetrating injury to the heart are taken to the operating room for exploration and assessment of their injury; abdomen, back, or flank: assess for signs of peritoneal irritation. Perform rectal examination, insert a nasogastric tube, and test urine to evaluate for possible penetrating injuries to the gastrointestinal or urinary tracts. If these are negative, perform local wound exploration in the patient with few penetrating skin wounds. In those with many wounds, local wound exploration is not feasible. In these patients and those with peritonitis, perform triple contrast CT. Laparoscopy can be used to assess penetration in those with anterior abdominal wounds. Laparotomy is indicated in those with peritonitis, suspected penetrating injuries to the gastrointestinal tract, and in any patient with deteriorating hemodynamic indices; buttocks: assess for peritonitis and rectal bleeding. If negative, perform triple contrast CT; extremities: assess pulses, motor, and sensory function. Perform radiological studies to assess trajectory. Vascular studies are done according to local protocol.

penetrating and blunt trauma, both of which may cause spinal cord instability. As is advocated by the ATLS, spinal injury should be assumed in any patient with multisystemic injury; the proper precautions should be taken while performing intubation or mobilizing the patient.[1] Placing a cervical collar not only allows some cervical stabilization, it actually marks those patients in whom spinal evaluation has not been completed.

Lung contusions are the hallmark of blast lung injury.[12] Lung contusions are often multiple diffuse and bilateral. Treatment of lung contusions is supportive and dictated by the severity of hypoxia. Unstable patients and patients in extremis are treated by orotracheal intubation and positive pressure ventilation. Positive pressure ventilation is a double-edged sword. It will ameliorate hypoxemia but will also induce further barotrauma to the lungs. Casualties with severe blast lung injury are commonly in need of high positive end-expiratory pressure (PEEP) levels as an adjunct to positive pressure ventilation. PEEP will further injure the already friable lung parenchyma and may lead to the development of pneumothorax, persistent bronchopleural fistula, and, possibly, air emboli. Several alternative modes of ventilation have been used to overcome hypoxemia without increasing PEEP excessively. Those we most commonly used were nitric oxide and high frequency jet ventilation.[13] There is not enough data to define which of these two methods is better due to the paucity of patients. The prone position is another mode that has been shown to improve oxygenation but this mode of treatment is more appropriate in the setting of an intensive care unit and is not a real alternative during the initial workup of severely injured patients. If nitric oxide and jet ventilation are not available, pressure-controlled ventilation or volume-controlled ventilation with limited peak inspiratory pressure can be used.[14] In the latter mode of ventilation, tidal volume is decreased to 6 ml/kg and respiratory rate is increased as needed.[15] This will allow decreasing peak inspiratory pressure while maintaining or increasing mean inspiratory pressure.

Patients whose main disorder is hypoxia due to severe pulmonary contusions will respond to orotracheal intubation and mechanical ventilation. Patients who respond inadequately to intubation and mechanical ventilation are assumed to be suffering from pneumothorax and bilateral thoracostomy tubes are inserted. The presence of significant intrathoracic bleeding dictates the need for urgent thoracotomy.

A word of caution is necessary. Blast causes severe lung contusions. The contused lung is relatively friable and the semirigid thoracostomy tubes may easily penetrate contused lung parenchyma leading to significant hemorrhage. Even if these tubes have been carefully placed within the pleural space, pressure lacerations may form in the lung parenchyma from direct contact with the chest tube. For the same reason, we do not

