Guideline

Electrocution and Electrical Injury – Emergency Management in Children

Document ID	CHQ-GDL-00735	**Version no.**	2.0	**Approval date**	26/03/2021
Executive sponsor	Executive Director Medical Services			**Effective date**	26/03/2021
Author/custodian	Director Emergency Department			**Review date**	26/03/2025
Supersedes	1.0				
Applicable to	All CHQ staff involved in the care and emergency management of children who have electrical injury.				
Authorisation	Executive Director Clinical Services				

Purpose

This guideline provides clinical practice guidelines for clinicians involved in the emergency management of children with electrocution and electrical injury.

Scope

This work instruction applies to all staff involved in the care and management of children with electrocution or an electrical injury

Introduction

Electrical injuries in children are almost always accidental. Most electrical injuries occur in the home. Incidence is increased among children younger than six years, often because of contact with electric cords (60-70%) or outlets (10-15%)[1,2] ; older children generally suffer high-voltage injuries from power lines while climbing trees or utility poles[2,3]. The incidence of electrical injuries decreases through the teenage years. There is an approximately 2:1 male to female ratio in childhood[4,5].

Electrocution occurs when current passes through a person and disrupts normal electrical function of cells.

Patients with electrical injuries represent a special challenge because they encompass a wide spectrum of presentations; thus, the patients require a detailed physical assessment and should be managed in line with APLS and ATLS algorithms.

Mechanism of Injury

Injuries due to electricity occur by three mechanisms:

- Direct Injury from electric current (e.g. cardiac ischemia/arrhythmia, compartment syndromes, rhabdomyolysis, peripheral nerve injury)
- Injury from conversion of electrical energy to thermal energy (burns)
- Mechanical effects of electric current (violent muscle contraction which may lead to fractures/dislocations, falls resulting in possible trauma)

The tissue damage inflicted by most electrical currents can be primarily attributed to the thermal energy (or heat) generated by the current. Tissues with higher resistance tend to heat up and coagulate. Skin, bone, and fat have high resistances, while nerves and blood vessels have lower resistances.

The classic injury pattern develops when the body becomes part of a circuit and is usually associated with entrance and exit wounds. **The skin findings can significantly underestimate the degree of internal thermal injury.** Careful clinical assessment, recognizing that surface findings may underestimate the extent of tissue damage or necrosis should be used to guide management.

Extent of damage done is determined by:
Amount of electrical current flow: High voltage (>1000V) vs low (<1000V)
Type of current (AC v DC): • AC (most common in Australian homes), is more dangerous, causes tetanic muscle contraction and 'lock-on' effect • DC is less dangerous, patient tends to be thrown away from source
Current path: • Trans-thoracic (hand to hand), has a high mortality (>60%) due to increased spinal cord and myocardial damage • Vertical (hand to foot), mortality >20% due to cardiac arrhythmias • Straddle (foot to foot) low mortality <5%
Which tissues did it flow through? • Moist tissue (mouth) or wet skin increases conduction and therefore results in a more severe injury
Duration: Prolonged contact increases severity of injury

Organ Involvement

Cardiac

The overall estimate of arrhythmia following electrical injury is approximately 15 percent; most of these are benign and occur within the first few hours of hospital admission[8,9]. However, acute electrical cardiac injury can result in sudden cardiac arrest due to asystole (usually with DC current or lightning) or ventricular fibrillation (AC current) prior to hospitalisation[10].

Ventricular fibrillation is the most common fatal arrhythmia, occurring in up to 60 percent of patients in whom the electrical current pathway travels from one hand to the other[11,12]. Spontaneous return of sinus rhythm has been noted after asystole in cases of electrical injury, but because respiratory paralysis lasts longer, the rhythm may degenerate to ventricular fibrillation due to hypoxia. Atrial dysrhythmias, first and second-degree heart block, and bundle branch blocks have been noted as well[9,11]. Changes in the ST segment and T wave, as well as conduction disturbances, generally resolve without specific treatment.

Damage to the myocardium is uncommon. Rare cardiac manifestations include coronary spasm and myocardial rupture due to coagulation necrosis[13-18].

