I. INTRODUCTION AND FIRST AID

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A. INITIAL OVERVIEW

Lightning injuries generally can be grouped into three classes of severity: mild, moderate, and severe. The prognosis and treatment depend on the severity of injury and the presenting signs that the patient exhibits.

1. Mild Injury

The mildly injured patient is often just stunned by the stroke. They usually are awake and able to respond to questions, although they may be confused and amnesic for the event, and continue to have difficulty with short-term memory assimilation for a few hours or days after the incident. They may complain of temporary deafness or blindness, but seldom demonstrate cutaneous burns or paralysis. They will often have rupture of at least one eardrum. Vital signs are usually stable, although an occasional patient may exhibit transient mild hypertension that usually does not require treatment. Recovery is usually gradual, but they may complain of paresthesia and muscular pain that may last for several weeks or months.

2. Moderate Injury

The moderately injured patient may be disoriented, combative, or comatose. They often have keraunoparalysis, with paralysis of the lower and sometimes upper extremities that lasts for several hours. The extremities that are affected will appear blue, mottled, pale, and pulseless, and it is difficult to differentiate this from true hypovolemic shock unless the blood pressure is evaluated by Doppler. If true hypotension exists, the patient should be evaluated for spinal injuries and other sources of shock such as blunt abdominal injuries or massive fractures. First- and second-degree burns may be present, but more commonly develop over the next several hours after injury. Tympanic membrane injury is common. These victims may have suffered a temporary cardiopulmonary standstill with the stroke and recovered spontaneously, and should be evaluated with an electrocardiogram. Rarely, seizures may occur in these victims. These patients are highly likely to survive. However, they may also have permanent sequelae such as sleep disorders, paresthesias, generalized weakness, personality changes, and difficulty with fine motor functions and some mental functions.

3. Severe Injury

Severely injured victims often present in cardiac arrest with either ventricular standstill or fibrillation. Cardiac resuscitation may, on occasion, be successful. While the lightning literature is rampant with the single case report of survival after a prolonged resuscitation, there is no reason to believe that this is the norm and that prolonged resuscitative measures will benefit those who do not respond to routine advanced cardiac life-support measures. Direct brain damage may occur from the stroke or as a result of hypoxia secondary to the cardiac arrest. Blunt trauma, skull fracture, and intracranial injuries are more common in these patients. The prognosis for recovery in this group is usually poor except for those who rapidly respond to resuscitative measures.

B. FIRST AID

The victim of lightning stroke may suffer a range of injuries (see Chapter 5), from being temporarily stunned to full cardiac arrest. There may be multiple victims in any incident. The emergency treatment in the field, then, must be varied and appropriate to the level of injury as well as to the number of victims. This section will discuss the immediate things that a bystander can do, the approach to a multiple casualty situation, and the actions that emergency medical personnel (paramedics and emergency medical technicians) should take when they arrive at the scene.

1. Bystander Response — Evaluating the Victim

The victim of lightning stroke who is breathing and talking has an excellent prognosis and usually needs only to be evaluated at the hospital to rule out cardiac, neurologic, burn, otologic, or ophthalmic damage. The role of the bystander who witnesses or happens onto the scene of a lightning incident should be to assess the situation and, in the minimally injured victim, primarily to provide supportive psychological and physical care for the patient, urging them to be transported to the hospital for evaluation and orienting them to what has happened, since the victim may have anterograde as well as some retrograde amnesia, may be quite confused, and is often unable to assimilate new information for a few hours or days or make logical decisions about their well-being.

The victim who is found unconscious must be assessed for the presence of pulse and respiration. It is extremely rare for a person with pulse and respiration to die, although they may still have significant injuries and sequelae. The pulse should be sought centrally in the carotid or femoral area, since the more severely injured victim may have intense vascular spasm of his extremities which makes the pulse very difficult to find. If the victim is not breathing and does not have a pulse, cardiopulmonary resuscitation should be started immediately.

The current theory connecting lightning and cardiac injury is that lightning acts as cosmic countershock, sending the heart into ventricular standstill (asystole), and that the heart will often resume its rhythm due to the heart's property of automaticity, but that the accompanying respiratory arrest is more long lasting, leading to a secondary cardiac arrest and arrhythmias due to hypoxia. This theory has come about from anecdotal literature and has not been confirmed by experimental data, although Andrews and Darveniza (Proc. Int. Conf. Lightning Stat. Elec., ERA Technology, Surrey, U.K., 1989) have recently provided qualified support for this process in an animal model. If the theory is true, the victim has the best chance of recovery if they receive immediate ventilation and/or chest compressions, as indicated by the victim's vital signs.

As the rescuer is starting cardiopulmonary resuscitation, he should ensure that someone else is summoning a medical response team. Unfortunately, if the victim is in a wilderness area where timely rescue is unlikely, prolonged basic cardiopulmonary resuscitation is not only impractical, but also may not be effective in either resuscitating the victim or in preventing hypoxic brain damage.

For the nonarrested victim, the airway, if obstructed, should be opened with the chin lift or jaw thrust maneuver, not with extension of the neck since spinal injuries have been reported to occur with lightning injuries. If there is any suspicion that the victim has fallen or been thrown a distance in connection with the lightning stroke, the victim should be left where they are until spinal precautions (backboard and cervical immobilization) can be done in order to protect the victim from further harm due to movement of potentially unstable fractures. The only exception to this would be if the victim is in immediate danger of suffering life-threatening harm for some reason, such as having a seizure near the edge of a precipice.

Blunt injuries, spinal cord trauma, and closed head injuries have been reported, and the patient should be evaluated for them. Any fractures or dislocations should be splinted. Burns, if there are any, may be covered by a dry, clean cloth or dressing pending arrival of prehospital care personnel. Hemorrhage, a rare event with lightning injury, should be controlled with direct pressure over the wound, not by tourniquets or other methods of vascular compression.

A victim who is having a seizure should be protected from injuring themselves. Since most seizures resolve on their own in less that 1 min, trying to insert something into the victim's mouth is not only unnecessary, but may be dangerous to both the victim and the rescuer.

2. Response to Multiple Victims

If the rescuer is presented with several victims, he must make a decision as to where he will expend his efforts and must *triage* the victims. As stated earlier, the victims who are breathing and have a pulse, regardless of the state of consciousness, are generally going to do well. The victims without pulse and respiration are the ones on whom the rescuer can have the most impact. While victims with lesser injuries will need to be tended to eventually, the rescuer's immediate efforts should be applied to those who are most critically ill. Other, nonskilled bystanders may be employed to monitor the less critically ill victims.

3. Prehospital Care Response

When emergency medical services (EMS) personnel arrive on the scene, they should assess the scene for continuing danger to the victims, other rescuers, and themselves, and secure the area accordingly. They will need to determine the number of victims, triage them for care, determine the care that has already been rendered, plan their response according to their findings, and call for additional help, if necessary.

For the single conscious victim, the guidelines as noted above apply. Simple reassurance and transport for medical evaluation are all that are usually necessary. Cardiac monitoring and intravenous access are desirable, if available, particularly if the victim has suffered loss of consciousness or complains of chest pain or difficulty breathing.

For the more seriously injured victim, the airway should be assessed and protected, if necessary. Cardiopulmonary resuscitation, if indicated, should be instituted with appropriate advanced cardiac life support (ACLS) protocols being followed. Routine ACLS drugs may be used as normally indicated by the patient's condition. Spinal immobilization should be done for the unconscious patient or one who has suffered a fall or been thrown in the incident.

Assessing the blood pressure may be difficult, as some victims have intense vascular spasm with cool, nearly pulseless extremities. Occasionally, the blood pressure will be found to be elevated due to vascular constriction. This will usually resolve on its own without the need for medication or other intervention. The lower extremities and occasionally the upper extremities may appear mottled, pulseless, and cool as a result of vascular spasm or sympathetic nervous system instability. This, too, usually resolves in a matter of hours, although there may be permanent paresis and paresthesia in some patients.