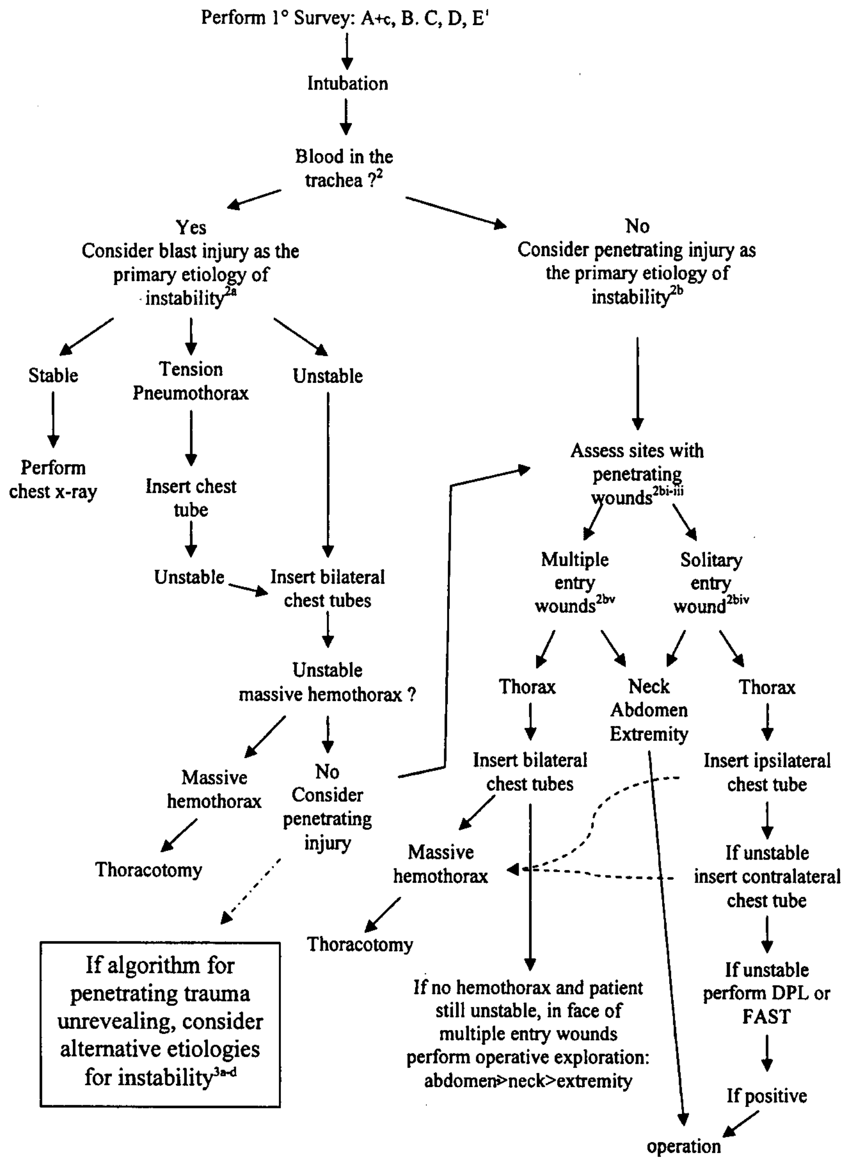

Fig. 2. Protocol: primary management of the unstable patient in an MCI caused by terrorist bombing: (1) assess airway, breathing, circulation, and disability. Assume spinal injury in all victims until imaging is done. (2) Once primary assessment reveals instability, consider intubation. If blood is present in the trachea, follow protocol for instability due to blast injury. If there is no blood, follow protocol for instability due to penetrating trauma. (a) Protocol for instability due to blast injury: (i) after intubation and institution of positive pressure ventilation, perform chest X-ray as quickly as possible. Consider chest tube insertion in patients still unstable after intubation, place bilateral chest tubes; patients with clear signs of tension pneumothorax, place chest tube in the side suspicious for tension pneumothorax and if still unstable, place chest tube in contralateral hemithorax; patients with pneumothorax on chest X-ray. (ii) If patient is still unstable, treat for possible penetrating trauma. (b) Protocol for instability due to penetrating trauma: (i) rapidly assess sites of penetrating wounds. (ii) Control significant external bleeding. Rule out significant bleeding from the back and gluteus by placing in the right and left lateral decubitus positions alternately. (iii) Insert two large-bore intravenous catheters. Draw blood for hemoglobin, platelets, blood type and cross-match, prothrombin time and partial thromboplastin time, human chorionic gonadotrophin for women of childbearing age, and arterial blood gas analysis. (iv) In case only a solitary penetrating wound is found, differentiate between a chest wound and a wound involving another compartment. In case of a chest wound, insert chest tube on the side of the penetrating wound. Consider thoracotomy for massive hemothorax. If patient is still unstable after chest tube insertion, and there is no significant hemothorax, insert chest tube in contralateral hemithorax. If still unstable and there is no evidence of significant hemothorax, consider cardiac tamponade or intra-abdominal hemorrhage. Unstable patients with a solitary penetrating wound to the neck, abdomen, or extremities are taken to the operating room for exploration. (v) In case of multiple penetrating wounds, insert bilateral chest tubes. Consider thoracotomy in patients with massive hemothorax. If no massive hemothorax, perform FAST or DPL. If these are negative, consider other etiologies of instability. (4) If patient with evidence of blast lung injury is unresponsive to resuscitative effort mentioned above, consider the following problems: (a) ineffective oxygenation: deep suction the patient. Verify placement of chest tube on X-ray. If there is a large air leak from one hemithorax, consider one lung intubation of contralateral hemithorax. (b) Undiagnosed pneumothorax: repeat chest X-ray and consider placing more chest tubes in each hemithorax. (c) Air embolism: increase infusion rate. (d) Thoracic compartment syndrome: if blood pressure drops with every attempt to apply positive pressure ventilation, insert a second chest tube bilaterally. If blood pressure still drops, take to operating room and perform decompressive thoracotomy.

