Electrical Injuries and Lightning Strikes

Patients presenting with electrical injuries have problems that can range from the very trivial to the fatal (in which case, they are said to have been electrocuted). If patients survive the initial exposure, the outlook is generally very good with few permanent injuries as a result.

Epidemiology[1]

- Electrical burn injuries account for about 5% of burns unit admissions.
- Electricians and linesmen are at highest risk but those working with electrical tools also form a significant proportion of this patient group. [2]
- Electrical injuries in children are unusual and are mainly due to misguided exploration outside the home. [3]
- For every death, there are two serious injuries and 36 reported electric shocks.
- Death most often occurs in young males (male:female = 9:1).
- Most deaths occur in the spring and summer months.
- Water greatly increases the risk of fatality.

Pathophysiology of electrical injury[1]

Electrical current causes damage through; [4]

- Direct process of physiological changes (altering cell resting membrane potential).
- Conversion of electrical energy into thermal energy, resulting in massive tissue destruction and coagulative necrosis.
- Secondary damage associated with falls and violent muscle contractions.

There are several factors that affect the degree of damage:

Current

Type of current
This may be direct or alternating. The latter is significantly more dangerous in a number of respects:

- It may result in tetanic muscular contraction, so preventing the casualty from letting go of the source.
- An alternating current of any more than 10 mA induces sweating. Skin moisture decreases its resistance (see below).
- Human tissue is most sensitive to frequencies between 40 Hz and 150 Hz. The frequency best suited for household use is about 50 Hz, so making household current particularly dangerous. This is all the more salient, as this is the frequency that is capable of producing ventricular fibrillation (VF).

Amount of current

- 1 mA = threshold of perception resulting in tingling sensation.
- >7-9 mA = muscular tetany preventing release of grip from current source (this is lower for children and women).
- 20-50 mA = pain and severe breathing difficulties leading to respiratory arrest.
- 50-100 mA = VF.
- >2 A = asystole.

Current path
The key issue affecting mortality is whether the current passes through the heart. For example, contact of the electrical source with both hands effectively results in a transthoracic pathway which is thought to account for about 60% of mortalities, whereas there is very low mortality related to a pathway passing through one leg and out of the other.

Voltage[2]

Generally, the greater the voltage, the greater the damage. The exception is with high-tension voltage: above this level, greater voltage doesn’t necessarily influence the degree of electrical injury, although greater thermal damage can occur. [5] This is accentuated or limited by the resistance of the tissue that the electricity passes through (see below):

- Low voltage:
  - <50 V: no danger.
  - 240 V: UK household supply (± 10%). This creates small, deep entrance and exit wounds.

- High voltage:
  - ≥1,000 V: there is often extensive tissue damage and limb loss. Contact with >70,000 V is invariably fatal.
  - 100 million V: lightning - this is quite different from a high-voltage electric shock and is treated separately below.
Resistance

As the current travels through the body, it follows the path of least resistance. Resistance varies in different tissues and will have a great influence on the extent of any injuries.

- At a cellular level, the injury resembles a crush injury more than it does a burn.
- The electrical current will pass through low-resistance tissues in preference, causing necrosis along the way.
- Since the skin resistance can be affected by moisture, electric current can be transmitted to deeper structures before it causes significant skin damage (there may be serious deep injury with spared skin).[7]
- A current passing along the surface of the body to earth can cause very deep burns over a large area.
- There will be a range of clinical manifestations with different effects on different organs.
- Be aware of potential secondary injuries from falling or being thrown to the ground.

Burns

- These range from first-degree to third-degree: there is typically a depressed charred central area with surrounding oedema. There may be several entry and exit wounds (the latter characteristically have an explosive appearance - round or oval grey craters with no inflammatory changes).[6]
- Arc burns are produced by the passage of a current of electricity from the source to the ground and may be associated with extensive skin damage.
- So-called 'kissing burns' are produced in flexor creases when muscle tetany causes the joint to flex and the current flows through opposing skin.[8]
- Flame burns occur when the current ignites clothing.