Renal

Rhabdomyolysis may result from massive tissue necrosis and can be complicated by pigment-induced acute kidney injury. In addition, hypovolemia due to extravascular extravasation of fluid can lead to prerenal failure and acute tubular necrosis.

Neurologic

Damage to both the central and peripheral nervous systems can occur after electrical injury. Manifestations may include loss of consciousness, weakness or paralysis, respiratory depression, autonomic dysfunction, and memory disturbances[19,20]. Sensory and motor findings due to peripheral nerve damage are common. The deficits may be "patchy" with the sensory deficits not corresponding to the motor findings. The clinical manifestations may be delayed for days to months after the injury.

Skin

Superficial, partial-thickness, and full-thickness thermal burns can occur following electrical injury. Burns are most common at the site of electrical contact and at places in contact with the ground at the time of injury. The degree of external injury cannot be used to determine the extent of internal damage, especially with low-voltage injuries**. Seemingly minor surface burns may coexist with massive muscle coagulation and necrosis, as well as internal organ injury.**

A unique type of burn seen with electrical injury is the **"kissing burn"**. This occurs at flexor creases, where the flexor surfaces adjacent to a joint touch. It is important to recognize this type of injury because it is often associated with extensive underlying tissue damage[21,22].

Oral burns can occur in young children from sucking or chewing on extension cords. **Delayed severe haemorrhage from the labial artery** (a branch of the facial artery, arising near the angle of the mouth) may occur when the eschar separates in up to 10% of patients and up to **2 weeks after the injury**[23,24].

Musculoskeletal

The areas of greatest thermal injury are often the deep tissue surrounding long bones, potentially resulting in periosteal burns, destruction of bone matrix, and osteonecrosis[3].

In addition to burn-related injuries, bones can fracture from falls, blast injuries, or under the stress of repetitive tetanic muscle contractions. It is reasonable to obtain imaging studies of the cervical spine to assess for fracture in patients with significant electrical injuries or an altered mental status.

Deep electro-thermal injury can result in tissue necrosis and oedema and the development of acute compartment syndrome, leading to rhabdomyolysis and/or visceral injury.

Eyes

Cataracts, hyphema, vitreous haemorrhage, and optic nerve injury can occur.

Ears

Ruptured tympanic membranes[25].

Other injuries

Vascular injury can result from an acute compartment syndrome or the electrical coagulation of small blood vessels. Delayed arterial thrombosis as well as aneurysm formation and rupture have been reported[12,26-28].

Damage to internal organs, including the lungs, stomach, small intestine, and colon, is uncommon, but when occur it can be complicated by fistula formation, perforation, secondary polymicrobial infection, sepsis, and death[29,30].

Electrical Injuries with Special Features

Lightning

Lightning injuries, are a small subset of electrical injuries[11,31]. Approximately 30 percent of those struck by lightning die and the survivors may have permanent disabilities[31,32]. Two-thirds of lightning-associated deaths occur within one hour of injury and are generally due to a fatal arrhythmia or respiratory failure[33,34].

Patients hit by lightning may present with pupils that are fixed and dilated or asymmetric due to autonomic dysfunction. As a result, **fixed, dilated, or asymmetric pupils should not be used as a reason to stop resuscitation**[3].

The incidence of superficial surface burns is high in victims of lightning injury, but deep burns are unusual[35]. The low incidence of deep burns is in part due to the short duration of contact and the "flashover effect", which occurs when the current travels on the skin surface and is discharged to the ground. This can result in the formation of branching cutaneous "feather" lesions, also called Lichtenberg figures, which fade rapidly but are pathognomonic of lightning injury[36]; thus, those with lightning injuries typically require *less fluid resuscitation than patients with thermal burns*.

Complications of lightning strikes can include hypoxic encephalopathy, intracerebral haemorrhage, cerebral infarction, and spinal fractures have been reported[37,38]. Keraunoparalysis is a temporary paralysis specific to lightning injuries that is characterized by blue, mottled, and pulseless extremities (lower more commonly than upper). These findings are often resolve within hours but can be permanent[39]. Cataracts, hyphema, vitreous haemorrhage, and optic nerve injury can also occur following lightning injury[3,35].

In addition, up to 80 percent of patients struck by lightning sustain ruptured tympanic membranes [25,40,41].