advocate bilateral insertion of 14-gauge needles in the second thoracic interspace before insertion of chest tubes. Insertion of 14-gauge needle is only allowed in the rare patient with clear clinical signs of tension pneumothorax.

Most of the patients suffering from solitary lung blast injury will stabilize with the interventions mentioned above. Secondary survey is done to rule out other possible injuries. Patients suffering from solitary blast lung injury are then relocated to a site within the hospital with intensive care capabilities for treatment of their hypoxic respiratory failure.

In the patient with evidence of penetrating wounds in the trunk, hemodynamic instability should be assumed to be secondary to a penetrating injury. Once the airway is secured, external hemorrhage is controlled. Multiple wounds may be present but only those wounds that are bleeding profusely are addressed at this stage. Since the patient is placed supine, it is a common tendency to treat only those wounds that are anteriorly placed. However, it is not uncommon to find the majority of entry sites at the back of the trunk.[16] The victims should be placed in the right and left lateral decubitus positions alternately and external hemorrhage from posterior wounds should be addressed.

Any method for arresting bleeding is legitimate under these circumstances. Methods include local pressure or quick approximation of skin edges with sutures to allow tamponading of the hemorrhage. Alternatively, skin wounds can be packed as suggested by Almogy et al.,[16] but our experience is that for these packs to be effective, the skin opening should be large enough to allow laparotomy towels to be easily inserted. Otherwise, they fall out. This technique is valuable whenever serious bleeding is encountered from profusely bleeding gluteal wounds where hemorrhage may be secondary to lacerations of the superior gluteal vessels. If the entry wound in the skin is small, it should be enlarged to allow effective packing. This is done by carefully inserting a finger through the wound to determine the direction of the tract. Skin and subcutaneous tissue over the path of the tract are then opened with a skin knife and Mayo scissors. A skin incision as large as 5 cm is usually necessary to allow effective packing of the gluteal muscles around the tract created by the shrapnel.

Once significant external hemorrhage is controlled, two intravenous catheters are inserted. Blood is drawn for determination of hematocrit, platelet, prothrombin, partial thromboplastin time, human chorionic gonadotropin in women of childbearing age, and arterial blood gas. Both warm crystalloids and blood are infused as indicated by ATLS protocols.

Evaluation is now directed at identifying the trajectory of the fragment with the aim of determining the anatomic compartments and organs affected by the projectiles. The problem is that most of the victims suffering from penetrating injury will have multiple entry wounds that are commonly small and often appear innocuous. Most of the fragments causing these wounds do not penetrate beyond the subcutaneous tissue. However, serious injury caused by a fragment that does penetrate deeply is not uncommon. The multiplicity of entry wounds in different compartments will make it difficult to identify the trajectory of the projectile causing the instability. Since we emphasize treatment of reversible etiologies of instability, chest tubes are inserted in both hemithoraxes. Thoracotomy is indicated if massive hemothorax is found. In the patient with evidence of penetrating wound in the abdominal trunk, it is always assumed that hemodynamic instability is due to a penetrating wound. Diagnostic peritoneal lavage (DPL) and focused abdominal sonography for trauma (FAST) are unnecessary in these patients and all hemodynamically unstable patients with penetrating wounds require laparotomy to rule out significant intra-abdominal injury. The only exception is the patient with combined thoracic and abdominal entry wounds, in whom instability promptly responds to intubation and chest tube insertion. In this patient, DPL can be done to rule out significant intra-abdominal hemorrhage. A high index of suspicion is the rule in patients presenting with instability and possible penetrating wounds to the abdomen.