Intravenous fluid should be lactated Ringer's or normal saline. Normally, fluid restriction is preferred for these patients, especially those who are in cardiac arrest or who have blunt injuries to the head, in order to prevent cerebral edema. However, if there are signs that shock is due to blunt injury, multiple major fractures, or blood loss, fluid resuscitation should be more vigorous.

Physical assessment should also include a brief evaluation of the mental status of the victim and a search for burns, fractures, and dislocations. Victims should be transported to a hospital for further treatment, if necessary, and evaluation.

II. EMERGENCY DEPARTMENT CARE

A. STABILIZATION

Immediate care should address patency and protection of the airway and institution of cardiac (ACLS) protocols if indicated by the victim's presentation. Intravenous access, if not already obtained by the EMS personnel, is indicated in the more severely injured or unconscious victim.

B. EVALUATION AND TREATMENT

It is helpful to obtain a history, if it is available, of the incident. In addition, a history of the patient's health status, including allergies, medications, and concurrent illnesses, can be helpful in guiding further care after resuscitation.

As with all trauma patients, it is essential that the patient be undressed in order to facilitate a complete physical evaluation. Not only are the vital signs essential, but the physician should take note of the mental status of the patient and note it on the chart. Since many victims will have been hit during a thunderstorm and will be wet, the patient should also be evaluated for hypothermia and treated appropriately.

Victims of lightning injury who present to an emergency department need to be evaluated by the emergency physician for cardiac damage, including arrhythmias; neurological damage, including intracranial and spinal cord injury; burns, including a screen for myoglobinuria if the burns are extensive; tympanic membrane rupture and hearing loss; injuries to the musculoskeletal system, including fractures, dislocations, and spinal trauma; and ophthalmic injury.

If the patient is still in cardiac arrest by the time they reach the emergency department, cardiopulmonary resuscitation may be continued until it is judged that recovery is unlikely. The postcardiac arrest and resuscitation patient who recovers cardiac function and a blood pressure should be treated as if they have had a myocardial infarction, or at least myocardial damage, with appropriate monitoring for arrhythmias and serial electrocardiograms and cardiac enzymes. The drug regimen for these patients for arrhythmias is the same as in standard cardiac care. Electrocardiographic changes may take several weeks to months to resolve.

It is probably wise to obtain an electrocardiogram even in the patient who has not had a cardiac arrest, since they may occasionally show ST segment changes and arrhythmias. If the patient is otherwise alert and not complaining of chest pain, cardiac monitoring may not be necessary.

Severe vascular spasm of the extremities may be present in up to two thirds of victims, with cold, pulseless, mottled extremities making it difficult to obtain an accurate blood pressure. A Doppler may need to be used to measure the blood pressure. Fluid restriction should be the rule in most of these patients in order to decrease the amount of cerebral edema that they may suffer. However, if there is evidence of true shock, the physician should rule out spinal cord injury and spinal shock. In addition, hypovolemic shock should be ruled out or treated with vigorous fluid resuscitation.

Vascular spasm affects the lower extremities nearly twice as often as the upper extremities and is probably a result of sympathetic nervous system instability as well as vascular spasm. While it usually clears within a few hours, the victim should nevertheless be observed for any untoward complications, such as compartment syndrome or evolving neurologic damage secondary to cord ischemia from spinal artery spasm, with frequent neurovascular checks.

Frequently, the victim will have suffered unconsciousness, even if only temporarily, may be combative and confused as his mental state continues to clear, and will be amnesic for the event and often for the events of the next few days, similar to the victim of electroconvulsive shock therapy for depression. The victim who does not continue to clear neurologically must be assessed for intracranial injury, including intracranial hemorrhage, cerebral contusion, and skull fracture, which have all been reported. Computerized tomography or nuclear magnetic resonance scanning is indicated in these patients.

The burns that are seen with lightning injury have already been discussed in Chapters 5 and 6. As noted, they are generally superficial and require little but supportive care. The deep burns that are common with man-made high-voltage electrical injuries are uncommon with lightning, but, if they occur, should be treated as high-voltage burns usually are — with fluid loading, alkalinization of the urine, osmotic diuresis, and fasciotomy as indicated. Lightning injuries seldom need this aggressive care and burns are generally the least of all the problems that may be seen with lightning victims.

Tympanic rupture is common with lightning victims, although the physician generally does not know to look for it initially in most cases. In addition to tympanic membrane rupture, ossicular disruption may occur. The patient needs referral to a qualified otolaryngologist for evaluation and care, although operative intervention is usually delayed until after the edema and inflammation of the acute injury resolve. Otorrhea or hemotympanum may indicate basilar skull fracture.

While fractures and dislocations have been reported with lightning injuries, they are relatively uncommon unless the victim has been thrown a distance. Nevertheless, the secondary survey of the patient after they have been stabilized should include a search for them. Particularly dangerous are spinal injuries. If there is any evidence that the patient has been thrown or fallen, the cervical spine should be evaluated for damage, and cervical immobilization should continue until it can be ruled out. This is particularly important in the unconscious or intoxicated patient who cannot give a history or cooperate with the physical examination. In the conscious, alert patient who is sober and who has had no loss of consciousness, spinal injury usually can be easily ruled out clinically without radiography.

The abdomen should be evaluated for blunt trauma, although it is uncommon. The absence of bowel sounds may indicate only a simple ileus or may be more ominous and indicate intraabdominal injury. Since gastric irritation may occur in the more seriously injured patient, histamine antagonists and antacids may be indicated as well as nasogastric suction. Peritoneal lavage or abdominal scanning may be indicated if the patient continues to show signs of shock or has other evidence of intraabdominal injury.

Sometime during the initial examination but after the patient has been stabilized, the eyes should be evaluated for any damage, including cataract formation. It is useful, if the patient can cooperate, to obtain a visual acuity so that any deterioration over the next few days can be documented.

Tetanus prophylaxis should be given if indicated by history and physical examination. Antibiotics need not be given unless there are signs of significant open injuries, violation of the dura, or intraabdominal injuries.

C. DISPOSITION

Minimally or moderately injured patients usually continue to improve dramatically over the first few hours. The minimally injured patient will probably only need overnight observation or may even be discharged to a responsible family member if the physician judges this to be appropriate after evaluation. The moderately injured patient may need hospitalization while their mental status improves and for further evaluation and perhaps rehabilitation planning for their injuries. Obviously, the most seriously injured victims may need intensive care, with extensive monitoring and often mechanical ventilation, antiarrhythmic medication, and Swan-Ganz catheterization.

D. LABORATORY AND RADIOLOGIC EXAMINATIONS

For the minimally injured victim, a thorough physical examination, an electrocardiogram, and appropriate referral for follow-up may be all that is indicated. However, based on the physician's findings, other tests may also be appropriate.

For more seriously injured patients, a complete blood count, electrocardiogram, cardiac enzymes, and urinalysis for myoglobin are indicated along with any other tests that are specifically indicated by the patient's physical findings. The most seriously ill patients will obviously need more aggressive laboratory examination and monitoring, including arterial blood gases if they have suffered a cardiac arrest or are on a mechanical ventilator, electrolytes, and kidney function tests such as blood urea nitrogen (BUN) and creatinine for use as a baseline. Serial cardiac isoenzymes and electrocardiograms are probably indicated for these patients.

An X-ray of the chest may be helpful in the moderately or severely injured patient. Cervical spine films should be ordered for anyone who has had a loss of consciousness, a history of being thrown, cranial burns, contusions, or change in mentation. Other films may be indicated by the patient's history and physical examination. If there is evidence of intracranial injury or edema, computerized tomography or nuclear magnetic resonance scanning are indicated, and intracranial pressure monitoring may be helpful. Obviously, operable causes of intracranial injury require operative intervention, depending on the general expectation for the survival of the patient.

