

## 28.6 Electric shock and lightning injury

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### ESSENTIALS

- 1 Death from electric shock is due to ventricular fibrillation, the lethal arrhythmia occurring at the time of the exposure. Routine admission for ECG monitoring is unnecessary.
- 2 Most deaths are caused by low-voltage (<1000V) exposures.
- 3 The amount of current passing through the body is determined mainly by tissue resistance, which is dramatically reduced by moisture.
- 4 Electrical injury resembles a crush injury more than a burn. The tissue damage below skin level is invariably more severe than the cutaneous wound would suggest.
- 5 There is a diversity of clinical manifestations seen with electrical injury.
- 6 Lightning injury is different from high-voltage electrical injury and has a unique range of clinical features. The management is predominantly expectant.

### ELECTRIC SHOCK

#### Introduction and epidemiology

Electricity is an integral part of our everyday world and electric shock is common. Patients may present to the emergency department (ED) with resulting injuries that range from trivial to fatal (termed electrocution). Although permanent disability can occur, it is reassuring to note that if the initial exposure is survived, subsequent death is unlikely. For each death caused by electricity, there are two serious injuries and 36 reported electric shocks.

There are approximately 20–30 electrical fatalities each year in Australia. Victims are predominantly male and relatively young. Death is just as likely to occur at home as in the workplace, most often in summer. Electricians and linesmen are most at risk. The ratio of low-to-high-voltage deaths ranges from 3:1 to 7:1. The presence of water is associated with fatality. Electrical burns represent 3–5% of admissions to burns units.

#### Physics of electricity and pathophysiology of electrical injury

Electrical current passing through the body can cause damage in two ways:

- 1 thermal injury
- 2 physiological change.

The threshold for perception of an electrical current is 1 mA, which results in a tingling sensation. Current greater than 10 mA can induce muscular tetany and prevent the patient letting go of the current source. Paralysis of respiratory muscles occurs at 20 mA. The threshold for ventricular fibrillation is 100 mA (Fig. 28.6.1). Cardiac standstill and internal organ damage occurs at 2A. The maximum 'safe' current tolerable for 1 s is 50 mA.

Ohm's law is fundamental to the understanding of the physics of electricity. This states that:

The amount of current passing through the body is directly proportional to voltage and inversely proportional to resistance (current [amperes] = voltage [volts]/resistance [ohms]).

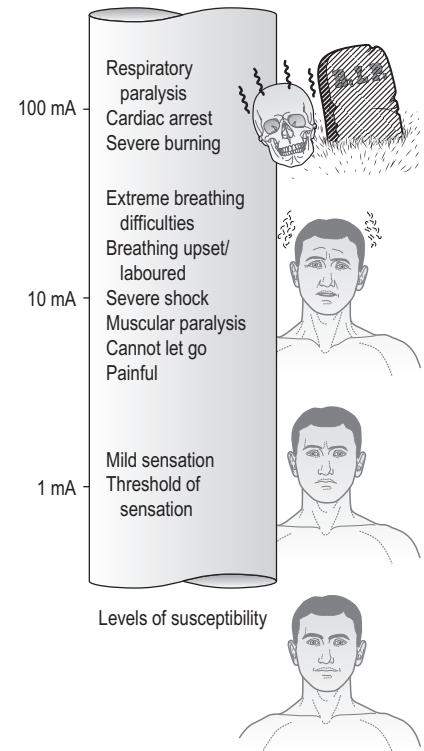


Fig. 28.6.1 The levels of electric shock and their effects.

Factors that determine the effects of an electrical current passing through the body are:

- type of current
- voltage
- tissue resistance
- current path
- contact duration.

#### Type of current

The vast majority of serious electrical injuries result from alternating current (AC), which is approximately three times as dangerous as direct current (DC). Alternating current can produce tetanic contraction of muscle such that the victim may not be able to let go of the current source. This is not a feature of direct current shock.

Human muscular tissue is sensitive to frequencies between 40 and 150 Hz. As the frequency increases beyond 150 Hz, the response

decreases and the current is less dangerous. In Australia, a frequency of 50 Hz is used for household current because this is optimal for the transmission and use of electricity and also has advantages in terms of generation. As such, household current lies directly within the dangerous frequency range. It also spans the vulnerable period of the cardiac electrical potential and is thus capable of causing ventricular fibrillation.

