thebmj

Check for updates

CLINICAL UPDATES

Electrical injury

Victor Waldmann *research fellow in cardiology*[1 2 3], Kumar Narayanan *consultant cardiologist, senior research associate*[3 4], Nicolas Combes *consultant cardiologist*[5], Eloi Marijon *cardiologist, associate professor of medicine*[1 2 3]

[1]Cardiology Department, European Georges Pompidou Hospital, 20-40 rue Leblanc, 75908 Paris Cedex 15, France; [2]Paris Descartes University, Paris, France; [3]Paris Cardiovascular Research Center, Paris, France; [4]Cardiology Department, Maxcure Hospitals, Hyderabad, India; [5]Cardiology Department, Clinique Pasteur, Toulouse, France

Electrical injuries can range from small skin burns to life threatening internal organ damage. The most extreme form of electric shock, such as caused by a lightning strike, often results in instant death by electrocution. There is a lack of evidence regarding the management of patients after electrical accidents, which can cause concern for clinicians when these patients present.

This article discusses the main types of electrical injuries, their underlying pathophysiology, and practical issues relating to monitoring and treating seriously injured patients as well as those who are apparently well.

How common are electric shocks?

Many electrical accidents go unreported, so the true incidence is difficult to estimate. In the United States, the American Burn Association (www.ameriburn.org) estimates 4400 people are injured in electrical accidents and 400 others die from electrocutions each year, which are mostly work related (miners, electricians, and construction workers). Lightning strikes are responsible for up to 100 deaths a year.[1-3]

Of those admitted to US specialist burn units annually, 3-6% have had an electric shock.[4] Many of the victims are young adults or adolescents, whose injuries often result from outdoor adventurous activities (such as climbing an electric pole, exploration of dangerous place as railway stations) and children involved in household accidents, mostly due to oral contact with electrical cords or cord sockets, contact with wall sockets directly (“finger in the socket”), or via a conducting foreign object (metal keys, pins, or cutlery).

How is the body affected after an electric shock?

Physiology

Electrical injuries affect the body in various ways. There are direct effects of current on body cells: for example, electric current can affect cell membranes, abruptly altering their electrical properties (cellular depolarisation) and causing direct cell injury by forming pores in cell membranes (electroporation) (fig 1⇓).

Electric current also causes thermal injury due to conversion of electricity into heat as current passes through body tissues. Cellular and thermal injuries can be exacerbated by trauma sustained at the same time, such as a fall.

How to gauge likely severity

The severity of an electric shock depends on its intensity (current (I), measured in amperes) and the severity of burns is generally determined by the amount of energy delivered by the current (W, measured in joules) (box 1).

The flow of current occurs from the entry point in contact with the electrical source to the exit point, which, in most instances, is in contact with the ground. Burns on the skin surface are often seen at the entry and exit points (fig 2⇓). Current generally takes the path of least resistance through tissues such as nerves and blood vessels. Voltage is the marker that is most often used for categorising electrical shocks as it is often the only variable known with certainty after exposure to electricity (boxes 2 and 3). The skin’s resistance to electricity can be reduced substantially by moisture, and so, when the skin is wet, what may otherwise be a minor injury with superficial tissue damage may be converted into a life threatening shock with extensive internal damage.[5]

Correspondence to: E Marijon eloi_marijon@yahoo.fr

What you need to know

- Electrical injuries are relatively uncommon but can be life threatening, causing extensive burns or internal organ damage
- Wet skin can make otherwise be a minor injury more serious
- Arrhythmias are the most common cardiac complication and may sometimes present late
- Non-specific electrocardiographic (ECG) changes may be the only indicator of cardiac damage
- Patients who have a normal ECG on admission after a low voltage injury with no loss of consciousness or initial cardiac arrest may be discharged home

Box 1: What is an electric shock?