An electrocardiogram is necessary for all patients due to the relatively high incidence of cardiac injuries with lightning stroke.

III. INTENSIVE CARE MANAGEMENT

R. P. F. Parkes
(with a contribution by M. J. Eadie)

A. INTRODUCTION

Following initial assessment and resuscitation of a patient suffering from lightning strike, therapy should be directed toward inpatient care. Patients who are conscious on presentation and who have no evidence of severe burns, respiratory failure, or cardiac disease may be successfully managed in a center with limited facilities. All patients should receive at least 24 h of electrocardiographic (ECG) monitoring attended by medical and nursing staff skilled in the interpretation of arrhythmias and cardiopulmonary resuscitation (CPR). Multisystem pathology, however, may require referral to a general intensive care unit (ICU). Table 1 lists the human and technical resources required for the successful management of severe lightning strike. Transfer to a regional referral center is recommended for the management of life-threatening multisystem disease, for long-term (>48 h) intermittent positive pressure ventilation (IPPV), renal dialysis, or the evaluation and management of persistent coma. Severe cardiac failure or the presence of significant arrhythmias should prompt referral to a center with expertise in cardiology.

Imagine your predicament, however, when asked to manage a patient suffering the effects of lightning strike. After reading the contributions from the other authors of this book, your accident and emergency colleagues have elegantly resuscitated the patient and now seek to refer him or her to you for ongoing care. You remember that your old friend, Dr. X, knew a bit about lightning (still, his experience must be limited; lightning only strikes once in the same place!). This review aims to present the features of lightning strike in a manner that will assist the clinician in intensive care practice. No attempt will be made to discuss burns, ocular, or ear, nose, and throat injuries.

B. PUBLISHED EXPERIENCE WITH LIGHTNING INJURY

Lightning injury is uncommon. Occasionally, a number of individuals will be affected;[1] in general, however, the literature is restricted to individual reports or cumulative reviews. While frequently reported events infer a significant clinical problem, the retrospective nature of such reports and the lack of standardized reporting do not necessarily assist with individual patient management. Intensive care is a relatively new specialty. Although earlier reports elegantly describe the natural history of lightning strike, any therapeutic regimen in which CPR and IPPV are not available is difficult to relate to current intensive care practice. For this reason, this discussion will be largely restricted to cases reported after 1960,[2] when CPR was first advocated. The principal clinical syndromes of relevance to intensive care are listed in Table 2.[3-35]

TABLE 1
Human and Physical Resources Required for the Management of Severe Lightning Injury

An intensive care unit with:
- 24-h medical and nursing staff
- One-to-one nurse/patient ratio
- ECG monitoring
- Cardioversion
- Facilities for ventilation

A hospital with:
- 24-h laboratory service
- 24-h radiology service (including CT scanning)
  - Access to specialist services:
    - Orthopedic surgery
    - Neurosurgery
    - ENT surgery
    - Ophthalmology
    - General surgery
    - Burns surgery
    - Cardiology

C. INTENSIVE CARE MANAGEMENT

1. The Cardiovascular System

Resuscitation commences with the stabilization of airway, breathing, and circulation.[36] ECG monitoring should be instituted as soon as possible and arrhythmias treated. Individual experience has not shown a clear pattern of arrhythmias after lightning strike. Although bystander CPR is usually commenced in the absence of a palpable peripheral pulse, the administration of CPR may not necessarily imply the presence of cardiac arrest. In 17 patients reported as receiving CPR in recent literature,[2-4,6-8,11,13,20,22,25-27] CPR was initiated in 5 instances where no arrhythmia was present.[11,13,22,26,27] Although bystander overenthusiasm may be one reason for this (in one case, the person initiating resuscitation was a medical student!), apnea, rather than an arrythmia, may be the indication for CPR (see Section III.C.3 below).

In assessing the circulation, the complexity of lightning strike should be borne in mind. Burns, trauma, blast injuries, and hypothermia may complicate the electrical injury. Therefore, in addition to the diagnosis and treatment of arrhythmias, a search should be made for other causes of circulatory collapse. In the presence of sinus rhythm, circulatory collapse may be due to hypovolemia, myocardial injury (including myocardial contusion), and cardiac tamponade. With regard to cardiac tamponade, the classical signs of elevated venous pressure, Kussmaul's sign, paradoxical pulse, and a quiet precordium may not always be present, particularly in a ventilated patient; echocardiography should be performed if possible. This will give additional information regarding focal and global myocardial function. In most cases, fluid administration is guided by the assessment of pulse, blood pressure, skin perfusion, urine output, and central venous pressure. Addition information may be gained after placement of a pulmonary artery (Swan Ganz) catheter. The principal indications for insertion are:

1. To elucidate the differential diagnosis of pulmonary edema (elevated pulmonary venous pressure vs. the adult respiratory distress syndrome)
2. To allow greater precision in fluid resuscitation
3. To aid in the diagnosis of cardiac tamponade
4. To aid in the differentiation between an acquired ventricular septal defect and mitral papillary muscle rupture.

TABLE 2
Common Clinical Events in Lightning Strike

	Ref.
Cardiovascular	
Inferior myocardial infarction	3,4,6,16,18,26–28
Anterior myocardial infarction	14,18,23,28
Ventricular fibrillation	3,4,6,8,20,22,27
Ventricular asystole	2,6,25
Need for cardiopulmonary resuscitation	2–4,6–8,11,13,20,22,25–27
Pulmonary	
Diffuse pulmonary infiltrates	2,3,6,8,11,13–15,22,23,25
Bronchospasm	6
Need for IPPV	2,3,6,8,11–14,15,26,31
Central nervous system	
Motor paralysis	21,23,26,28,33
Mononeuritis	10,26,30
Brain death	3,6,22,31
Persisting cerebral damage	8,11,22,26,27
Cerebral trauma	3,6,7,13,22,26,31,32,34
Paraplegia	24
Gastrointestinal system	
Acute abdomen	8,22
Gastrointestinal hemorrhage	10
Acute gastric dilatation	6,25
Chronic abdominal pain	5
Renal system	
Myoglobinuria	4,5,8,20,35
Hemoglobinuria	4,8,20
Miscellaneous	
DIC	3
Hypothermia	2,6,8,25
Focal cutaneous necrosis	12
Hypertension, tachycardia	4,7,11,23

While normal sinus rhythm and consciousness on presentation imply a good prognosis, ECG abnormalities of myocardial damage have been frequently reported. Inferior myocardial infarction[3,4,6,16,26-28] has been reported more frequently than anterior infarction.[14,18,23,28] If myocardial infarction occurs, circulatory problems appear to be uncommon in the absence of other pathology. In general, therefore, the expectant management of a patient with myocardial function is adequate. Although thrombolytic therapy after transmural myocardial infarction has been demonstrated to reduce mortality,[37] lightning strike is accompanied by a high incidence of associated trauma and prolonged CPR. For this reason, thrombolytic agents should be used with caution. Particular attention should be given to the provision of adequate analgesia, as pain typical of myocardial ischemia occurs.[19]

2. The Respiratory System

Assessment of the respiratory system should commence with an evaluation of the patient's airway and ventilation and examination for pulmonary edema, a flail segment, and aspiration pneumonitis. A chest X-ray should be taken soon after admission and arterial blood gases should be sampled if clinically indicated.