Electrical weapons

Electrical weapons, including the stun gun and the Taser deliver bursts of high-voltage, low-amperage direct current[42]. Reviews and studies including a study of electrical weapons use against minors found no evidence that they cause "dangerous laboratory abnormalities, physiologic changes, or immediate or delayed cardiac ischemia or arrhythmias" when exposure lasts 15 seconds or less[43]. Significant injuries are rare, but may include cutaneous burns, lacerations, rhabdomyolysis, testicular torsion, ocular injury, and miscarriage[42,44].

People can also be injured if they fall after being "stunned". Prolonged observation and diagnostic testing are not necessary in patients who are otherwise asymptomatic and alert following such an exposure to these weapons[43,45].

Assessment and Management

Patients presenting following a significant electrical exposure are susceptible to a wide range of injuries, including those sustained from falling or being thrown, and should be carefully examined, with particular attention paid to the organ systems most often affected. Some injuries may not be apparent initially and frequent reassessment is essential.

Important areas to assess include the following:

- Airway, breathing, and circulation
- Cardiovascular function: assess cardiac rhythm; examine pulses
- Skin: Inspect for burns; look for blisters, charred skin, and other lesions; pay attention to skin creases, areas around joints, and the mouth (particularly in young children)
- Neurologic function: assess mental status, pupillary function, strength and motor function, and sensation
- Ophthalmologic: assess visual acuity; inspect the eyes, including a funduscopic examination
- Ear, nose, and throat: inspect the tympanic membranes; assess hearing
- Musculoskeletal: inspect and palpate for signs of injury (eg, fracture, acute compartment syndrome), and be certain to examine the spine

Cardiopulmonary resuscitation

Prolonged CPR should be undertaken following electrical injury regardless of the initial rhythm, since good outcomes have been noted even among patients with asystole[11,46]. Usual triage priorities are reversed if multiple victims are present: patients without signs of life are treated first[11]. The treatment for particular arrhythmias is unchanged[35].

Patients can have spontaneous cardiac activity but paralysis of the respiratory muscles. Prompt restoration of gas exchange via a secure airway may prevent secondary cardiac and neurologic dysfunction or death.

As noted before**,** lightning injury can result in clinical signs typically associated with severe brain injury which may not accurately reflect the patient's neurologic status. Therefore, prolonged CPR may be indicated and clinical judgement should be used to determine the appropriate duration of resuscitative efforts.

Trauma resuscitation and neurologic evaluation

The patient who suffers a serious electrical burn or lightning strike has sustained significant trauma. Appropriate trauma resuscitation should be performed, beginning with a rapid assessment of the airway and cardiopulmonary status. Coexisting smoke inhalation or airway burns must be excluded. Cervical spine immobilisation and clearance are necessary and tetanus prophylaxis should be administered. Coma or neurologic deficit, including alterations in mental status, should prompt brain and spine imaging. A careful secondary survey is needed once the initial resuscitation is complete.

Cardiac injury

The survivor of a high-energy (>1000 V) injury should be evaluated with and electrocardiogram (ECG) and have cardiac and hemodynamic monitoring due to the high incidence of arrhythmia and autonomic dysfunction, especially if there have been arrhythmias in the field or emergency department, loss of consciousness, or if the initial ECG is abnormal[35.]

Serum CK-MB measurements and ECG changes are poor measures of myocardial injury following electrical trauma[21]. The diagnostic and prognostic value of cardiac troponin has not been formally studied in this setting. However, some researchers believe that troponin-I levels and echocardiography can detect myocardial injury after electric shock[47]. Consultation with a cardiologist is advised.

Fluid resuscitation and myoglobinuria

Patients with soft tissue injuries from a severe electrical exposure often **require aggressive IV fluid replacement**, especially if there are signs of muscle necrosis; Parkland and similar formulas used for fluid resuscitation following thermal burns should not be used in victims of electrical injuries, since surface burns may grossly underestimate the extent of injury. Given the risk of hyperkalemia, IV fluids containing potassium should be avoided.