The rare victim with a solitary entry wound is assessed according to commonly used trauma guidelines. Unstable patients with solitary entry wounds in the abdomen, neck, or extremity should be taken immediately to the operating room for exploration and surgical control of bleeding. If the fragment penetrates the chest, an ipsilateral chest tube is placed first. In the case of massive hemothorax, thoracotomy is indicated. If the patient has no evidence of massive hemothorax, a contralateral chest tube is inserted if instability persists. Chest tubes in these patients are both diagnostic and therapeutic. If the patient is still unstable after bilateral chest tubes have been inserted, one should infer the fragment has penetrated either the abdomen or pericardium. The abdomen may be distended. If there are no clear signs of intra-abdominal hemorrhage, either a FAST or DPL should be done. FAST has the advantage of allowing assessment of both the pericardial and intraperitoneal compartments. However, availability of FAST may be limited in the context of an MCI. DPL is a good alternative in assessing intraperitoneal injuries in these circumstances. In the case of the unstable victim of explosion, only a DPL finding of visibly blood-stained lavage fluid should be considered a reliable indicator to proceed immediately with laparotomy. Although life-threatening intraperitoneal injuries may be encountered in a patient with microscopic blood in the DPL specimen, these injuries do not explain hemodynamic instability and should not be given priority at this time.

Once hypoxia from blast lung injury and internal hemorrhage has been addressed, persistent instability is usually caused by unresolved thoracic pathology followed by head trauma and/or spinal trauma. Unresolved thoracic pathology includes ineffective oxygenation, undiagnosed residual pneumothorax, air embolism, and thoracic compartment syndrome.

Ineffective oxygenation is manifested by hypoxia and more than one cause may be encountered. Airway bleeding and severe lung contusion were discussed above. Significant bronchopleural fistulas are not uncommon in patients with severe blast lung injury. Patients with significant bronchopleural fistula will show evidence of air leaking through the chest tubes. High frequency jet ventilation has been suggested as an effective treatment to lower the air leak.[13] If hypoxemia persists, one should consider single lung intubation of the lung contralateral to the side with the most significant air leak.[17] Otherwise, operation is indicated. Residual pneumothorax is secondary to ineffective chest-tube drainage. Pneumothorax will further decrease the vital capacity of the contused lung, leading to worsening hypoxemia.[18] Secondary pneumothorax should always be considered in a patient who suddenly deteriorates after having responded to initial resuscitation. In these severely injured victims, placing another pair of chest tubes may be the only way to diagnose and treat pneumothorax since the yield of chest X-rays in these circumstances is low. The presence of severe lung contusions and hemothorax makes it difficult to assess the extent and significance of coexistent pneumothorax.

Air embolism is a complication of lung blast injury and is a main concern in patients treated by positive pressure ventilation. However, the real incidence of clinically significant emboli is unknown.[12] Clinical clues suggesting air embolism include significant air leak coupled with low blood pressure and low end tidal CO_2. Placing the patient in positions other than supine has been suggested as useful treatment for air embolism. Nevertheless, positioning the patient in Fowler or Trendelenburg may increase the likelihood of cerebral or coronary air embolism, respectively.[19] The prone and lateral decubitus positions, that place the atria above the ventricles, are not practical in the initial treatment of a severely injured victim. Prevention of air embolism is important and is dependent on fluid resuscitation and restoration of capillary pressure to reduce the likelihood of air entry into the vascular system.