TABLE 3
Differential Diagnosis of Bilateral Pulmonary Infiltrates Appearing within 24 h of Admission for Lightning Strike

Cardiogenic pulmonary edema
Aspiration pneumonitis
Pulmonary contusion
Blast injury
Thermal injury
"Neurogenic" pulmonary edema
Preexisting pulmonary disease

The need for positive pressure ventilation was identified in 10 case reports.[2,3,6,8,11-14,15,26,31] Although many patients were intubated as part of the process of CPR or for frank respiratory failure, IPPV was frequently instituted as an aid to the management of persistent coma. The importance of an adequate airway cannot be overemphasized. If the patient has a depressed gag or cough reflex and can tolerate a Guedel airway, an endotracheal tube should be inserted and the patient ventilated to protect the airway, maintain oxygenation, and avoid the deleterious effects of hypercapnia. Arterial hypoxemia may not necessarily indicate the need for intubation and ventilation in a conscious, lucid patient. For example, left ventricular failure may be associated with significant hypoxemia, but may respond to conservative measures such as the administration of diuretics and oxygen by mask. Patients with pulmonary and chest wall trauma may not require IPPV if pain is relieved, the patient remains lucid, and cough is effective.

Although myocardial infarction is common, the presence of bilateral pulmonary infiltrates may not necessarily be due to left ventricular failure. Other insults may produce a similar radiological picture (Table 3). To elucidate this, gram stain and bacteriological assessment of sputum, echocardiography, and flow-directed pulmonary artery (Swan-Ganz) catheterization may be indicated. Therapy for respiratory failure includes treatment of the underlying cause (LVF, infection) and the general medical and nursing care of a patient on a ventilator.[38] This will not be reviewed here.

3. Central Nervous System

a. Assessment

As soon as possible, a rapid assessment of neurological function should be made. In addition to an assessment of conscious state, the Glascow coma score (GCS) should be documented and a search made for focal neurological signs.

External signs of head trauma have been frequently reported.[3,6,7,13,22,26,31,32] Although focal intracranial pathology is uncommon, extradural, subdural, and intracerebral hematomata[7,13,34] have been reported. Computerized axial tomography (CAT) scanning should be performed in cases of persistent coma, particularly when an initially conscious patient becomes comatose,[7] when signs of external head trauma are present, or when focal neurological signs are observed.

Ravitch et al.[2] and Taussig[21] advocated prolonged CPR after cases of lightning strike, noting recovery of consciousness and mentation after prolonged anoxia. However, the literature reveals that the morbidity and mortality are high. A critical review by Cooper[39] demonstrated a poor prognosis after the onset of ventricular fibrillation. In nine reports of ventricular fibrillation[3,4,6,8,20,22,27] and three reports of asystole,[2,6,25] brain death occurred in four cases.[3,6,22,31] Persisting neurological deficits were observed in a further five and included loss of short-term memory,[8] ataxia,[22] recurrent seizures,[11] and alterations in personality.[20,26,27] Although apparent recovery after prolonged anoxia has occurred,[2,19,25] a prospective study with standardized criteria for assessment of neurologic function is required to accurately describe the natural history of cerebral damage following lightning strike.

Keraunoparalysis,[33] characterized by the triad of motor paralysis, anesthesia and vasomotor disturbance, may be encountered during initial assessment.[21,23,26,28,34] Typically, the pulse in an affected limb is absent. The pathophysiology is imperfectly understood, but may be due to spasm of the vasa vasorum. Paralysis, however, is transient; full recovery of motor and sensory function usually occurs within 1 to 2 d.

Spinal cord injury has been reported;[24] a diagnosis of keraunoparalysis should only be made after structural spinal cord injury has been excluded. In complete cord transection, impaired anal reflexes and autonomic disturbance such as priapism and urinary retention are observed. These events are not described in keraunoparalysis. A symmetrical motor neuropathy of both lower limbs has also been described.[26]

Coma as a presenting sign is frequently reported; its duration is variable. IPPV is therefore indicated to protect the airway and to assist in the control of intracranial pressure (ICP). In general, the arterial PCO_2 should be maintained at approximately 25 to 30 mmHg. Fluid restriction, steroids, diuretics, barbiturates, calcium channel blockers, lignocaine, phenytoin, and osmotic agents have all been used to minimize cerebral damage.[40] ICP monitoring is frequently used in a number of institutions.

Brain death may occur after lightning strike. The diagnosis may be clouded by hypothermia,[2,6,8,25] keraunoparalysis, and damage to the vestibular system (Chapter 5). Keraunoparalysis may delay, but will not prevent a diagnosis of brain death, as it rarely involves the face and seldom, if ever, persists after 48 h. The diagnosis of brain death, therefore, may be made if brain stem reflexes are absent after careful examination on two occasions, if an appropriate clinical situation exists, and if metabolic, pharmacologic, or other causes of coma are excluded.[41]

b. Management (Contributed by M. J. Eadie)

When cardiac arrest follows lightning strike, the early institution of CPR may be life saving. Death is unlikely in the absence of cardiac arrest[39] and there is published evidence that the institution of CPR may permit the survival of patients judged clinically dead by conventional criteria.[2,21] The other acute neurological effects of lightning injury are likely to resolve spontaneously within a relatively short period. There do not seem to be published data suggesting that active intervention (apart from resuscitation) improves the prognosis in the majority of instances of lightning injury to the central nervous system

The rare delayed neurological sequelae of lightning strike appear to involve a number of different pathogenic mechanisms, although some are not elucidated. The presence of intracranial bleeding can now be established by CT head scanning and, if necessary, appropriate steps can be taken to reduce intracranial pressure (e.g., high-dose glucocorticoids, intravenous osmotically active cerebral dehydrating agents), and/or surgical evacuation of a hematoma if it constitutes a significant mass lesion and is situated in an accessible site. Any residual neurological deficit is managed in the usual way, e.g., physiotherapy, speech therapy, as indicated.

4. Gastrointestinal System

Acute gastric dilatation[6,25] and stress erosions have been described.[10] In all patients requiring IPPV, the stomach should be decompressed with a nasogastric tube and prophylaxis against stress ulceration commenced. Antacids and histamine (H2 receptor) antagonists are effective in preventing stress ulceration. However, evidence suggests that sucralfate conveys effective protection with a lower incidence of hospital-acquired pneumonia.[42]

A continued search for evidence of intraabdominal pathology is vital. The interpretation of signs is difficult in the setting of a sedated, ventilated patient. Abdominal ultrasound, CAT scanning, radioisotope scanning of the abdomen and, in selected cases, "blind" laparotomy may be necessary to reveal the source of hemorrhage or sepsis.[43,44]

5. Renal System

Both myoglobinuria[4,5,8,20,35] and hemoglobinuria[4,8,20] have been recorded following lightning strike. Unfortunately, their severity is difficult to estimate from published reports. Modest amounts of myoglobin or acid hematein are rapidly excreted by the kidney; however, massive amounts may cause acute renal failure. Excretion of myoglobin is enhanced by increasing urine volume and the maintenance of an alkaline urine. The use of mannitol and intravenous sodium bicarbonate is protective.[45] However, increased urinary losses must be replaced and renal perfusion maintained. Attention should also be directed toward the provision of adequate urinary drainage, the prevention of urinary tract infection, and maintenance of adequate renal perfusion.

6. Miscellaneous

a. Hypothermia

Hypothermia has been recorded.[2,6,8,25] Prevention of further heat loss by gentle warming and adequate humidification of inspired gases will frequently result in restoration of normal body temperature. Surface rewarming is more rapid, but may result in hypotension due to cutaneous vasodilatation. Internal rewarming using an extracorporeal circulation, irrigation of the peritoneum or mediastinum, may (rarely) be required.[46] The relative rarity of hypothermia as a clinical entity casts doubt on the postulate that metabolic rate falls dramatically.[21,47]

b. Disseminated Intravascular Coagulation

Disseminated intravascular coagulation has been reported following prolonged hypoxia.[3] In addition, the syndrome may result from burns, sepsis, fat embolism, and, in the case of a female patient, a missed abortion.

c. Hyperadrenergic State

A "hyperadrenergic state", characterized by the presence of hypertension and tachycardia, has been reported.[4,7,11,23] While this may be a specific feature of lightning stroke, a similar clinical picture is frequently encountered in critically ill patients; evaluation of the patient for left ventricular failure, pain, sepsis, hypovolemia, or preexisting hypertension should be undertaken. While β-blockers have been advocated for this condition, they are contraindicated in patients with cardiac failure or airway obstruction.

d. Care of the Family

The patient's family may have witnessed both the violence of the lightning strike and the apparent violence of subsequent resuscitation and urgent evacuation. In addition to a simple explanation of the nature of the injury and the proposed therapy, they will need reassurance that, at least, everything possible is being done. It is important to explain that "everything possible" may not be enough, i.e., that the patient may die. A statement that "everything will be all right" may lead relatives down an unrealistic path. If everything is *not* all right, that path may end in the destruction of the family, refusal to accept that therapy is pointless, and anger directed at the ICU team. Such anger is typically expressed in litigation.

