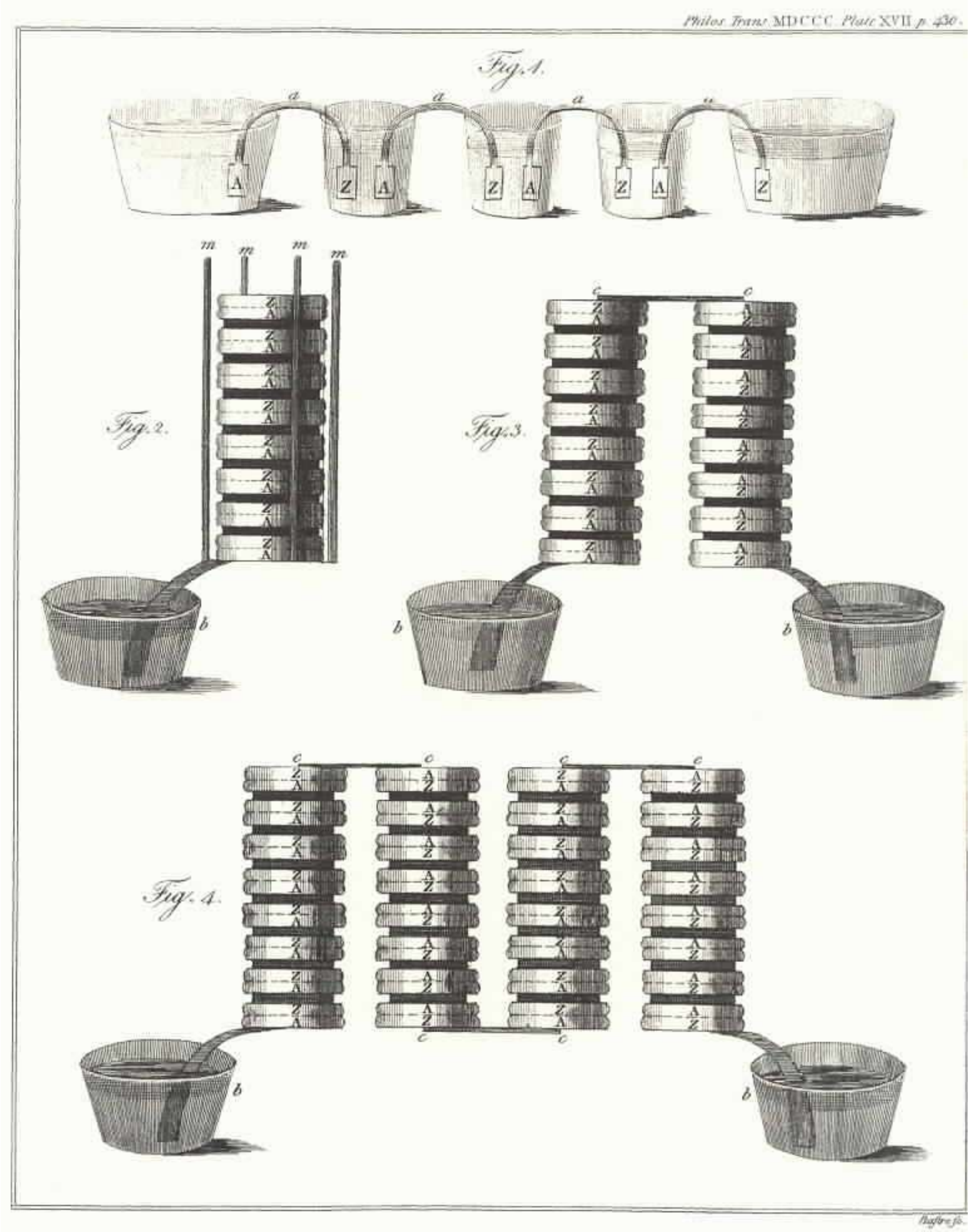
THE NORTHERN HOSPITAL

ELECTROCUTION



Volta's crown of cups and column batteries, Philosophical Transactions, 1800.