Cardiac system

- VF is the usual cause of immediate death from electrocution; this occurs immediately.[9]
- Other arrhythmias have been reported: right bundle branch block and nonspecific ST and T-wave changes occur most commonly.[6] There may be supraventricular tachycardia and, occasionally, atrial fibrillation.
- Acute myocardial infarction has been reported.
- It is worth noting that cardiac markers will be raised, regardless of cardiac damage, so don’t use these as an indication of cardiac damage.[6]
- Delayed arrhythmias are extremely rare and tend to be found in patients who have a previous history of ECG abnormalities (known or subclinical).[10]
Nervous system
- **Acute complications**: these include respiratory arrest, seizures, altered mental state, amnesia, coma and expressive dysphasia. Motor deficits have also been reported.
- **Delayed complications**: these include spinal cord injury (common) and complex regional pain syndrome (CRPS).\[1, 12\] Acute ischaemic stroke has also been reported.\[13\]
- **Peripheral nerve injury**: this may occur in the presence or the absence of concurrent soft tissue injury - the prognosis is good in the latter case.

Renal system
- Acute tubular necrosis, leading to acute kidney injury, is common, usually secondary to myoglobinuria, direct damage to renal vessels and inadequate rehydration.\[6\]
- High-output renal failure (less common).
- Transient renal changes: oliguria, albuminuria, haemoglobinuria, renal casts.

Delayed complications: these include spinal cord injury (common) and complex regional pain syndrome (CRPS).\[11, 12\]

Effects on the vascular system
Large and small vessel thrombosis may occur, resulting in surrounding tissue damage. Thrombi can also occur at distant sites from the entry point ± late rupture.\[6\] There may also be immediate or delayed haemorrhage at the affected site.

Musculoskeletal effects
- Muscle cell disruption occurs, releasing myoglobin and creatinine phosphokinase.
- Tetanic muscle contractions can result in bone fractures and dislocations as well as torn muscles.
- There may be patchy swelling and necrosis with delayed development of sepsis.\[6\]
- Compartment syndrome can develop.\[8\]
- Secondary injuries arise from being thrown back from the source.

Additional complications
- Organ perforation may occur due to damage of the visceral walls and a pneumothorax has been described, two days after a significant electrical injury.\[14\]
- The most common electrical injury seen in children younger than 4 years is the mouth burn. These burns may cause facial deformities and growth problems of the teeth, jaw and face.\[15\]
- Cataract formation is well documented after significant electrical injury - this occurs days to years later.
- Psychological sequelae: the degree is not necessarily related to the amount of physical injury and problems may last for years.

Electrical shock in pregnancy\[1\]
- **General points**: there is little information available about electric shocks during pregnancy and the accepted high rate of mortality may be due to publication bias. However, it is well documented that fetal skin is 200 times less resistant than the skin postnatally, so less electricity may cause significantly more harm. Indeed, an amount enough to cause minimal injury to the mother may be lethal to the fetus. Furthermore, the path of transmission becomes important here: the current path may completely bypass the maternal heart but, if it travels through the uterus, the fetus may be seriously injured.
- **Fetal harm**: other than cardiac arrest, fetal complications include intrauterine growth restriction, oligohydramnios, fetal movement reduction and spontaneous abortion.
- **Therapeutic electric shocks (such as defibrillation)**: these are safe on account of the current path followed which does not include the uterus.

Pre-hospital management of electrical injuries
- Separate the patient from the source, using a non-conducting instrument (eg, rubber, wood) and, if possible, turn off electrical supply. It is particularly important not to touch the patient before the power has been turned off in high voltage situations, even with non-conducting material.
- Commence cardiopulmonary resuscitation if required. VF is the most common arrhythmia.
- Summon help - early defibrillation provides the best chance of survival.