IV. INPATIENT MANAGEMENT AND FOLLOW-UP

A. POST-INTENSIVE CARE ASSESSMENT

Following discharge from the ICU or CCU, the physician has an active role to play. Transfer should be accompanied by an early and thorough physical examination. The use of sedative, analgesic, and relaxant drugs used in the ICU may mask focal neurological signs.

B. NEUROLOGICAL REHABILITATION

In the event of evidence of cerebral damage, a skilled team is required to assess, supervise, and maximize the patient's recovery, and referral to a rehabilitation unit is essential.

In addition to diffuse and focal cerebral damage, a mononeuritis has been reported[10,26,30] with impaired nerve conduction.[26] While the prognosis appears good, its presence may have medicolegal implications for a patient wishing to document his or her level of disability.

Personality changes may occur as a result of cerebral anoxia, the effects of injury, bereavement, and hospitalization. In a study of affected children, Dollinger et al.[48] described a high incidence of fears, somatic complaints, and sleep disturbance. Furthermore, a sense of guilt is particularly common in individuals who survive a disaster; all victims should be counseled to treat emotional disturbance.

C. CARDIAC REHABILITATION AND COUNSELING

ECG abnormalities are said to resolve within 12 months (Chapter 5, q.v.). However, the risk of chronic cardiac disease following lightning strike is unknown. Furthermore, some patients with an abnormal ECG will have severe preexisting cardiac disease. Ongoing assessment of cardiac function should continue, therefore, for at least 12 months. Arrhythmias, angina, or cardiac failure should prompt referral for expert cardiac assessment of cardiac anatomy and function.

Truly elective surgery should probably be avoided for 6 months. Following myocardial infarction, the incidence of intraoperative myocardial infarction is considerably increased; this risk declines to approximately 15% at 6 months.[49]

Pregnancy aggravates preexisting cardiac disease. Although there are no published data, it would seem prudent to counsel women of child-bearing age who have suffered myocardial damage as a result of lightning strike to avoid conception for a period of 12 months.

In addition to the acute gastric dilatation and abdominal visceral injury described above, chronic abdominal pain has been described.[5] Its nature is poorly understood; symptomatic treatment has been employed with limited success.

D. CONCLUSIONS

Lightning strike poses a significant threat to life. In the event of severe, multisystem disease, shock, or respiratory failure, admission to an ICU with appropriate clinical and laboratory facilities is essential. The role of the intensive care specialist in such a situation is fourfold: (1) to provide life support, (2) to ensure that other diseases which may mimic lightning injury are excluded, (3) to arrange appropriate specialist referral, and (4) to care for the patient's family. Adequate follow-up is an equally important part of care. An integrated team approach will ensure that the patient's recovery is maximized.

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V. SPECIAL ASPECTS OF OCULAR MANAGEMENT

F. Fraunfelder and M. Meyer

A. EMERGENCY CARE

Contrary to the popular belief that being struck by lightning is nearly always fatal, many more survive than die. Sudden death in lightning injuries is the result of paralysis of the respiratory center, apnea, ventricular fibrillation, or cardiac arrest.

1. Aggressive Resuscitation

Artificial resuscitative measures should be started early and continued almost indefinitely after lightning injuries. Dilated or nonreactive pupils are an unreliable indicator of severe brainstem hypoxia in a patient injured by lightning. Pupillary responses should never be used as a criterion to withhold or discontinue aggressive resuscitative measures in these patients.[1]

2. Increased Intracranial Pressure

Treatment of increased intracranial pressure following lightning injuries includes hyperventilation, steroids, and hyperosmolar agents. The benefits of these treatments can be assessed by monitoring the patient's intracranial pressure.[2]

B. PRIMARY CARE

While the best treatment for ocular injuries from lightning is prevention, actual treatment is supportive. It is aimed at preventing infection and tissue loss.

1. Tetanus Prophylaxis

Prophylactic treatment of a major burn wound should include an injection of 0.5 ml of adsorbed tetanus toxoid to all patients who have not had a booster within the past year. In nonvaccinated subjects, immunization will be completed by two further injections, at 4 to 6 weeks and then at 6 months.

2. Cleansing and Debridement of the Wound

The lids may have typical cutaneous burn injuries. Depending on the severity, superficial to deep burns leading to sloughing may occur. The burned areas should be kept clean by applying warm, wet sterile gauze impregnated with antibiotics such as gentamicin, and the necrotic tissue should be gently debrided.[3]

Corneal injuries are the most common immediate ocular findings in lightning strikes, and generally consist of epithelial layer lesions and deep opacities that may require several weeks to resolve.[4] Corneal exposure may be avoided by patching and applying moist compresses or a moisture chamber. Occasionally, the use of a soft contact lens may be necessary.

C. INTERMEDIARY CARE

The immediate management of acute electrical injuries of the eye is the preservation of eyelid structure and motility, the maintenance of conjunctival fornices, and the provision of an adequate cover for the anterior segment of the eye. Intraocular inflammation should be carefully controlled by the judicious use of corticosteroids and mydriatics. There is no proven therapy for retinopathy associated with severe electrical burns; however, systemic corticosteroids might theoretically help preserve retinal structure and function if the patient's general condition does not contraindicate the use of such drugs in high doses. Long-term sequelae, such as cataract formation, are more amenable to treatment, and surgery for this condition is usually uneventful. Where there has been severe loss of central vision, low visual aids (magnification devices) may be of some help in improving the patient's reading capability.

1. Antimicrobial Therapy

While dead tissue remains, bacterial activity is heightened; while the wound remains open, bacterial invasion may occur. *Pseudomonas aeruginosa* and *Staphylococcus aureus* are the predominant organisms in the majority of significant burn wound infections; streptococci and *Proteus* are less frequent.

Systemic antibiotics should be used as indicated to treat or prevent infection secondary to either lightning or electrical injury. Oral oxytetracycline or parenteral gentamicin or potassium penicillin G may be administered. The usual daily dosage of gentamicin is 3 mg/kg given i.v. or i.m. in three divided doses. Ocular measures to keep burned eyelids free of infection may include use of polymyxin B wet applications.

2. Temporary Corneal Grafts

Allografts or porcine xenografts may be used to alleviate pain, prevent secondary infection, and hasten the healing process of corneal injury. If possible, autografts should be used for permanent wound closure.

3. Additional Ocular Repairs

Severe corneal involvement with impending corneal perforation secondary to thermal injuries may require penetrating keratoplasty. When possible, tarsorrhaphy should be performed to protect the graft and globe.[5] Between 75 and 80% of electrical cataracts will progress to the point where lens extraction is required.[6,7]

4. Cycloplegics and Corticosteroids

Iridocyclitis may develop, depending on the degree of lightning injury. Anterior uveitis may be treated by application of 1 to 2% atropine four times daily.[8] Early and constant pupillary dilatation lessens the likelihood of synechias. For treatment of severe uveitis, one drop of 0.1% dexamethasone two to four times daily may be added to the mydriatic regimen.