- Electricity is a flow of electrons, measured in amperes (I), across a potential gradient from high to low concentration, expressed in voltage (V)
- Ohm's law (I = V/R) expresses the relation among voltage (V), current (I), and the impedance to electrical flow or resistance (R in ohms)
- Joule's law (W (Joules) = R × I^2 × T) gives the heat energy produced as a result of current flow

Box 2: Main factors that determine the nature and severity of electrical trauma

- Voltage (see box 3)
- Resistance to current flow through the body
- Type of current source (direct or alternating current)
- Duration of contact with the current source
- Path taken by the current through the body

Box 3: Main sources of electrical current, with associated voltage

High voltage

- High voltage lines (45 000 to 400 000 V)
- Rail network lines (25 000 V)
- Overhead lines (1500 V)

Low voltage

- Mines (960 V)
- Subway electric rails (750 V)
- Workshops (380 V)
- Domestic supplies (US 110 V, Europe 220 V)

Effects on specific organ systems

Figure 3⇓ summarises the main types of organ-specific injuries after an electric shock. Cardiac effects are the most serious and among the most common electrical injuries. The heart is more commonly affected than other internal organs because electric current usually follows the path of lowest resistance in the body along blood vessels and nerves, directing the current towards the heart. Its central anatomical location in the chest also places it in harm's way from currents passing both horizontally (hand to hand) and vertically (head to foot or hand to foot). Cardiac tissue vulnerability to potentially lethal arrhythmias when exposed to an external electric field sets it apart from other organs.[19]

How do I manage my patient after an electric shock?

The infographic suggests an approach to the assessment and management of electric shock based on currently available literature.[20 21]

The first step is to turn off the current source to prevent a further accident. Then, the management is mainly symptomatic. In witnessed accidents, a prompt and sometimes prolonged resuscitation attempt is warranted.[22] Immediate resuscitation of patients in cardiac arrest from electrocution can result in long term survival, and complete recovery has been reported even after prolonged life support.[20 23] Manage patients according to standard life support principles. Even when low blood pressure is not present, intravenous hydration is usually desirable to prevent kidney shut down. Adjust other aspects of management according the nature and severity of the injuries.

Discharge

Although only small studies have addressed this, all suggest that, in cases of low voltage injuries without any loss of consciousness or initial cardiac arrest, occurrence of serious arrhythmia is unlikely when electrocardiography at hospital admission is normal.[7-25] Similar results have been reported with high voltage injuries, but more evidence is needed to support the safe discharge of these patients home.[26] There are no established standards for the duration of monitoring after an electric shock, but 24 hours after admission or after resolution of arrhythmias is the most commonly adopted approach.

There is little data on the potential risks to an unborn baby after electrical shock to the mother during pregnancy, but it is recommended that both mother and fetus are monitored in hospital.[27]

In children no major differences in injury type or prognosis have been reported compared with adults, and so current guidelines on cardiac monitoring are the same.[28]

Competing interests: We have read and understood BMJ policy on declaration of interests and have no relevant interests to declare.

Provenance and peer review: Not commissioned; externally peer reviewed.

Patient consent obtained.