Thoracic compartment syndrome due to lung blast injury is a rare entity one of us once experienced and may be the most extreme manifestation of this mechanism of injury. Nevertheless, if treated promptly the victim may be salvaged. Thoracic compartment syndrome has been described following cardiac and noncardiac thoracic procedures, both elective and following trauma.[20,21] Cardiac decompensation is caused by inability of the heart to expand due to the constrictive effect of mediastinal components such as edematous tissue, hematomas, or presence of ventricular assist devices. This constrictive effect is alleviated by leaving the thoracic cavity open followed by delayed closure of the chest a few days later.

The mechanism of thoracic compartment syndrome following explosions is similar. Severe blast combined with fluid resuscitation will lead to chest wall edema which will in turn decrease the chest wall's compliance. This, coupled with extensive lung contusions and positive pressure ventilation, may lead to diastolic heart failure. Clinically, thoracic compartment syndrome will manifest as significant blood pressure collapse every time positive pressure ventilation is applied. Tension pneumothorax, which manifests similarly, is ruled out by inserting thoracostomy drains bilaterally. If diastolic failure persists after bilateral chest tube placement, the patient should undergo thoracic decompression. This is best achieved with a median sternotomy. Both pleural spaces should be opened. Areas with massive air leaks are sutured closed or stapled. The thoracic incision is temporarily closed with a 3-L cystoscopy irrigation plastic bag (Bogotá bag) and packing.

Treatment of the Victim In Extremis within the Context of an MCI Caused by a Terrorist Bombing

A patient is considered in extremis when concomitant to respiratory failure and profound shock, some signs of life are found such as electrical pulse, reactive pupils, or spontaneous respiratory efforts or movement. In extremis trauma patients require a "treat then diagnose" approach.[22] In MCIs caused by terrorist bombings, patients arriving in extremis are not common. Their number probably depends on the rapidity of the medical evacuation from the site of disaster to the hospital. The worst event experienced by any of us included four such patients.

Confusion exists as to whether very severely injured victims should be treated at all, and if they are to be treated, how and when. For trauma victims arriving in extremis, the results of any immediate treatment are extremely poor. However, isolated reports of trauma patients who survive after arriving in extremis and in cardiac arrest are not rare. These reports serve as an incentive to attempt resuscitation in this special patient population.[22] However, traditional teaching is that in MCIs, victims who have a very low chance of survival are allocated to a no/minimal treatment site.[23-27] Some authors advocate withholding optimal treatment as long as there is an ongoing flow of casualties and the eventual number of victims to be treated is unknown.[24]

To date, the magnitude of number of severely injured patients encountered after these events does not justify a change in indications for resuscitation from those which are commonly accepted in other trauma scenarios. We therefore start treating severely injured patients as they arrive and we offer them all of the resources possible, as though they had been wounded in circumstances in which there are no other casualties. We do not