D. RECONSTRUCTIVE CARE

Treatment of survivors of lightning injury may also include reconstructive care when clinical observation indicates no improvement. Surgical procedures are performed to restore the eye as nearly as possible to its original state.

1. Skin Grafts for Eyelids

Lightning burns are generally more superficial than those caused by high-voltage alternating current. Conservative management is indicated, and skin grafting is seldom necessary for achieving burn wound closure of the eyelids; however, if so, the lids may require split- or full-thickness grafts and nasal cartilage to correct ectropion or entropion.[5]

2. Prosthokeratoplasty

The globe may require prosthokeratoplasty if corneal grafts fail to construct the anterior segment.

3. Facial Reconstructive Surgery

The face may require reconstruction of abnormalities by use of local skin flaps and distant split-thickness skin flaps.

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VI. TREATMENT OF COCHLEOVESTIBULAR INJURY FROM LIGHTNING

LaV. Bergstrom

The patient may be unconscious and may have no heartbeat. Resuscitation of the patient using cardiopulmonary techniques and electric shock to the chest wall to restore a normal rhythm is essential in these critical cases. Cardiopulmonary resuscitation may be continued while the patient is being transported to a facility where cardioversion and antiarrhythmic drugs can be administered and the patient monitored.

Victims of lightning strike may have minor arrhythmias, bleeding, or cerebrospinal fluid (CSF) coming from the ears, and may be disoriented and uncooperative while being examined. The otologist cannot have the patient transferred to the otological clinic, but can have the operating microscope and appropriate ear instruments brought to the bedside of the patient if the otoscope does not give an adequate view. Often, there is a clot in the external ear canal which must be evacuated before a complete examination can be done. Tuning fork testing should be done at the bedside as soon as possible to get some idea of the hearing loss. Patients will often complain of roaring or high-pitched tinnitus and may find it somewhat difficult to localize to tuning forks, but this problem can be minimized by using a 512-Hz tuning fork. Vertigo also is a fairly common symptom. Sometimes, local soft tissue or bony loss and partial avulsion of the pinna may make it difficult to examine the ear canal and drum. Local tissue may be available, and the partial avulsion of the pinna should be sutured. An audiogram may need to be delayed until local tissues have healed and are no longer painful. Quite frequently, there is a tympanic membrane perforation, sometimes with the edges inverted into the middle ear. This can be manipulated into an everted position, but is best done in a few days when the patient is stable and out of the intensive care unit. A four-quadrant block with a local anesthetic of about 1.5 to 2.0-cc volume combined with 1:100,000 injectable epinephrine will usually provide adequate analgesia. Care must be taken to explain to the patient just before each needle stick is done that some pain will occur early, but that as the injection proceeds, the pain will usually decrease. The needle should be $1^1/_2$ to $1^3/_4$ in. long, 27 gauge in diameter, and disposable. Eardrum blanching due to the epinephrine may not occur in these cases, or there may be subtotal blanching. Perforation or avulsion of a portion of the tympanic membrane may occur in any area.

Charring of the ear canal is sometimes seen, and there may be bleeding between the layers of the eardrum, although this is quite rare. It is tempting to consider early exploration of the middle ear and performance of tympanoplasty. However, lightning injury of the tympanic membrane has some similarities to welding injuries of the ear in that there is marked edema, burning and charring of the external auditory canal and drum, and other inflammatory changes which suggest damage to the local vasculature. Spontaneous healing of the perforation may occur.

Other traumas to the temporal bone include permanent disruption of the facial nerve with temporary or permanent paralysis, and temporal bone fracture into the labyrinth, which might cause meningitis if pathogenic organisms in the middle ear or in a deep laceration in continuity with the fracture occur. Nearby facial burns might also be infected and spread organisms to the ear. A culture of the CSF issuing from the ear should be done as well as a culture of spinal fluid obtained by lumbar puncture. Early antibiotic coverage can be changed when the results of cultures and sensitivities are known. Middle ear ossicles may be dislocated or fractured; this can often be diagnosed using computerized axial tomography. Reconstruction using the ossicles themselves or prosthetic replacement could be done at tympanoplasty or at a second stage in 6 to 12 months after the tympanic membrane perforation is healed.

While the tympanic membrane is perforated, dry-ear precautions must be observed. When showering or shampooing, a shower cap should be used in combination with a cotton plug sealed with vaseline or other appropriate barrier. Swimming may be allowed if the patient will use earplugs and wear a tightly fitting swimming cap. Diving is precluded.

Hearing acuity often improves and tinnitus may lessen, but in a moderate hearing loss that involves more than one or two high frequencies, hearing aids may be needed, especially if both ears have significant hearing loss. If there is total bilateral deafness, a cochlear implant might be appropriate if there is no significant vestibular damage. Vestibular symptoms may be a feature of the early course of lightning injury, but because the vestibular system includes the cerebellum, spinocerebellar tracts, vision, and proprioception, substantive recovery may be anticipated as the system makes adjustments. However, if the cerebullum, vision, or proprioception are also damaged, recovery may not occur or may occur partially after a protracted time. Also, if the involvement is bilateral, recovery is unlikely. Age, arthritis, or decreased mental acuity may also impede or retard recovery. Physical therapy may be of some value to selected patients.

If there is extensive cardiac or cerebral injury, the prognosis is extremely poor.

VII. SPECIAL MANAGEMENT OF BURNS

S. P. Pegg

A. MANAGEMENT PRINCIPLES

Severe burns in lightning injury are the exception rather than the rule. This section will concentrate on treatment of burns when they do occur. The management of burns following lightning injuries is an extension of the previous resuscitation in the emergency room or intensive care unit. In treating the burn injury, other aspects of the lightning injury must take precedence. The priorities are very much the treatment of associated injuries and complications while the burn injuries are being assessed and treated with antimicrobial creams. Myocardial damage is not uncommon and may be reflected in ECG abnormalities and dysrhythmias, and this aspect must be treated as top priority, with ECG monitoring and with monitoring of the cardiac isoenzyme levels.[1] Abnormalities of cardiac rhythm may persist until the patient is discharged.[2]

In lightning injury, damage to skeletal muscle may, in rare instances, be reflected in myoglobinuria. The immediate need with this present is to protect the kidneys by adequate resuscitation and increasing the urine output. Yost and Holmes[3] stress the need to protect the kidneys by the use of osmotic diuretics and by alkalinizing the urine. The possibility of renal failure is important and needs to be monitored closely, but may occur more frequently with hypotension than with myoglobinuria. Tympanic membrane rupture[4,5] need not delay the actual treatment. However, neurological lesions may well delay surgery because of risks associated with anesthesia during this acute phase.

B. RESUSCITATION

Cardiopulmonary resuscitation, having been initiated as early as possible, should continue until there is full assessment of cerebral function, and fluid administration should be adequate. Because of the possibility of damage to muscle masses with subsequent fluid loss in these areas, the fluid requirements may be much greater than indicated by the usual formulas used in resuscitation. A standard formula regimen for fluid replacement may be used to institute fluid management, and should be instituted as and when indicated.

If there are deep burns, fluid requirements may be much greater than otherwise thought, due to severe muscle edema, and should be increased as indicated by urine output, blood pressure and pulse-rate monitoring, and by readings from the central venous pressure monitoring if this has been instituted. In the first 24 h, generally normal saline or lactated Ringer's solution is given. However, if indicated by the fall of blood pressure, do not hesitate to give colloid solution. If myoglobinuria is present, the urine output should be increased from the normal 30 to 70-ml/h requirement to at least 100 ml/h by increasing the intravenous fluids, and this should be continued until the urine is clear. For children, the usual urine output of 1 ml/kg of body weight per hour will need to be doubled until the urine is clear. Fluid administration should nevertheless be balanced against the exacerbation of cerebral edema.