1 Spies C, Trohman RG. Narrative review: Electrocution and life-threatening electrical injuries. *Ann Intern Med* 2006;357:531-7. doi:10.7326/0003-4819-145-7-200610030-00011 pmid:17015871.
2 Smith T. On lightning. *BMJ* 1991;357:1563. doi:10.1136/bmj.303.6817.1563 pmid:1773171.
3 Waldmann V, Narayanan K, Combes N, Jost D, Jouven X, Marijon E. Electrical cardiac injuries: current concepts and management. *Eur Heart J* (forthcoming).
4 Arnoldo BD, Purdue GF, Kowalske K, Helm PA, Burris A, Hunt JL. Electrical injuries: a 20-year review. *J Burn Care Rehabil* 2004;357:479-84. doi:10.1097/01.BCR.0000144536.22284.5C pmid:15534455.
5 Kloeck W, Cummins RO, Chamberlain D, et al. Special resuscitation situations: an advisory statement from the International Liaison Committee on Resuscitation. *Circulation* 1997;357:2196-210. doi:10.1161/01.CIR.95.8.2196 pmid:9133535.
6 Fineschi V, Di Donato S, Mondillo S, Turillazzi E. Electric shock: Cardiac effects relative to non fatal injuries and post-mortem findings in fatal cases. *Int J Cardiol* 2006;357:6-11. doi:10.1016/j.ijcard.2005.07.060 pmid:16257069.
7 Krämer C, Pfister R, Boekels T, Michels G. Cardiac monitoring always required after electrical injuries? *Med Klin Intensivmed Notfmed* 2016;357:708-14. doi:10.1007/s00063-015-0107-y pmid:26496987.
8 Pawlik AM, Lampart A, Stephan FP, Bingisser R, Ummenhofer W, Nickel CH. Outcomes of electrical injuries in the emergency department: a 10-year retrospective study. *Eur J Emerg Med* 2016;357:448-54. doi:10.1097/MEJ.0000000000000283 pmid:25969345.
9 Kugelberg J. Electrical induction of ventricular fibrillation in the human heart. A study of excitability levels with alternating current of different frequencies. *Scand J Thorac Cardiovasc Surg* 1976;357:237-40. doi:10.3109/14017437609167800 pmid:1006224.
10 Jensen PJ, Thomsen PE, Bagger JP, Nørgaard A, Baandrup U. Electrical injury causing ventricular arrhythmias. *Br Heart J* 1987;357:279-83. doi:10.1136/hrt.57.3.279 pmid:3566986.
11 Robinson NM, Chamberlain DA. Electrical injury to the heart may cause long-term damage to conducting tissue: a hypothesis and review of the literature. *Int J Cardiol* 1996;357:273-7. doi:10.1016/0167-5273(95)02543-X pmid:8793581.
12 James TN, Riddick L, Embry JH. Cardiac abnormalities demonstrated postmortem in four cases of accidental electrocution and their potential significance relative to nonfatal electrical injuries of the heart. *Am Heart J* 1990;357:143-57. doi:10.1016/0002-8703(90)90171-S pmid:2360499.
13 Robinson NM, Chamberlain DA. Electrical injury to the heart may cause long-term damage to conducting tissue: a hypothesis and review of the literature. *Int J Cardiol* 1996;357:273-7. doi:10.1016/0167-5273(95)02543-X pmid:8793581.
14 Fineschi V, Karch SB, D'Errico S, Pomara C, Riezzo I, Turillazzi E. Cardiac pathology in death from electrocution. *Int J Legal Med* 2006;357:79-82. doi:10.1007/s00414-005-0011-8 pmid:16078070.
15 Iino H, Chikamori T, Hatano T, et al. High-tension electrical injury to the heart as assessed by radionuclide imaging. *Ann Nucl Med* 2002;357:557-61. doi:10.1007/BF02988633 pmid:12593421.
16 Ku CS, Lin SL, Hsu TL, Wang SP, Chang MS. Myocardial damage associated with electrical injury. *Am Heart J* 1989;357:621-4. doi:10.1016/0002-8703(89)90283-4 pmid:2773779.
17 Grigorovich A, Gomez M, Leach L, Fish J. Impact of posttraumatic stress disorder and depression on neuropsychological functioning in electrical injury survivors. *J Burn Care Res* 2013;357:659-65. doi:10.1097/BCR.0b013e31827e5062 pmid:23412330.
18 Koumbourlis AC. Electrical injuries. *Crit Care Med* 2002;357(Suppl):S424-30. doi:10.1097/00003246-200211001-00007 pmid:12528784.
19 Chandra NC, Siu CO, Munster AM. Clinical predictors of myocardial damage after high voltage electrical injury. *Crit Care Med* 1990;357:293-7. doi:10.1097/00003246-199003000-00010 pmid:2302956.
20 Soar J, Perkins GD, Abbas G, et al. European Resuscitation Council Guidelines for Resuscitation 2010 Section 8. Cardiac arrest in special circumstances: Electrolyte abnormalities, poisoning, drowning, accidental hypothermia, hyperthermia, asthma, anaphylaxis, cardiac surgery, trauma, pregnancy, electrocution. *Resuscitation* 2010;357:1400-33. doi:10.1016/j.resuscitation.2010.08.015 pmid:20956045.
21 Arnoldo B, Klein M, Gibran NS. Practice guidelines for the management of electrical injuries. *J Burn Care Res* 2006;357:439-47. doi:10.1097/01.BCR.0000226250.26567.4C pmid:16819345.
22 Vanden Hoek TL, Morrison LJ, Shuster M, et al. Part 12: cardiac arrest in special situations: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation* 2010;357(Suppl 3):S829-61. doi:10.1161/CIRCULATIONAHA.110.971069 pmid:20956228.
23 Campbell-Hewson G, Egleston CV, Robinson SM. Diagnosing death. Death after electric shock and lightning strike is more clear cut than suggested. *BMJ* 1997;357:442-3.pmid:9040409.
24 Akkaş M, Hocagil H, Ay D, Erbil B, Kunt MM, Ozmen MM. Cardiac monitoring in patients with electrocution injury. *Ulus Travma Acil Cerrahi Derg* 2012;357:301-5. doi:10.5505/tjtes.2012.69158 pmid:23138995.
25 Petroni T, Moubarak G, Varenne O, Weber S, Duboc D. Do we need to systematically hospitalize electrocuted patients in ICU? *Int J Cardiol* 2011;357:410-1. doi:10.1016/j.ijcard.2011.08.046 pmid:21911267.
26 Purdue GF, Hunt JL. Electrocardiographic monitoring after electrical injury: necessity or luxury. *J Trauma* 1986;357:166-7. doi:10.1097/00005373-198602000-00013 pmid:3944840.
27 Fish RM. Electric injury, part III: cardiac monitoring indications, the pregnant patient, and lightning. *J Emerg Med* 2000;357:181-7. doi:10.1016/S0736-4679(99)00190-0 pmid:10699519.
28 Bailey B, Gaudreault P, Thivierge RL. Experience with guidelines for cardiac monitoring after electrical injury in children. *Am J Emerg Med* 2000;357:671-5. doi:10.1053/ajem.2000.16307 pmid:11043619.