### Voltage

Voltage is the electromotive force in the system. In general terms, the greater the voltage the more extensive the injury, but it must be remembered that the amount of current passing through the body will also be determined by resistance (Ohm's law). High voltage is defined as greater than 1000 V. Household voltage in Australia is 240 V. Voltages less than 50 V (50 Hz) have not been proved hazardous. Survival has been reported following shocks of greater than 50 000 V.

### Resistance

Different tissues provide differing resistances to the passage of electrical current. Bone has the highest resistance, followed by, in decreasing order, fat, tendon, skin, muscle, blood vessels and nerves. Importantly, however, skin resistance varies greatly according to moisture, cleanliness, thickness and vascularity. Moist skin may have a resistance of 1000  $\Omega$  and dry, thick, calloused skin a resistance of 100 000  $\Omega$ . By Ohm's law, dry skin resistance to a contact with a 240 V potential results in a current of about 2.4 mA, which is just above the threshold for perception. However, the resistance of wet or sweat-soaked skin drops to 1000  $\Omega$ , increasing the current flow to 240 mA, which is easily enough to induce ventricular fibrillation. Not surprisingly, moisture has been identified as a key factor in over half of electrocutions.

### Current path

Prediction of injuries from knowledge of the current path is unreliable. Mortalities of 60% for hand-to-hand (transthoracic) and 20% for head-to-foot passage of current are quoted, but have not been verified. When current passes hand-to-hand (or hand-to-foot), only about 5% of the total current passes through the heart. If current passes leg-to-leg, no current traverses the heart.

### Contact duration

The longer the duration of contact, the greater the potential for injury. Fortunately, most contacts are brief and frequently result in the victim being thrown back from the current source. This may result in a secondary injury, especially if the victim falls from a height.

Unfortunately, exposures to more than 10 mA of alternating current can induce sweating. Moisture decreases skin resistance and increases current flow, thereby reducing the ability to release the current source. This can progress to a fatal exposure.

### Prevention

All members of the community must be encouraged to treat electricity with respect and to practise electrical safety. Licensed electrical contractors should be used to carry out any electrical repairs or installations. Water and electricity should never be mixed.

Residual current devices are useful in providing an additional level of personal protection from electric shock. These devices continuously compare current flow in both active and neutral conductors of an electrical circuit. If current flow becomes sufficiently unbalanced, then some of the current in the active conductor is not returned through the neutral conductor and leaks to earth. These devices operate within 10–50 ms and disconnect the electricity supply when they sense harmful leakage, typically 30 mA.

### Clinical features

Electrical injury resembles a crush injury more than a burn. Invariably, the damage below skin level is more severe than the cutaneous wound suggests. The current passing through low-resistance structures produces massive necrosis of muscles, vessels, nerves and subcutaneous tissues.

The clinical manifestations differ from thermal burns in the following ways:

- there are direct effects on the heart and nervous system
- electrical injury classically involves deep structures
- the small entry and exit wounds do not accurately indicate the extent or depth of tissue damage
- a diversity of clinical manifestations is seen with electrical injury.

### Burns

As electricity traverses the skin, energy is converted to heat. The smaller the area of contact, the greater the current density, heat production and the consequent skin and adjacent tissue destruction.

Electrothermal burns are best characterized by arc burns, which result from the external passage of current from the contact point to the ground. These may be associated with extensive damage to skin and underlying tissue. Secondary flame burns may occur when the current arc ignites clothing or nearby combustibles.

Electrical burns may range from first degree to third degree. The typical appearance is of a central depressed charred black area surrounded by oedema and erythema. Single or multiple exit wounds may be present.

### Cardiac

Ventricular fibrillation is the usual cause of immediate death from electric shock and occurs at the time of the shock. Delayed arrhythmia resulting in death is exceptionally rare. Sinus tachycardia is common and non-specific ST- and T-wave changes may be observed. Atrial fibrillation occurs infrequently and usually resolves spontaneously. Acute myocardial infarction following electric shock has been reported.