"...A number of pieces of zinc, each the size of half a crown, were prepared, and an equal number of pieces of card cut in the same form, a piece of zinc was then laid upon the table, and upon it half a crown, upon this was placed a piece of card moistened with water, upon the card was laid another piece of zinc, upon that another half a crown, then a wet card, and so alternately until more than forty pieces of each had been placed upon each other, a person then, having his hands well wetted, touched the piece of zinc at the bottom with one hand, and the half crown at the top with the other: he felt a strong shock, which was repeated as often as the contact was renewed..."

The Morning Chronicle, London 30 May 1830.

The "natural philosophers" of the Eighteenth century Enlightenment, were imbued with an unwavering belief that all knowledge was good and must in some way at least be useful, even though this usefulness may not have always been apparent at the time. In this spirit Beccaria writing to his colleague Boscovich, on the fascinating yet little understood phenomenon of statically generated electricity in April 1768, wrote,

"...Electricity reveals new worlds. They are pigmy worlds, you may think, but who knows that one day giants too may amuse themselves with them".

In the following generation natural philosophers continued with their researches into electricity building on the foundations that had been laid by Franklin, Beccaria and others, until one day in 1799 a breakthrough was made by a certain Italian philosopher by the name of Alessandro Volta. His discovery remained totally obscure to the general public at large, but created great interest among the learned "philosophic" elite of the time.

Thus it was that in an obscure article of the London Morning Chronicle by an anonymous journalist on 30 May 1830, one of the most momentous scientific discoveries in history was announced to the world. None at that time, including it's discover had the slightest idea of its significance and how it would transform the world. For the first time in history the curious force of electricity had been harnessed into a form by which it could be stored and utilized. Alessandro Volta had constructed the world's first battery. It was the beginning of the electrical age that would transform the world forever. Even though the long term implications were unknowable, the discovery fascinated the learned of Europe. Volta was called to present his invention to no less a personage than Napoleon Bonaparte himself. Bonaparte was so intrigued by the "battery", that he enthusiastically acclaimed the new "French" invention, (after the battle of Marengo Lombardy had been incorporated into the territories of the French Empire) and made Volta a Count.

Napoleon's motives were not entirely "philosophic" however. Although an adherent to the enlightenment philosophies, his reasons for the promotion and edification of Volta had more to do with a propagandist demonstration to the rest of Europe of the cultural and enlightened superiority of France. It was also meant as a reassurance to the learned elite of Europe of the honourable and progressive intentions of the ever expanding reach of Bonaparte himself. Volta himself, had not deliberately set out to harness the phenomenon of electricity for the future benefit of humankind, whatever that might turn out to be. In fact he had produced his "Voltaic battery" in order to refute an archaic concept on "Galvanism" and "animal electricity". Basing his discovery in part on the work of the Englishman, Nicholson in attempting to recreate nature itself, by building an artificial electric fish.

Volta expected that his invention may possibly have some application in the field of medicine, however in a rapidly industrializing age its possible application to motion, mechanics and engines of various kinds was not lost to others. Contrary to their expectations however the earliest successful applications of the harnessing of electricity would occur in the fields of chemistry and communications in the form of the revolutionary new telegraph. In the early Twentieth century, giants of invention such as Thomas Edison together with the captains of industry (Beaccaria's giants) would eventually usher in the electrical age.

Volta's recent biographer Giuliano Pancaldi, mused "How are we to account for the natural philosopher's inability to predict how and where their "useful knowledge" was going to become really useful? How do unintended consequences arise in a field like science and technology that we have been taught to regard as a well-disciplined field of human endeavour? And note that even today, in what we regard as a mature technological age, scientists and technologists do not perform much better than their late Eighteenth century predecessors in predicting the useful applications of scientific and technological research".

Beccaria's speculation to his friend in 1768 that one day electricity would dominate the world was entirely correct. In the light of the story of Volta's invention it is fascinating to muse today on what historians of future centuries will look back at on our own time to point out an "obscure invention" that would change the world forever, (...the discovery of the Higgs Boson perhaps?) yet to the majority of its contemporaries remained completely unappreciated. All great discoveries whilst bringing great benefit to humankind, invariably also bring new problems. In the field of medicine Volta's invention led to an unexpected new medical problem, only previously experienced by the rare lightning strike delivered from the heavens…electrocution.