Acute hypotension should prompt a search for thoracic or intraabdominal bleeding secondary to blunt trauma. Large fluid shifts can occur following electrical injury, and clinicians should pay close attention to volume status and electrolytes throughout the course of management. Physiologic measures, including heart rate, blood pressure, and urine output, are useful in guiding resuscitation. Urine output should be maintained at approximately 1 to 1.5 mL/kg per hour until the urine is clear of myoglobin[3,21,48]; However, in patients who develop acute kidney injury and are oliguric or anuric, care must be taken to avoid massive fluid overload from excessive fluid administration.

Serum electrolyte concentrations, particularly potassium, should be measured approximately every two to four hours early during management, depending upon the prior value, renal function, and clinical status.

The combination of aggressive fluid repletion and restrictive surface burns can lead to the development of increased intraabdominal pressure and the abdominal compartment syndrome.

Skin wounds

Wounds are treated in a similar manner to flame or other thermal burns. Patients with burns may require treatment with fasciotomy. Appropriate dressing and topical antibacterial prophylaxis is indicated for non-superficial burns and should be applied after consultation with the local burn team. The value of prophylaxis with intravenous antibiotics is controversial[12].

Gastrointestinal injury

Gastrointestinal injury is uncommon, but persistent ileus, abdominal pain, or tenderness should prompt abdominal imaging and surgical consultation[3]. Injury to abdominal organs can occur as a result of vascular injury and may require laparotomy. Symptoms and signs of injury may be delayed.

Patients have a greater chance of developing gastric ulcers following electrical burns (Curling's ulcers)[3,48,49]. Therefore, it is prudent to provide prophylactic therapy, particularly in patients with severe burns and those who cannot or are not permitted to take food by mouth.

Miscellaneous

After stabilisation, careful otologic examinations may reveal injuries that are amenable to delayed repair[3,48,50]. Ophthalmologic evaluation is warranted because of the potential for delayed development of cataracts[3]. Cataracts generally develop several days after injury, though there may be a lag of up to two years[49,51].

Diagnostic Studies and Disposition

Otherwise healthy children who are exposed to common household electric current (low-voltage, no water contact) and who are asymptomatic in the ED with normal physical examination and have no evidence of LOC, arrhythmia or cardiac arrest in the field may be safely discharged[52]. An initial ECG is recommended for all patients if it hasn't been done prior to arrival.

Patients with mild persistent symptoms or minor cutaneous burns should undergo ECG and urinalysis, and if normal they should be observed for 4-6 hours (from injury) and discharged with appropriate follow-up based upon the severity of their wounds and any comorbidities.

Otherwise, the following studies are recommended:

- Urinalysis - To evaluate for myoglobinuria (positive for blood but no red blood cells)
- Basic serum electrolytes (including potassium and calcium) with renal function studies
- Creatine phosphokinase (CK, to detect muscle injury)
- Full blood count
- Radiographic studies of any region in which injury is suspected.
- The value of serum troponin to assess cardiac injury is uncertain and should be discussed with a cardiologist.

Repeated studies as clinically indicated.

Injured patients should be admitted to an intensive care setting or a surgical ward.

When exposure to high-voltage (>1000 V) is suspected, 24 hours of cardiac monitoring is prudent despite the apparent absence of injury. Additional indications for monitoring include documented loss of consciousness or arrhythmia in a patient exposed to lower-voltage.

Consultation

Key Stakeholders who reviewed this version

- QCH Emergency Department Senior Medical Officers
- Director Paediatric Emergency Department
- Divisional Director Critical Care

Definition of terms

Term	Definition
AC	Alternating current
APLS	Advanced paediatric life support
ATLS	Advanced trauma life support
CPR	Cardiopulmonary resuscitation
DC	Direct current
ECG	Electrocardiogram
ED	Emergency department
IV	Intravenous
LOC	Loss of consciousness
PICU	Paediatric intensive care unit