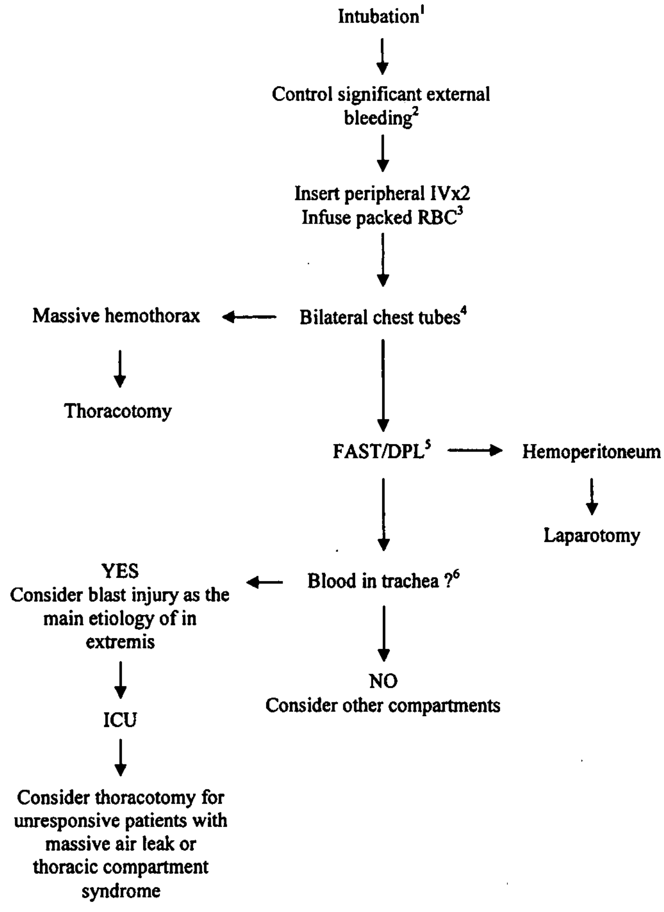

Fig. 3. Treatment of the patient in extremis in an MCI. Protocol: primary management of the patient in extremis in an MCI caused by a terrorist bombing: (1) intubate the patient. (2) Control significant external bleeding. Rule out significant bleeding from the back and gluteus by placing in the right and left lateral decubitus positions alternately. (3) Insert two large-bore intravenous catheters. Infuse warm crystalloid solution and packed red blood cells (RBC). (4) Insert chest tubes in both hemithoraxes: (a) a finding of massive hemothorax or thoracic compartment syndrome should prompt thoracotomy. (5) Perform FAST or DPL to rule out hemoperitoneum. In case of hemoperitoneum, proceed with laparotomy. (6) Once massive hemothorax and intraperitoneal bleeding is ruled out, patients are triaged as suffering from either blast lung injury or other etiologies. In principle, all these patients should be further resuscitated in the intensive care unit. Differentiation between blast lung injury and other etiologies is more than semantic. Patients with blast lung injury with massive air leaks and thoracic compartment syndrome who do not respond to resuscitation should undergo thoracotomy.

wait until the influx of patients has terminated and the proportions of the disaster are known.

Due to the paucity of in extremis patients, and their poor outcome, it is hard to draw conclusions from experience as to the exact treatment algorithm that will produce the best results. Postmortem studies indicate that most of the victims from bombing incidents die from blunt forces.[28,29] Most of these, however, die immediately at the site of the disaster. Overall, these victims represent as many as 80% of the deaths. The rest of the victims will die from either blast effects or projectiles. Some of this latter group survive to reach the hospital and present as moribund victims.

The general principles of care for in extremis patients injured by a bomb explosion are similar to those in blunt and penetrating trauma (Fig. 3). If the victim has no cardiac activity and there is no evidence that there was such activity in the immediate period before arrival at the emergency room, the patient is pronounced dead on arrival. If there is a terminal rhythm or a wide complex rhythm, victims are still resuscitated since this means that these victims deteriorated only a short time prior to arrival.

In the case of injuries from explosion, reversible causes of injury include hypoxia, tension pneumothorax, and hemorrhage. Due to the multiplicity of injuries suffered by these victims, we have adopted an algorithm of treatment that emphasizes an orderly approach to anatomical compartments with reversible pathologies. After intubation and control of significant external bleeding, thoracic injuries are assessed first followed by evaluation for possible hemorrhage in other compartments.

Emergency room thoracotomy is commonly used in patients presenting in extremis.[6] We discourage performing this procedure in victims suffering from significant blast lung injury. The noncompliant contused lung coupled with hemothorax will not allow adequate exposure for safe placement of an aortic clamp. In the moribund patient with multiple penetrating wounds, the presence of blood in the endotracheal tube may serve as a guide to whether the victim is suffering from significant blast lung injury or not, and whether emergency room thoracotomy should be attempted or not.

Limitations of the Protocols

The protocol of treatment of victims employed in HYMC was developed based on experience gained in 16 bombing events, in which almost 500 victims were treated. The protocol is biased toward injuries caused by blast and penetrating injuries since these were the main mechanisms of injuries experienced (Table I). We did encounter victims suffering from severe blunt injury and severe burns. However, these represented a minority of the patients. Life-threatening crush injury was not seen because the scenarios we responded to did not include building collapse. Head injuries are commonly encountered in urban terrorist attacks causing building collapse and are a major cause of mortality in immediate survivors. These mechanisms of injury should be taken into consideration when approaching patients injured in a bomb explosion. Needless to say, the main emphasis in treatment of all of these patients is to stabilize airway, oxygenation, and hemodynamic stability, which is what our algorithm emphasizes. Further evolution of these protocols will be necessary as more experience is gained with this patient population.

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