Satellite photographs at night show artificial light produced by species Homo Sapiens - Electricity dominates the image of 21st century Earth from space. In Volta's day no white specks would have been seen ....at all.

ELECTROCUTION

Introduction

Ever since **Alessandro Volta** first harnessed the power of electricity, humanity has come to rely in on it ever more in the years since, such that today a world without electricity is inconceivable.

Electrical injury is common, although a good general awareness and respect for the dangers of electricity means that fatalities are fortunately relatively uncommon.

The major determinants of an **electrical injury** relate to:

1. The total current
2. Its type
3. Its duration
4. Its anatomical pathway
5. Associated thermal effects.

Electrical injuries may occur due to exposure to household or industrial electrical currents or due to lightning strike.

In significant electrical injuries the true extent of deep tissue injury may not be obvious on first assessment, and seemingly minor entry and exit wounds may be associated with extensive deep tissue damage.

Electrical injuries more closely mimic crush injuries (with rhabdomyolysis), than they do thermal burns injuries.

A high index of suspicion is essential to avoid underestimating the severity of injury.

See also separate documents on:

- **Lightning injury (in Environmental Folder)**
- **Taser Shock (in Environmental Folder)**

Epidemiology

There are around 20 - 30 electrical fatalities in Australia per year (2015)

Pathophysiology

The degree of tissue injury in electrocution will depend on:

1. Total **current**:

- **It is the total current that runs through the body, rather than the voltage of an electrical system, which ultimately determines the degree of tissue damage.**

2. Type of current:

   - DC or AC

3. Current pathway.

4. Duration of exposure to the current.

5. Associated thermal injury, secondary to the current.

Total Current:

Ohm's law: V = I.R

I = V/R

The total current is therefore determined by Ohm's law, which shows that the current will depend directly on the voltage and inversely with respect to the resistance.

For current to flow through the body:

- The body must complete a circuit (of high potential to low potential).
- The current must overcome the resistance.

Current:

1. It is the magnitude of the **current** that determines tissue damage.

2. Current is directly proportional to the voltage (often known) and inversely to the resistance (usually not known).

3. Small voltages may be fatal if resistance is very low and large voltages may not be harmful if the resistance is high.

4. In general terms:

   - **1 milliampere** (mA) generally represents the minimal threshold for perception of an electrical current, experienced as a mild tingling sensation.

   - Currents of **10 mA** and above can induce skeletal muscle tetany - thus rendering a patient incapable of letting go of the current source.

     Furthermore, exposures of > 10 mA of A.C can induce sweating, and so can increase current flow even further.

   - Currents of **20 mA** and above can induce respiratory muscle paralysis.

- Currents of **100 mA** and above can induce that traverse the heart, can induce ventricular fibrillation.

- Currents of **2 A** and above can induce asystole as well as directly damage soft tissue organs.

The maximum "safe" current tolerable is **50 mA** for a period of **1 second**.

Voltage:

1. High verses low voltage:

   - High voltage is usually defined as ≥ **1000 volts.**

   - Low voltage is usually defined as < **1000 volts.**

2. Household voltage in Australia is **240 volts**.

3. Generally voltages less than 50 volts (at 50 Hz) have not proved hazardous.

4. Survival has been recorded at shocks greater than 50,000 volts (presumably due to high resistance and/ or very brief exposure times).

Resistance:

1. Resistance is different for different tissues:

   - **Nerve < vessels < muscle < skin < tendon < fat < bone**

     The less the resistance of the tissue, the greater will be the current (for a given voltage) the greater will be the tissue damage.