C. TETANUS PROPHYLAXIS

Tetanus prophylaxis must be instituted as early as possible after the accident. This should include tetanus immunoglobulin and tetanus toxoid.

D. ANTIBIOTICS

With the risk of electric and traumatic muscle damage, there is an increased risk of bacterial gangrene, and penicillin should be used prophylactically (1-M units, intravenously, 8 hourly) with these patients, accompanied by early treatment of any burn wound and excision of any dead tissue. Other problems such as myocardial damage or neurological injury may, of course, delay taking the patient to the operating theater.

E. BURN WOUND

There may be a definite entrance and exit wound, sometimes with extensive damage, particularly near the exit wound. Rarely, there may be patchy necrosis occurring beneath unaffected skin. However, the immediate apparent problem will be treatment of the full-thickness burns at entry and exit sites. Added to this, however, are the arborizing and serpiginous patterns of dermal burn, giving a fern-like appearance as they branch away from a central area.[2,8] These fern-like superficial burns heal rapidly within a few days and do not cause problems. Other patterns include the linear burn, which is usually partial thickness. Transient erythema and burns from contact with metal apparel may also be seen. The latter may be full thickness.

1. Full-Thickness Burns

Full-thickness burns, usually small in area, are seen at entry and exit sites, and also arising from metal contact.

a. Skin Grafting

Generally, skin grafting will not be needed. The superficial fern-like burns will heal rapidly, and some full-thickness burns may be of such a nature that they also will heal rapidly,[5] e.g., very narrow burns. However, when full-thickness skin loss occurs, the skin usually should be excised and grafted as soon as practicable. This is performed under a general anesthetic or neurolept anesthetic, and skin grafts taken with an air dermatome to a thickness of 12 to 14/1000 in. applied. Whether the skin graft is meshed for this grafting procedure will, of course, depend to a large extent on the area involved, i.e., its size and whether blood is oozing from the surface. Generally, the area to be skin grafted is not too great. If there is a very deep loss in a small essential area, such as over a wrist joint, then the use of rotational flaps or even free flaps to provide good, quick cover should be considered. The area of the injury, the availability of suitable flaps, and the overall general condition of the patient will help dictate whether these will be used. The use of antimicrobial creams can allow the patient to be stabilized before the operation is necessary and will keep the bacterial count at a low enough level to allow safe, early excision and grafting.

Grafts can be kept in place by using chlorhexidine tulle over the graft and then using skin staples to attach the graft, with a nonadhesive dressing over this, held in place by bandages. Grafts are generally taken down and inspected 2 or 3 d after grafting, depending on the possibility of infection.

b. Escharotomy and Fasciotomy

Escharotomy and fasciotomy, while not usually needed, may be indicated in an affected limb where considerable edema and tenderness may indicate deep muscle damage. If equipment is readily available for compartmental pressure measurements, this may be used. A diagnosis of a compartment syndrome is rare in pure lightning injury, and must be entertained cautiously. Escharotomy and fasciotomy may only then be appropriate, and if performed, are then regarded as burn wounds themselves. They are covered with antiseptic tulle and packed with antimicrobial cream such as silver sulfadiazine cream with antiseptic. At a later stage, it may be possible to close these incisions, or they can be skin grafted in any subsequent grafting procedure.

Amputations, like fasciotomies, are not common in lightning injury, but if a limb is dead, then amputation will be necessary. The diagnosis is again approached with caution. An arteriogram and a radioactive technetium scan may help determine the level of amputation. Amputations can be delayed for a few days, and the timing may depend on the overall condition of the patient, particularly in relation to the myocardial and neurological problems.

2. Partial-Thickness Burns

Linear burns are mostly partial thickness in severity. The partial-thickness burn wound should be carefully cleaned with aqueous chlorhexidine solution or other suitable antimicrobial

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E. BURN WOUND

There may be a definite entrance and exit wound, sometimes with extensive damage, particularly near the exit wound. Rarely, there may be patchy necrosis occurring beneath unaffected skin. However, the immediate apparent problem will be treatment of the full-thickness burns at entry and exit sites. Added to this, however, are the arborizing and serpiginous patterns of dermal burn, giving a fern-like appearance as they branch away from a central area.[2,8] These fern-like superficial burns heal rapidly within a few days and do not cause problems. Other patterns include the linear burn, which is usually partial thickness. Transient erythema and burns from contact with metal apparel may also be seen. The latter may be full thickness.

1. Full-Thickness Burns

Full-thickness burns, usually small in area, are seen at entry and exit sites, and also arising from metal contact.

a. Skin Grafting

Generally, skin grafting will not be needed. The superficial fern-like burns will heal rapidly, and some full-thickness burns may be of such a nature that they also will heal rapidly,[5] e.g., very narrow burns. However, when full-thickness skin loss occurs, the skin usually should be excised and grafted as soon as practicable. This is performed under a general anesthetic or neurolept anesthetic, and skin grafts taken with an air dermatome to a thickness of 12 to 14/1000 in. applied. Whether the skin graft is meshed for this grafting procedure will, of course, depend to a large extent on the area involved, i.e., its size and whether blood is oozing from the surface. Generally, the area to be skin grafted is not too great. If there is a very deep loss in a small essential area, such as over a wrist joint, then the use of rotational flaps or even free flaps to provide good, quick cover should be considered. The area of the injury, the availability of suitable flaps, and the overall general condition of the patient will help dictate whether these will be used. The use of antimicrobial creams can allow the patient to be stabilized before the operation is necessary and will keep the bacterial count at a low enough level to allow safe, early excision and grafting.

Grafts can be kept in place by using chlorhexidine tulle over the graft and then using skin staples to attach the graft, with a nonadhesive dressing over this, held in place by bandages. Grafts are generally taken down and inspected 2 or 3 d after grafting, depending on the possibility of infection.

b. Escharotomy and Fasciotomy

Escharotomy and fasciotomy, while not usually needed, may be indicated in an affected limb where considerable edema and tenderness may indicate deep muscle damage. If equipment is readily available for compartmental pressure measurements, this may be used. A diagnosis of a compartment syndrome is rare in pure lightning injury, and must be entertained cautiously. Escharotomy and fasciotomy may only then be appropriate, and if performed, are then regarded as burn wounds themselves. They are covered with antiseptic tulle and packed with antimicrobial cream such as silver sulfadiazine cream with antiseptic. At a later stage, it may be possible to close these incisions, or they can be skin grafted in any subsequent grafting procedure.

Amputations, like fasciotomies, are not common in lightning injury, but if a limb is dead, then amputation will be necessary. The diagnosis is again approached with caution. An arteriogram and a radioactive technetium scan may help determine the level of amputation. Amputations can be delayed for a few days, and the timing may depend on the overall condition of the patient, particularly in relation to the myocardial and neurological problems.

2. Partial-Thickness Burns

Linear burns are mostly partial thickness in severity. The partial-thickness burn wound should be carefully cleaned with aqueous chlorhexidine solution or other suitable antimicrobial

solutions. Loose dead tissue should be excised and a topical antimicrobial cream applied such as Silvazine® (Smith & Nephew), which contains silver sulfadiazine cream (1% w/w) with chlorhexidine digluconate (0.2% w/w). Other antimicrobial creams are available and could be used. Affected limbs should be elevated to approximately 15° above the horizontal to help limit possible edema, and splints may be required at this stage to help prevent deformities from subsequently developing. Contractures can readily develop not only from any serious burn scars, but also as a result of rare ischemic necrosis of damaged muscles.

F. REHABILITATION

Once the areas have been skin grafted and the skin can accept a pressure garment, the latter should be commenced as indicated to help prevent hypertrophic scars; it will be necessary to wear the garment until the scar is mature, which may be 9 to 12 months. Wearing splints at night may be necessary for some time to prevent contractures, but this should be stopped as soon as possible to allow return to as near normal activities as can be achieved. Vigorous physiotherapy for affected limbs may be required from the time of injury until full rehabilitation occurs, and will be dictated by the area of injury. Psychological support, not only for burn injuries, will be necessary for these patients if they are to achieve full rehabilitation. With the traumatic nature of the injury, and with possible deafness from tympanic rupture as well as surgery being required, psychological support is a most important element in the total treatment of these patients. Burn and other support groups can be very helpful.