### Nervous system

Both acute and delayed neurological sequelae have been described following electric shock. Acute complications include respiratory arrest, seizures, altered mental state, amnesia, coma, expressive dysphasia and motor deficits. Reported delayed complications include spinal cord injury (myelopathy) with local amyotrophy and long tract signs, and reflex sympathetic dystrophy.

Peripheral nerve injury is usually associated with significant soft-tissue injury. It has also been reported in the absence of soft-tissue injury and such cases appear to have a good prognosis.

### Renal

Acute renal failure may occur secondary to myoglobinuria. Electric shock results in disruption of muscle cells with the release of myoglobin and creatine phosphokinase, similar to a crush injury. Transient oliguria, albuminuria, haemoglobinuria and renal casts are common and there have been reports of high-output renal failure.

**Vascular**

Large and small vessel arterial and venous thrombosis are responsible for the tissue damage in electrical injury. Vascular complications have included immediate and delayed major vessel haemorrhage, arterial thrombosis and deep vein thrombosis.

**Musculoskeletal**

Tetanic muscle contractures can result in compression fractures of vertebral bodies, fractures of long bones and dislocations of joints. Injuries may also result from a secondary fall, rather than from the electric shock.

**Other**

Numerous complications involving other systems, including the eye (especially cataracts) have been reported following electric shock.

**Electric shock in pregnancy**

Reports of electric shock in pregnancy are rare and the true incidence is unknown. A high mortality has been reported in the literature. However, this may represent publication bias and a prospective cohort study concluded that, in most cases, accidental electric shocks during pregnancy do not pose a major fetal risk.

If there was an immediate problem, the mother may notice a sudden cessation of fetal movements. However, there is no preventative action possible in the ED. Other reported fetal complications of electric shock include intrauterine growth retardation, oligohydramnios and abortion.

Fortunately, therapeutic electric shocks, such as DC cardioversion and electroconvulsive therapy, are known to be safe in pregnancy. The critical factor is current path: accidental electric shocks include the uterus, whereas therapeutic shocks do not.

**Treatment****Pre-hospital**

Everyone should be aware of the pre-hospital management of electric shock. Most importantly, the rescuer should avoid becoming a further victim. The victim can be separated from the electrical source by using rubber, a wooden handle, a mat or any other non-conductive substance or, if possible, by turning off the electricity supply. Cardiopulmonary resuscitation

(CPR) should begin immediately, if indicated, and help summoned. CPR may need to be prolonged. Ventricular fibrillation is the most common lethal arrhythmia after electric shock and early defibrillation provides the greatest chance for survival.

**Emergency department**

The majority of patients who present to the ED after electric shock are relatively well. Following appropriate assessment to exclude primary or secondary injury, an ECG should be performed. Cardiac monitoring is not indicated if the patient is asymptomatic and has a normal ECG. Most patients are able to be reassured and discharged directly from the ED. Measurement of creatine phosphokinase levels is not required. It should be remembered that exposure to an electric shock is an unpleasant experience and this should be acknowledged. Tetanus status should be checked.

Many patients have a degree of muscle pain following electric shock owing to the tetanic nature of alternating current. Simple analgesia is appropriate. Any secondary injury, such as fractures or loss of consciousness, should be treated as dictated by the injury.

If an arrhythmia is present it will usually resolve spontaneously and not require specific treatment. Delayed lethal arrhythmias have not been reported in patients without initial arrhythmias.

Severe electrical injury with extensive soft-tissue damage should be managed as a crush injury. This is more likely following high-voltage exposure, which results in a large exudation and sequestration of fluids in the damaged area. Emergency management includes adequate volume replacement and treatment of acidosis and myoglobinuria.

Emergency physicians should be aware of the low potential for fetal harm following electric shock in pregnancy. Publication bias suggests that apparently minor exposures can have profound effects. It would be prudent to adopt a conservative approach of performing a fetal heart Doppler assessment with obstetric follow up including ultrasound.

**Prognosis**

The prognosis for the majority of patients surviving the initial shock is excellent. Those with significant soft-tissue injury or secondary injury may be left with long-term deficits.

**Disposition**

The majority of patients presenting to the ED following an electric shock will be suitable for discharge home following assessment and reassurance as detailed above. Those suffering muscle pain secondary to tetanic contractions should be given simple analgesia and instructed to follow up with their general practitioner.