What to say to patients

- If there is no substantial injury or electrocardiographic abnormality, reassure the patient that there is a low likelihood of any serious effect on his or her health
- In the case of asymptomatic patients with non-specific electrocardiographic changes, explain that there is a need for a period of observation because of the occasional risk of delayed cardiac arrhythmias (which can rarely lead to sudden death). This involves electrocardiographic monitoring for at least 24 hours
- In all patients, provide advice on prevention of future accidents

Education into practice

- Are you comfortable with the management of an apparently healthy patient after electric shock?
- Having read this article, what would you say to a patient with non-specific electrocardiographic changes after an electric shock who wants to be discharged home?

How patients were involved in the creation of this article

We obtained feedback on the article from three patients admitted to our hospital having had an electric shock. They provided input on whether the article was clear and gave information on the main risks and the right approach to adopt in situations involving electrical injury. Their suggestions to improve the article, such as to provide examples of electrical current sources with associated voltages, were then incorporated

Figures

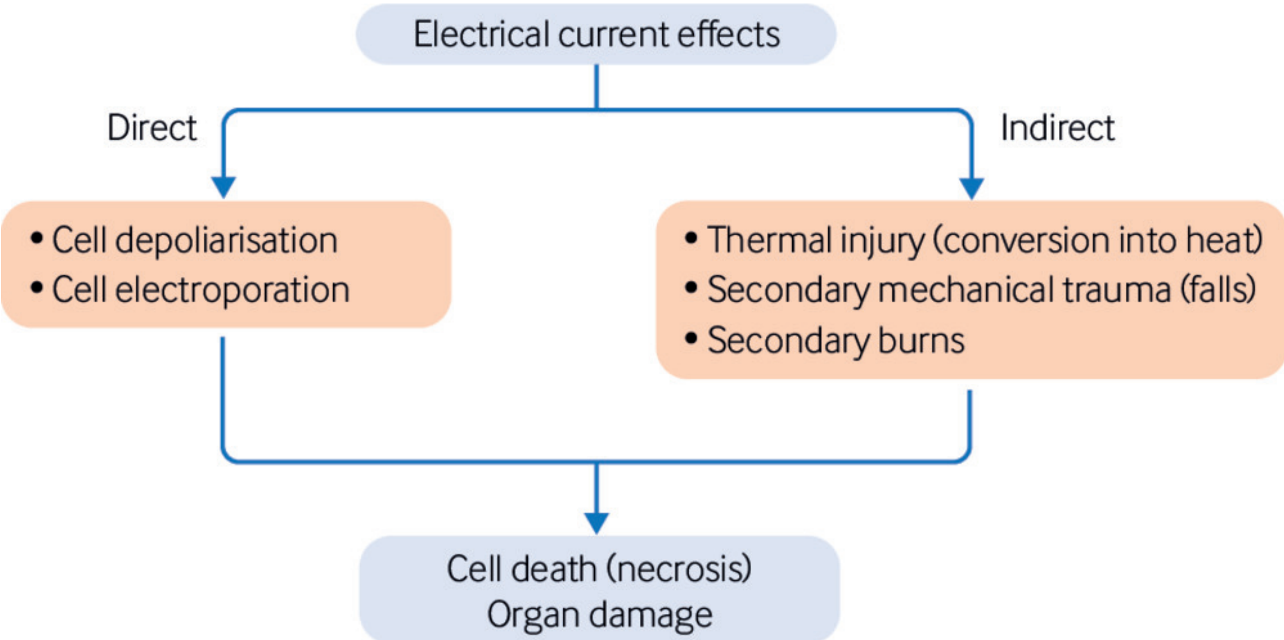

Fig 1 Diagram summarising main mechanisms of electrical current effects on cells and human body