Further management of electrical injury\[1\]
Once in the emergency department, a full survey should be carried out including basic blood tests with a particular note of the renal function. ECG is mandatory. Check beta-hCG and tetanus status. Pregnant women should have an urgent ultrasound scan, even for apparently minor shocks.

- **Minor shocks**: if the patient is asymptomatic and has a normal ECG, they can safely be discharged with reassurance. Delayed arrhythmias are exceptionally rare and are usually preceded by a pre-existing ECG abnormality.\[2, 10\] If the patient is pregnant and is well with a normal ultrasound scan of the fetus, liaise with the obstetric team before discharge. **NB**: low-voltage burns (of the type sustained from domestic electricity) are not associated with systemic complications but the local burn is almost always full-thickness. Necrosis may extend within days and early surgical intervention with grafting tends to be favoured by burns specialists.\[6\]
- **Mild-to-moderate shocks**: arrhythmias and neurological sequelae (such as aphasia) require simple observation and tend to resolve spontaneously. Offer simple analgesia for muscle pain from tetany.
- More severe shocks:\[6\]
  - Stabilise any life-threatening dysrhythmia.
  - Transfuse crystalloid early: titrate volume against central venous pressure, pulse and blood pressure - not by using the burns formulae.
  - Check blood gases (look for acidosis, may require bicarbonate), U&Es (including creatinine). Consider a clotting screen and blood typing or cross-matching in case surgery is required.
  - Perform ECG.
  - Perform cervical spine, chest and pelvic radiographs on any casualty who was previously unconscious, as well as imaging of any injured limb.
  - Assess for injuries, system by system.
  - Involve senior clinicians.

Even if the shock was relatively minor, there may be a degree of psychological distress or shock - be aware of this and offer support as required.

Prognosis:\[8\]
- Mortality: if the initial shock is survived, the chances of survival are excellent. If a life-threatening cardiac dysrhythmia is successfully reversed or does not occur, it is unlikely that it will develop subsequently.\[6\]
- Morbidity: this depends on the extent of the soft tissue and other associated injuries but recovery from injuries tends to be good.

Prevention:\[16\]
- Provision of information (via leaflets, health visitors, talks, etc) is the key to prevention.
- Never mix water and electricity.
- Always use licensed electricians.

The case of lightning injury:\[1\]

Background
Lightning occurs when particles moving in a thunderstorm create static electricity and negative charge builds up at the bottom of the cloud. When the difference between this and the positively charged ground is great enough, an electrical discharge occurs. Lightning strikes the earth more than 100 times each second and 8 million times per day.\[17\] There is a 1 in 2,000,000 chance of being killed by lightning in the UK.\[8\] The chance of being struck increases if the person is wet or carrying a metal object. Thus, hikers, campers, golfers and other outdoor sports enthusiasts most often sustain lightning injuries.\[18\]
Types of lightning strike[17]
- **Direct hits**: occur outside, often when the person is carrying a metal object (umbrella or even a hair clip).
- **Contact injuries**: these can occur when a person is touching an object that is struck.
- **Flash discharge**: when a high-resistance object close to the victim (eg, a tree) is hit, the resistance to direct current flow in the air between the tree and victim is less than that to direct current flow in the tree and, as lightning seeks the path of least resistance, it will jump from the tree to the victim. This can also happen between people.
- **Ground current phenomenon**: if a person is standing with their feet spread and is struck, they may create a potential difference large enough to create a circuit between the legs and ground. This method of injury may account for the high mortality (30%) of lightning victims with leg burns and for the fact that burns to the arms and trunk are not important predictors of mortality in lightning strikes.
- **Blunt trauma**: can occur if the person is thrown by massive skeletal muscle contraction.
- **Flashover effect**: the current passes over and around the casualty's body but not through it. Clothes and shoes are torn apart but there are only superficial skin wounds (unless the clothes catch fire and burn the skin before being blasted off).[2]