Patients with cardiac arrhythmias require admission for observation until the arrhythmia resolves. Those with evidence of neuropathy should be referred to a neurologist, as nerve conduction studies may be required.

Severe electrical injuries with extensive soft-tissue damage require admission to hospital and, sometimes, to an intensive care unit. All patients with electrical burns should be reviewed by a burns specialist and referral to a specialist burns unit may be indicated. Minor burns may be suitable for elective review.

Secondary injuries, such as loss of consciousness or fractures, should be admitted or referred on their merits.

**The Taser**

The Taser is a development of the stun gun. It is used by the police service to fill the operational gap between the baton and the gun for controlling potentially dangerous and violent suspects. 'tasered' victims are occasionally brought to the ED for assessment.

The device is a battery operated unit resembling a hand gun that fires two barbed electrodes on 7 m long copper wires at 60 m/s. The barbs attach to the subject's skin or clothing and deliver up to 50000V of electricity in rapid pulses over 5 s. The current can cross up to 5 cm of clothing.

Electricity delivered by a taser is neither pure AC nor pure DC and is probably akin to rapid-fire low-amplitude DC shocks. The output is believed to stay near the surface of the body in the skin and muscles and does not penetrate into the internal organs. There is no evidence to date that this form of electrical delivery interfered with cardiac or neurological function in the 30000 volunteers or in the reported operational uses.

One author concluded that the pre-existing injuries and toxic conditions leading to the patient being tasered are the most important problems requiring medical treatment after Taser use. It seems that the device is essentially safe on healthy people. However, there is limited evidence to base recommendations for

the assessment and management of patients that are brought to the ED after being 'tasered'. Suggestions for management of these patients attending EDs are:

- Most healthy subjects may be safely discharged after barb removal and a clinical assessment. It may be appropriate to consider a bedside blood sugar level (BSL), ECG and a venous blood gas.
- High-risk patients are those with known cardiac disease including implanted pacemaker or defibrillator, pregnancy, drug or alcohol intoxication, bizarre behaviour at the time of arrest, other psychiatric disturbance or coincidental medical problems. Often the coexistent condition (e.g. intoxication or mental health issue) will need to be addressed.
- Any patient with chest pain or abnormal ECG should be assessed as per routine clinical practice.
- Pregnant women >24 weeks' gestation should be considered for cardiotocographic monitoring.
- Look closely for direct injury from the barbs or indirect injury from falls. Barb injuries should be approached as a potential penetrating injury and managed accordingly. There are likely to be small puncture wounds and minor burns at the barb sites. On occasion, medical intervention will be required if the barbs are not easily removed, if the barb tip breaks off in the skin or if the barbs have struck vulnerable areas (e.g. mouth, eyes, neck and groin).
- Most patients will complain of muscle aches and anxiety.

It is clear that, properly used as a method of restraining violent people, Tasers are less likely than guns to cause injury and death of the target (and of the police officer). They are also generally more effective than other methods of restraint. The deaths that have followed taser use have occurred in people who were out of control and who had taken potentially fatal drugs. It is likely that the deaths would have occurred whether or not the Taser was used. However, the medical effects of multiple shocks on such persons is unknown.

## LIGHTNING INJURY

### Introduction and epidemiology

There are several deaths each year in Australia from lightning. For each death, there are five

injuries. These events are always prominent and emergency physicians should be familiar with the pathophysiology. In addition, about 60 people each year report injuries caused by lightning surges while using the telephone during thunderstorms.

Many myths surround lightning injury; they include:

- Lightning strike is invariably fatal. In fact, the mortality is 30%. In addition, the probability of long-term impairment after recovery is low.
- A victim of lightning is charged and dangerous to touch. This false notion has led to the withholding of CPR, with fatal results.
- Lightning should be treated in the same way as high-voltage electrical injury. This is incorrect.

### Physics

Lightning occurs most commonly during thunderstorms. Particles moving up and down in a thunderstorm create static electricity, with a large negative charge building up at the bottom of clouds. Electrical discharge (lightning) occurs as a result of the great charge difference between the negatively-charged thundercloud underside and the positively charged ground. The duration of the lightning stroke is between 1 and 100 ms.