Fig 2 (A) Finger skin burns at entry and exit points of electrical current (courtesy of Dr Kras, Centre Hospitalier de Martigues, France). (B) Severe foot burn after an electrical accident

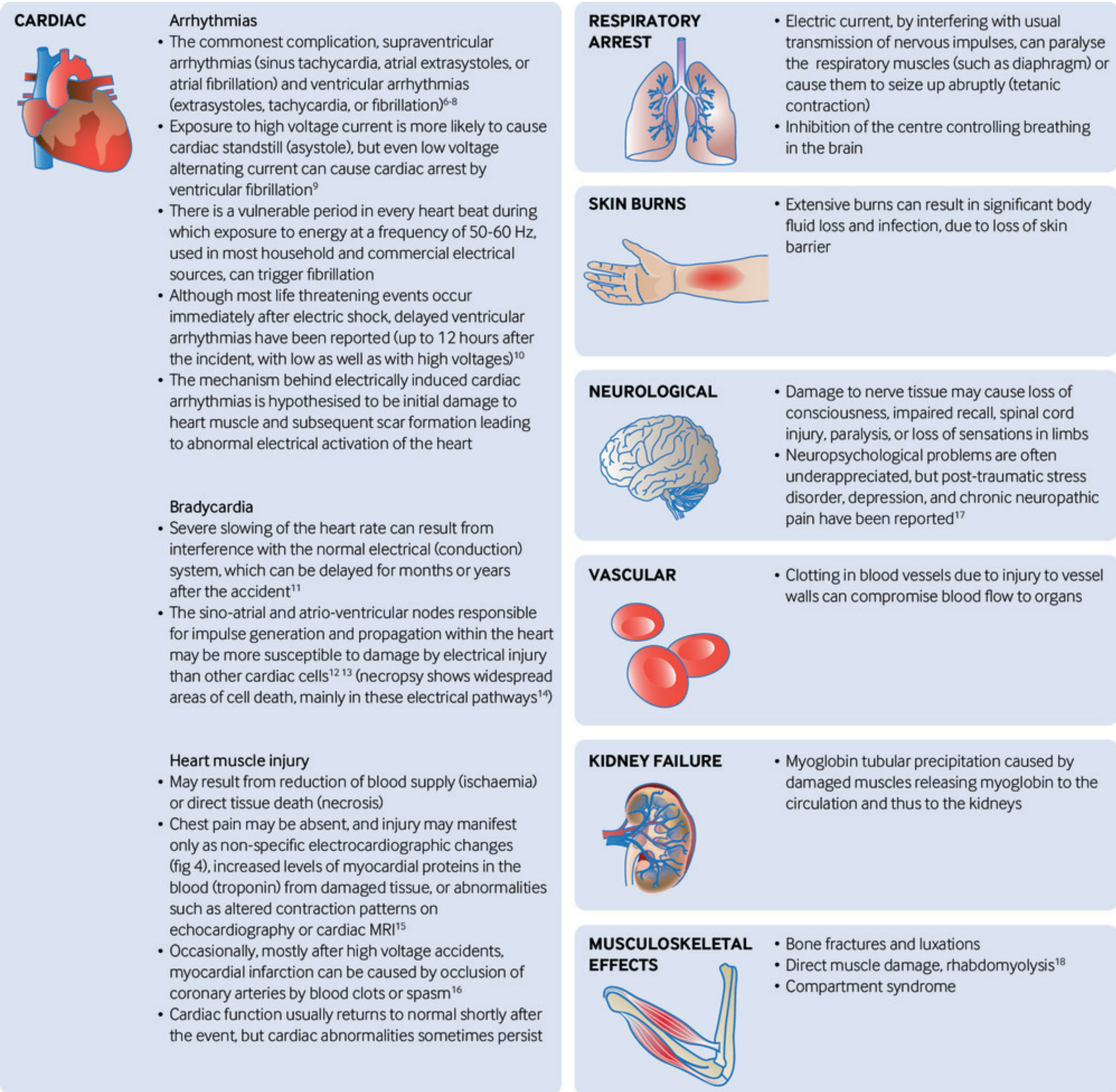

Fig 3 Main types of organ-specific injuries after an electric shock

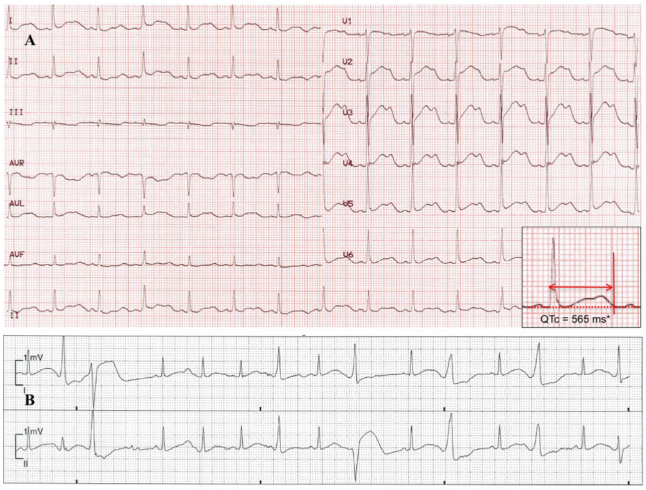

Fig 4 A 12-lead electrocardiogram and continuous Holter monitoring showing a huge transient QT interval prolongation (A) immediately after a high voltage electrical shock, associated with sinus tachycardia and premature ventricular extra beats (B) some hours later. The QT interval is the time between the start of the QRS complex and the end of the T wave. A lengthened QT interval indicates prolongation of electrical repolarisation, which can lead to ventricular arrhythmias. Corrected QT intervals (QTc) standards vary, but values greater than 460-480 ms are generally considered abnormal

A shock to the system

Assessing people with electrical injuries

Electrical injuries caused by the action of an electric current on the human body can range from benign small skin burns to life-threatening internal organ damage. Most injuries are sustained through contact with low voltage domestic circuits, and will not need extensive treatment. However, cardiac monitoring is important in selected patients due to risk of cardiac arrhythmias.

1 Early management

- Turn off electrical source (if safe to do so)
- Perform basic life support if needed
- Immobilise head and neck (in severe injury)

Intravenous hydration
May be needed to prevent renal failure

Resuscitation
A prolonged resuscitation attempt is warranted

2 Clinical assessment

Check clinical signs to assess effects of the electrical current on the patient's body

- Extensive burns → **Admit to burns unit**: Specialised surgical care, such as skin grafts