References and suggested reading

1. Baker MD, Chiaviello C. Household electrical injuries in children. Epidemiology and identification of avoidable hazards. Am J Dis Child 1989; 143:59.
2. Rabban JT, Blair JA, Rosen CL, et al. Mechanisms of pediatric electrical injury. New implications for product safety and injury prevention. Arch Pediatr Adolesc Med 1997; 151:696.
3. Jain S, Bandi V. Electrical and lightning injuries. Crit Care Clin 1999; 15:319.
4. Baxter CR, Waeckerle JF. Emergency treatment of burn injury. Ann Emerg Med 1988; 17:1305.
5. Skoog T. Electrical injuries. J Trauma 1970; 10:816.
6. Cabanes J. Physiologic effects of electric currents on living organisms, more particularly humans. In: Electric Shock Safety Criteria: Proceedings of the First International Symposium on Electric Shock Safety Criteria, Bridges JE, Ford CL, Sherman IA, Valnberg M. (Eds), Pergamon Press, Tarrytown 1985.
7. Lee RC, Zhang D, Hannig J. Biophysical injury mechanisms in electrical shock trauma. Annu Rev Biomed Eng 2000; 2:477.
8. Purdue GF, Hunt JL. Electrocardiographic monitoring after electrical injury: necessity or luxury. J Trauma 1986; 26:166.
9. Das KM. Electrocardiographic changes following electric shock. Indian J Pediatr 1974; 41:192.
10. Lown B, Neuman J, Amarasingham R, Berkovits BV. Comparison of alternating current with direct electroshock across the closed chest. Am J Cardiol 1962; 10:223.
11. Spies C, Trohman RG. Narrative review: Electrocution and life-threatening electrical injuries. Ann Intern Med 2006; 145:531.
12. Avni T, Levcovich A, Ad-El DD, et al. Prophylactic antibiotics for burns patients: systematic review and meta-analysis.BMJ 2010;340:c241.
13. Lichtenberg R, Dries D, Ward K, et al. Cardiovascular effects of lightning strikes. J Am Coll Cardiol 1993; 21:531.
14. Ku CS, Lin SL, Hsu TL, et al. Myocardial damage associated with electrical injury. Am Heart J 1989; 118:621.
15. Xenopoulos N, Movahed A, Hudson P, Reeves WC. Myocardial injury in electrocution. Am Heart J 1991; 122:1481.
16. McBride JW, Labrosse KR, McCoy HG, et al. Is serum creatine kinase-MB in electrically injured patients predictive of myocardial injury? JAMA 1986; 255:764.
17. Kinney TJ. Myocardial infarction following electrical injury. Ann Emerg Med 1982; 11:622.
18. Kirchmer JT Jr, Larson DL, Tyson KR. Cardiac rupture following electrical injury. J Trauma 1977; 17:389.
19. Ramati A, Pliskin NH, Keedy S, et al. Alteration in functional brain systems after electrical injury. J Neurotrauma 2009; 26:1815.
20. Cherington M. Spectrum of neurologic complications of lightning injuries. NeuroRehabilitation 2005; 20:3.