Lightning strike is very different from high-voltage electric shock (Table 28.6.1) and produces different clinical effects, requiring a different management approach.

An interesting phenomenon called 'flashover' seems to save many victims from death by lightning. Current passes around and over, but not through the body. The victim's clothing and

shoes may be blasted apart. Only cutaneous flame-type burns result.

## Clinical features

### Immediate

- Cardiac arrest. This takes the form of asystole, as opposed to the ventricular fibrillation of high-voltage electrical injury. The heart is thought to undergo massive depolarization. Although primary lightning-induced arrest may revert quickly, it can be followed by secondary hypoxic arrest.
- Chest pain and muscle aches.
- Neurological deficits. A person struck by lightning may be rendered unconscious. On first regaining consciousness, they may be mute and unable to move. This is transient and usually resolves within minutes, but may take up to 24 h.
- Contusions from shock waves.
- Tympanic membrane rupture.

### Delayed

- Keraunoparalysis. Lightning-induced limb paralysis is extremely common. Flaccidity and complete loss of sensation of the affected limb are observed. Peripheral pulses are generally impalpable and the affected limb takes on a mottled, pale, blue appearance. The mechanism is unclear, but may be lightning-induced vasospasm. The condition is self-limiting and resolves within 1–6 h.
- 'Feathery' cutaneous burns (Lichtenberg flowers). These burns, pathognomonic of lightning injury, may appear immediately but more often become visible a few hours after injury. Burns may be severe but heal remarkably easily.

Table 28.6.1 Lightning versus high-voltage injury

Factor	Lightning	High voltage
Time of exposure	Brief instantaneous	Prolonged tetanic
Energy level	100 million V 200 000 A	Usually much lower
Type of current	Direct	Alternating
Shock wave	Yes	No
Flashover	Yes	No

Adapted from Cooper MA. Lightning injuries. In: Auerbach P, et al (eds). Management of wilderness and environmental emergencies. New York: Macmillan; 1983: 500–21.

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- Cataracts. Occur more commonly than following electrical injuries.
- Myoglobinuria and haemoglobinuria are rare.

### Other

- Sensorineural deafness.
- Vestibular dysfunction.
- Retinal detachment.
- Optic nerve damage.

Reports of lightning strike in pregnancy reveal a high rate of fetal death *in utero*, despite maternal survival.

## Treatment

### Pre-hospital

The important principle is that those who appear dead should be resuscitated first. Immediate institution of basic cardiopulmonary resuscitation in the field for those in asystole prevents secondary hypoxic cardiac arrest during the interval until cardiac function resumes spontaneously. Fixed dilated pupils should not be taken as an indicator of death after lightning strike.

### Emergency department

Most lightning strikes are unwitnessed and diagnosis may be difficult in the unconscious or confused patient. The diagnosis should be considered where such patients were found outdoors in stormy weather. The presence of multiple victims, exploded clothing, linear or punctuate burns, keraunic markings or

tympanic membrane rupture all add weight to the diagnosis. The differential diagnosis includes cerebrovascular event, seizure disorder, spinal cord injury, closed-head injury, Stokes–Adams attack, myocardial infarction and toxin effects.

Standard trauma resuscitation measures should be adopted. Examination of the ears for tympanic rupture and eyes for lens/corneal defects, retinal detachment and optic nerve injury is especially important. If the conscious state deteriorates after arrival, cranial computed tomography scan is indicated. Examination of the cardiovascular system should include an ECG.

Burns are rarely more than superficial and are managed expectantly using standard treatments. Tetanus prophylaxis should be arranged.

Treatment of lightning-induced limb paralysis is expectant. If it does not resolve within a few hours, other causes should be considered. Fasciotomy is unnecessary.

Standard therapy for ocular complications, such as retinal detachment or cataracts, is indicated. Baseline visual acuity should be documented for future reference.

## Prognosis and disposition

For survivors of the initial strike the prognosis is excellent unless significant secondary injury has occurred. Admission for observation is indicated for those with abnormal mental status or ECG, or with significant burns or traumatic complications. The burns usually heal

well and grafting is rarely required. For those with ocular complications, long-term ophthalmic follow up is necessary.

### Controversies

- Timing and extent of development of tissue necrosis associated with electrical injury.

### Further reading

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