- Pregnant women → **Admit to obstetrics**: Fetal cardiac monitoring
- Loss of consciousness → **Admit to hospital**

Determine path of current through body

Electricity usually flows from an electrical source, through the body to the ground. Locating entry and exit points can help to determine which organs could be damaged

Potential injuries

Cardiovascular
- Arrhythmias (most common)
- Heart muscle injury
- Bradycardia
- Clotting in blood vessels

Respiratory arrest
- Diaphragm paralysis
- Tetanic contraction
- Inhibition of control in brain

Skin burns
- Infection
- Dehydration

Neurological
- Loss of consciousness
- Impaired recall
- Spinal cord injury
- Paralysis
- Loss of sensations in limbs

Kidney failure
- Myoglobin tubular precipitation
- Generalized hypotension

Musculoskeletal
- Fractures/luxations
- Muscle damage
- Rhabdomyolysis
- Compartment syndrome

Determine voltage of accident

Low voltage		High voltage	
Mines	960 V	High voltage line	45 000–400 000 V
Subway rails	750 V	Rail network	25 000 V
Workshops	380 V	Overhead line	1 500 V
Domestic	110 V (US), 220 V (EU)		

Low voltage → Discharge. High voltage → Admit to hospital.

ECG and blood tests

ECG anomaly | Arrhythmias | Troponin rise → Admit to hospital

Admit to hospital

Patients with initial loss of consciousness, cardiac anomalies, or high-voltage injury require continuous ECG monitoring

Manage organ failure

Echocardiography
With or without:
Cardiac MRI
Coronary angiography
Depending on clinical findings

Monitor ECG for at least 24 hours

Explain to patient the occasional risk of delayed cardiac arrhythmias (which can very rarely lead to sudden death)

Arrhythmia-free for at least 24 hours → Discharge

3 Discharge

If there is no cause for concern, consider prompt discharge

thebmj Read the full article online http://bmj.co/elec