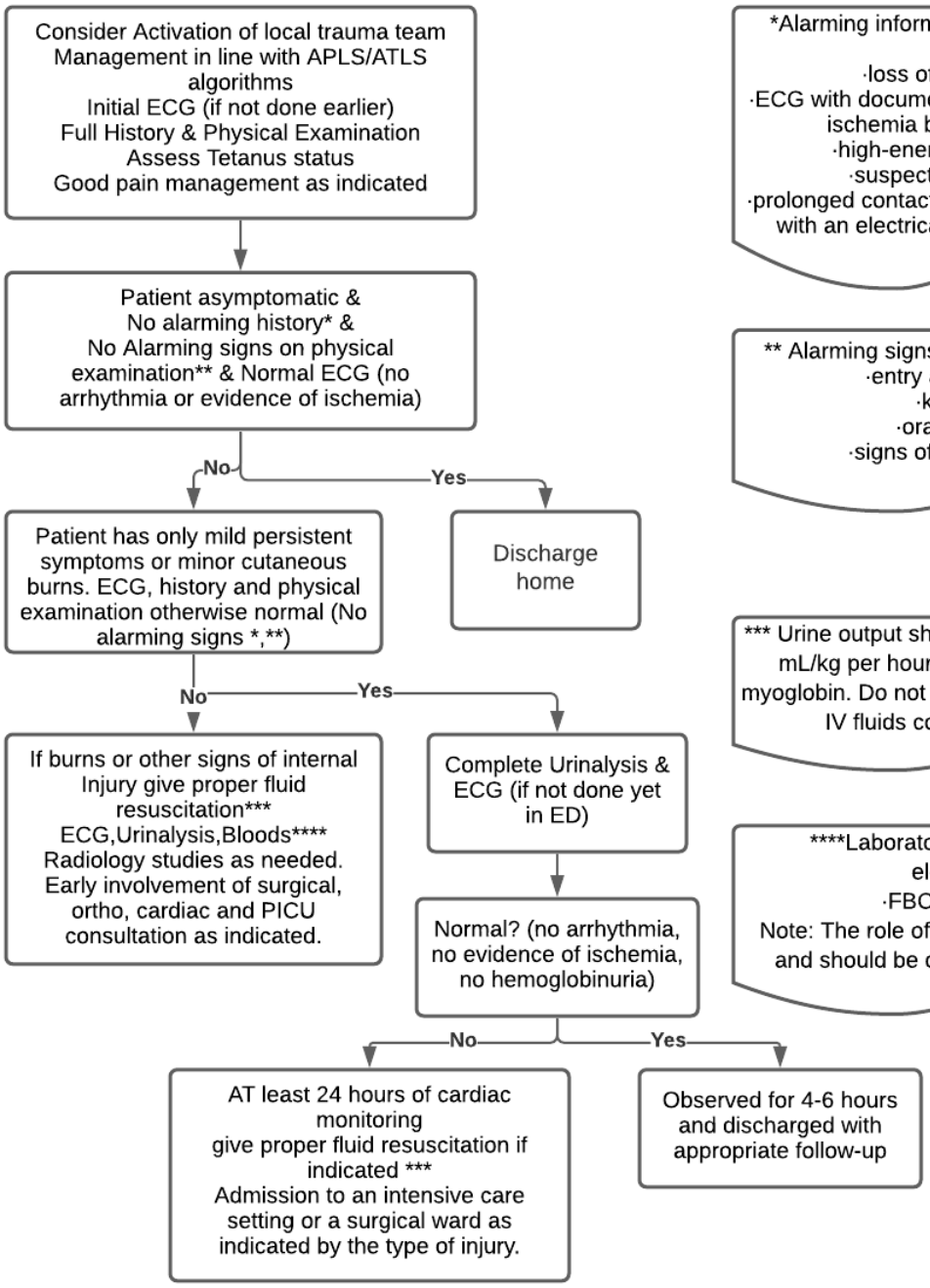
21. Czuczman AD, & Zane RD, Electrical injuries: a review for the emergency clinician. Emergency Medicine Practice. Evidence Based Medicine. 2009, Vol 11 (no. 10)
22. Cooper MA. Emergent care of lightning and electrical injuries.Semin Neurol. 1995;15(3):268-278
23. Banks K, Merlino PG. Minor oral injuries in children. Mt Sinai J Med. 1998;65(5-6):333-342.
24. Zubair M, Besner GE. Pediatric electrical burns: management strategies. Burns. 1997;23(5):413-420.
25. Gluncić I, Roje Z, Gluncić V, Poljak K. Ear injuries caused by lightning: report of 18 cases. J Laryngol Otol 2001; 115:4.
26. Moncrief JA, Pruitt BA Jr. Electric injury. Postgrad Med 1970; 48:189.
27. Hunt JL, McManus WF, Haney WP, Pruitt BA Jr. Vascular lesions in acute electric injuries. J Trauma 1974; 14:461.
28. D'Attellis N, Luong V, Grinda JM. A shocking injury. Lancet 2004; 363:2136.
29. Haberal M, Uçar N, Bayraktar U, et al. Visceral injuries, wound infection and sepsis following electrical injuries. Burns 1996; 22:158.
30. Rijhwani A, Sunil I. Colonic fistula complicating electric burns--a case report. J Pediatr Surg 2003; 38:1232.
31. Ritenour AE, Morton MJ, McManus JG, et al. Lightning injury: a review. Burns 2008; 34:585.
32. Zafren K, Durrer B, Herry JP, et al. Lightning injuries: prevention and on-site treatment in mountains and remote areas. Official guidelines of the International Commission for Mountain Emergency Medicine and the Medical Commission of the International Mountaineering and Climbing Federation (ICAR and UIAA MEDCOM). Resuscitation 2005; 65:369.
33. Centers for Disease Control and Prevention (CDC). Lightning-associated deaths--United States, 1980-1995. MMWR Morb Mortal Wkly Rep 1998; 47:391.
34. Duclos PJ, Sanderson LM. An epidemiological description of lightning-related deaths in the United States. Int J Epidemiol 1990; 19:673.
35. Davis C, Engeln A, Johnson E, et al. Wilderness medical society practice guidelines for the prevention and treatment of lightning injuries. Wilderness Environ Med 2012; 23:260.
36. Vega LA, de Quevedo García JA, Santamariá CT, Porras MC. Clinical picture: An unwanted tattoo. Lancet 2001; 358:1681.
37. Cherington M. Neurologic manifestations of lightning strikes. Neurology 2003; 60:182.
38. Caksen H, Yuca SA, Demirtas I, et al. Right thalamic hemorrhage resulting from high-voltage electrical injury: a case report. Brain Dev 2004; 26:134.
39. ten Duis HJ, Klasen HJ, Reenalda PE. Keraunoparalysis, a 'specific' lightning injury. Burns Incl Therm Inj 1985; 12:54.
40. Wetli CV. Keraunopathology. An analysis of 45 fatalities. Am J Forensic Med Pathol 1996; 17:89.
41. Patten BM. Lightning and electrical injuries. Neurol Clin 1992; 10:1047.
42. Fish RM, Geddes LA. Effects of stun guns and tasers. Lancet 2001; 358:687.
43. Vilke GM, Bozeman WP, Chan TC. Emergency department evaluation after conducted energy weapon use: review of the literature for the clinician. J Emerg Med 2011; 40:598.
44. Mehl LE. Electrical injury from Tasering and miscarriage. Acta Obstet Gynecol Scand 1992; 71:118.
45. Pasquier M, Carron PN, Vallotton L, Yersin B. Electronic control device exposure: a review of morbidity and mortality. Ann Emerg Med 2011; 58:178.
46. Schwarz ES, Barra M, Liao MM. Successful resuscitation of a patient in asystole after a TASER injury using a hypothermia protocol. Am J Emerg Med 2009; 27:515.e1.
47. Celebi A, Gulel O, Cicekcioglu H, et al. Myocardial infarction after an electric shock: a rare complication. Cardiol J 2009; 16:362.
48. Browne BJ, Gaasch WR. Electrical injuries and lightning. Emerg Med Clin North Am 1992; 10:211.
49. Apfelberg DB, Masters FW, Robinson DW. Pathophysiology and treatment of lightning injuries. J Trauma 1974; 14:453.
50. Cooper MA. Lightning injuries: prognostic signs for death. Ann Emerg Med 1980; 9:134.
51. Strasser EJ, Davis RM, Menchey MJ. Lightning injuries. J Trauma 1977; 17:315.
52. Chen EH, Sareen A. Do children require ECG evaluation and inpatient telemetry after household electrical exposures? Ann Emerg Med. 2007;49(1):64-67.