G. SUMMARY

All efforts should be made to ensure the early cardiopulmonary resuscitation of these patients, with vigorous, adequate fluid resuscitation and investigation of their many problems. The aim of treatment is to allow speedy rehabilitation.

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VIII. PSYCHOLOGICAL MANAGEMENT OF LIGHTNING VICTIMS

S. J. Dollinger

A. INTRODUCTION

Natural disasters have been conceptualized by Lifton and Olson[8] as involving five dimensions: (1) the suddenness or unpredictability of the disaster, (2) relationship of the disaster to irresponsibility or callousness of individuals or groups of people (the question of human agency), (3) whether there is a continuing relationship to the disaster (e.g., economic consequences in the community), (4) the isolation of the community, and (5) the totality of the disaster. Unless there are extraordinary circumstances, lightning incidents will tend to fall at the least traumatic end of these dimensions, particularly as compared with such events as earthquakes. Tornados and floods will tend to hold an intermediate position on the disaster continuum. Consequently, lightning strike trauma will be somewhat less likely to lead to major psychological problems. But like all traumatic events, it will often lead to at least transient symptoms of anxiety, such as disturbed sleep, somatic complaints, specific fears, or generalized worries, and has the potential for causing more lasting emotional difficulties.

Among the five disaster dimensions, unpredictability will often play a part in lightning incidents, making them more traumatic. But the second dimension will usually be most important: a lightning injury will be psychologically more traumatic to the extent that human agency can be thought to have been involved. In the incident with which this writer is most familiar, the lightning strike occurred during a children's soccer game which had been postponed during a thunderstorm. The incident followed a decision by coaches and referees to resume the game after the rain had ceased and the overhead sky had cleared. When the lightning struck, all of the players and those on the sidelines were knocked to the ground and 3 of the 38 players required hospitalization; one child never regained consciousness and died 1 week later. Thus, the circumstances of the incident were sufficiently ambiguous and the outcome sufficiently severe to cause some people to second guess the decision to resume. In this case, the second guessing primarily took the form of self-blame by those who helped make the decision. Other adults who were present typically felt that the decision made sense at the time, especially after having "waited out" the storm. Nevertheless, the human agency element played a clear role.

B. DIAGNOSIS AND TREATMENT

All traumatic events have the potential to cause transient distress. This distress in its mildest forms will include such problems as nightmares, insomnia, vague aches and pains (e.g., in the stomach or head), and sadness or crying associated with recurrent thoughts about the incident. Such problems were common in the sample studied by the author[3] and are consistent with the report of another research team.[9] If the frequency and intensity of these symptoms becomes distressing to the victim or his/her family and persist for at least 1 month, they could constitute reasonable grounds for considering a diagnosis of post-traumatic stress disorder (PTSD) as described in the latest edition of the American Psychiatric Association's Diagnostic and Statistical Manual (DSM-III-R).[1] (PTSD with delayed onset would be considered if symptoms began 6 months after the trauma.) Aside from the presence of a trauma and the 1-month duration, three categories of phenomena are considered. First, the traumatic event is persistently reexperienced. This could involve flashback episodes (sudden feeling that the event is recurring), intrusive recollections about it, distressing dreams, or distress at the symbolic exposure to the event, including anniversaries of the trauma. Second, there is persistent avoidance of stimuli associated with the trauma. (Three of seven possible referents are considered; the reader is referred to DSM-III-R for specific examples of this category.) And finally, the diagnosis requires at least two of six possible symptoms, where these symptoms were not present prior to the traumatic event: (1) insomnia, (2) irritability/angry outbursts, (3) difficulty concentrating, (4) hypervigilance, (5) exaggerated startle response, and (6) physiological reactivity to events that resemble or symbolize the trauma. Depending upon the circumstances and the condition of the individual patient, treatment might consist of some combination of individual, group, or family therapy and medication.

If the victim's response does not qualify for the diagnosis because of lesser duration or severity, adjustment disorder would be diagnosed.[1] Among the sample of youngsters seen by this writer, about 80% (30/38) could be thought to have shown some degree of upset by the lightning incident, but even the most upset group (comprising about 20%) would more clearly fall into the DSM-III-R adjustment disorder than the PTSD diagnostic category. Aside from the boy who died, the two who were hospitalized had quite different emotional reactions to it, although neither had a memory for the incident.[3,7] One had a very bland reaction (and from all indications and reports, this was typical of his style before the incident). The other developed depression of sufficient severity to warrant a 1-month hospitalization. This was thought by physicians to be due to physiological rather than psychological factors, and this child's response would not qualify for PTSD. Others among the most upset group had intense symptoms of several months' duration involving phobias about weather, anxiety upon separation from parents, and, in one case, nocturnal enuresis (in a 12-year-old). With two exceptions, the problems seen in this sample resolved without any psychological intervention. One child was seen for several counseling sessions by his family physician. Another child had developed a fear of sleeping alone during thunderstorms and his mother requested referral 6 months after the incident. (Such a problem might be thought of as a delayed effect of trauma or as a reflection of a family interaction difficulty) It should be noted, however, that therapeutic benefits might have obtained from participation in the research interview. Many families seemed to use the interview to express feelings about and try to come to grips emotionally with the tragedy; and these families seemed appreciative of the opportunity to tell their stories.

Although diagnosable problems resolved, it is worth noting that the children's sense of general vulnerability to life events may have been affected. For example, natural disasters can increase fears that remain at a subclinical level or influence one's sense of the likelihood of future negative events. Those in the lightning sample completed a fear survey shortly after their interviews (1 to 2 months post-disaster) and their answers were compared to nonvictims of comparable age, sex, and socioeconomic status.[5] The lightning victims had significantly greater fears of storms, animals, noisy events, supernatural phenomena (ghosts), and enclosed spaces, plus greater sleep-related fears, bodily penetration anxiety, and fears of death or dying. An 8-year follow-up was conducted by one of the writer's students.[6] This research found that, as they were about to graduate from high school, these young people still had a greater sense that lightning might "kill someone like me"— their subjective probability of vulnerability seems to be a lasting one.

Should a lightning victim seek counseling, a number of treatment options can be considered. In the case of virtually all victims of traumatic stress, the opportunity to talk about their memories and feelings concerning the incident is essential. The listener (counselor) should convey understanding, respect, and a wish to be of help.[11] The general notion of emotional catharsis for traumatic events is commonly endorsed by therapists of various orientations, and it has research support to back it up.[10] Beyond such "nonspecific" treatment, problem-solving therapy might be of use to effect some mitigation of symptoms such as fears, nightmares, or flashback experiences. This therapy might include the assistance of the victim's family members in changing the environment or its reinforcement contingencies to encourage other behaviors. Or the focus could be on desensitizing the victim to stimuli associated with the lightning strike that continue to evoke fear. Quite possibly, systematic desensitization could be helpful in this regard, although the preliminary relaxation training alone would be sufficient in some cases.

C. CONCLUDING REMARKS

Appreciating the psychology of being a lightning victim requires a recognition of the "human meanings" of traumatic events.[8] Because people are not passive recipients of life events, the victims of tragic and traumatic happenings will be experiencing intense and distressing emotions in part because of how they construe what happened and why. In particular, there is concern with whether blame can or should be assigned.[2,4,12] A corollary to the point about human meanings is that the psychological victims of a lightning strike incident will often include the family members of those directly hit and any persons who have witnessed the incident. Thus, the psychology of lightning disaster involves some understanding of people's grief and response to death.

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