Clinical effects[17]
The clinical effects are very different from a high-voltage shock, on account of the brief and instantaneous time of exposure and the fact that it is a direct current. The flashover effect diverts the current around the body and so internal injury is spared. The popular belief that lightning is invariably fatal is wrong (the mortality rate is in fact about 30%).[19]

- **Immediate effects** - cardiac arrest (asystole) which may revert but which may be followed by a secondary hypoxic arrest. There may be chest pains, muscle aches and neurological deficits (ranging from unconsciousness to transient muteness which tends to resolve within 24 hours). Contusions and tympanic rupture have also been reported.
- **Delayed effects** - limb paralysis is common with flacciditiy also being observed. The peripheral pulses may not be palpable and the skin takes on a mottled blue appearance. 'Feathery' cutaneous burns (Lichtenberg flowers) may occur immediately or over several hours but tend to heal well.[20] Cataract formation, retinal detachment, optic nerve dysfunction, myoglobinuria, sensorineural deafness and vestibular dysfunction have all been reported.
- **Pregnancy** - there is a high rate of fetal or neonatal death (about 50%), even where maternal survival occurs.[21]

Most lightning strikes are unwitnessed and the patient may simply present as unconscious or confused - send to emergency department for assessment.

Immediate management[22]
- After the lightning has struck, the victim is safe to touch - check for responsiveness.
- Commence immediate cardiopulmonary resuscitation (CPR) - this may prevent the secondary hypoxic cardiac arrest.
- Carry out CPR even if the casualty appears dead (pupils may be fixed and dilated as a result of muscular paresis - they do not necessarily represent brain death).
- Be aware of the possibility of a spinal cord injury (evidence of head injury or tenderness or haematomas of the neck or back noted if the patient is conscious).
- If a group of persons is struck by lightning, direct attention to those with no signs of life, because the others will probably recover, although burns or injuries may need treatment.

It is worth remembering that a high proportion of patients with cardiopulmonary sequelae die despite best resuscitative efforts but this should not deter aggressive and persistent attempts. There is a higher chance of success in victims of lightning strikes than in patients with cardiac arrest from other causes.

Further management
- As described above, most strikes are unwitnessed. Telltale clues include a casualty (or multiple casualties) found outdoors on a stormy day, exploded clothing, cutaneous burns (linear, punctate or feathery) and tympanic membrane rupture.
- Carry out full trauma assessment to look for immediate effects and initiate resuscitation as appropriate. ECG is mandatory and CT scan of the head may be indicated where consciousness deteriorates. If the patient is conscious, don't forget to document the visual acuities.
- Check tetanus prophylaxis status.
- Liaise with relevant departments (medical, renal, audiological medicine and ophthalmology) for monitoring of delayed effects.
- Consider differential diagnoses, including cerebrovascular event, spinal cord injury, seizure, closed head injury, Stokes-Adams attack, myocardial infarction, overdose.

Outcome
This is generally excellent for those who survive the initial strike. The outcome is coloured by the quantity and severity of secondary trauma. Permanent sequelae are found in 75% of cases.[23]

Prevention[24]
The best treatment for lightning strike injuries is prevention:

- Remain indoors (or inside a closed car), away from doors and windows, fireplaces and metal objects, to avoid side flashes.
- When outside and unable to find shelter, maintain distance from tall trees, hilltops, or other exposed areas. A person caught outside in the open without cover should crouch on the ground with his or her limbs close together.
- Do not swim in a lightning storm.
- Lightning strikes through an airplane are not unusual and generally cause little or no damage.
Further reading & references

16. Electrical safety at work (link to resources); Health and Safety Executive
22. No authors listed; 2005 American Heart Association (AHA) guidelines for cardiopulmonary resuscitation (CPR) and emergency cardiovascular care (ECC) of pediatric and neonatal patients: pediatric basic life support. Pediatrics. 2006 May;117(5):e889-1004.

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