Guideline revision and approval history

Version No.	Modified by	Amendments authorised by	Approved by
1.0 28/09/2016	Director Paediatric Emergency Department	Divisional Director, Critical Care	Executive Director Hospital Services
2.0 09/03/2021	Director Paediatric Emergency Department	Divisional Director, Critical Care	Executive Director Clinical Services

Keywords	Electrocution, Electrical, 00735
Accreditation references	NSQHS Standards (1-8): 1 Clinical Governance, 4 Medication Safety ISO 9001:2015 Quality Management Systems: (4-10)

Appendix 1: Management of Paediatric Patients with Electrical Injury



*Alarming information in history of current injury:
·loss of consciousness,
·ECG with documented arrhythmia or signs of ischemia by prior to ED arrival
·high-energy injury (>1000 V)
·suspected lightning injury
·prolonged contact (more than a few seconds) with an electrical source

** Alarming signs on physical examination:
·entry and exit wounds
·kissing burn
·oral/labial burns
·signs of smoke inhalation

*** Urine output should be approximately 1-1.5 mL/kg per hour until the urine is clear of myoglobin. Do not use Parkland formula. Avoid IV fluids containing potassium.

****Laboratory tests ior significant electrocution:
·FBC, Chem20, CK
Note: The role of serum troponin is ucertain and should be discussed with cardiology