     Bone has the highest resistance to electrical current, and any bone in the current path can therefore generate significant heat. This can result in thermal injury to surrounding muscle, and the risk of limb-threatening **compartment syndrome**. [4]

2. Skin resistance varies greatly, depending on:

   - Moisture:

     ♥ On average wet skin has 40 times less resistance to current flow than dry skin and therefore will allow a much greater current to pass through the body. [4]

   - Thickness (callus):

     ♥ Wet skin may have a resistance of 1000 Ω while thick, while dry (and callused) skin may be as high as 100,000 Ω.

By Ohm's law therefore, a 240 volt source, results in a current of 2.4 mA in dry skin, which is just above the threshold for perception.

On the other hand the same 240 volt source can result in a current of 240 mA, in wet skin - more than enough to induce VF.

Unsurprisingly water has been identified as a critical factor in serious electrocutions.

- Vascularity

Type of Current

This refers to **alternating current (AC)** versus **direct current (DC)**.

A.C

1. Most **household** and **commercial** sources of electricity.

2. Electrons flow back and forth at a certain frequency (Hertz, Hz).

3. Causes relatively more damage (about **3 times**) than D.C current of the same magnitude.

   The greatest risk to human tissue from AC current is within the frequency range of **40 - 150 Hertz**. These *frequencies* are able to produce **tetanic** contraction in human skeletal muscle tissue (the victim is unable to let go of the electrical source, leading to increased exposure to current) and they also span the vulnerable period of the cardiac cycle, that may induce **ventricular fibrillation**.

   As frequency rises beyond 150 Hz, the risk of tetanic response decreases and the current is less dangerous in this regard, (though increasing current will result in more direct tissue injury).

4. Mains supply in Australia is **240 volts** at **50 Hz AC**.

   This is because 50 Hz is most efficient for electrical transmission, (but the drawback, of course, is that this lies directly within the dangerous frequency range.

   (Standard mains supply in the USA is 110 volts at 60 Hz AC).

   50 Hz also spans the vulnerable period of the cardiac electrical potential and thus may induce VF.

D.C

1. In lightning, defibrillators, car batteries, high-tension power lines.

2. Electrons flow in one direction only.

3. Causes *relatively* less damage (than AC *of the same magnitude*).

4. DC usually causes a single strong contraction of skeletal muscle that may fling the victim away from the current source.

Pathway of Current

The exact pathway that a current takes through the body will also determine which tissues are damaged, although prediction of actual injuries from knowledge of current path is not very reliable

Traditionally mortality has been quoted to be greater for **hand to hand** (hence trans-thoracic) pathways and less for **head to foot** pathways, though this has not been definitely verified.

If current passes **from leg to leg**, then no current traverses the heart.

Current travels primarily via **nerves** and **blood vessels** as these tissues are of lowest resistance, relative to the other tissues of the body.

The tissues most at risk include:

1. **Brain**

2. **Heart**

    - The heart is typically affected by a current travelling **hand** to **hand**.

3. **Vascular system:**

    - The vasculature maybe affected by both vascular spasm and delayed thrombosis.

4. **Fetus:**

    The fetus is less resistant than the mother due to:

    - Hyperemic uterus and amniotic fluid being good conductors of electricity.

    - Fetal skin being 200 times less resistant than postnatal skin.

Duration of Exposure:

The longer the duration of exposure, the greater will be the tissue damage.

Thermal Injury:

- As current traverses the tissues, some of the electrical energy is converted into thermal energy.

- The degree of thermal energy will depend on **Joule's Law**:

- ♥ **Heat = $I^2 \times R \times t$**

- Tissues with greater resistance, e.g. tendon, fat, bone will suffer the greatest degree of **thermal** injury from a given current.

Clinical Features

1. Electrical burns:

   Burns are due to current generated heat which can be:

   Direct burns:

   - The smaller the area of contact, the greater will be the current density, and hence heat production, and the greater will be the consequent adjacent tissue destruction from burns.

     - ♥ AC generally causes entrance and exit wounds of the same size.

     - ♥ DC tends to produce small entrance and larger exit wounds.

     Although electrical burns often appear to be less impressive than flame burns on the surface, appearance cannot be used to predict the severity of internal injury.

     High-voltage injuries may largely spare the skin surface but cause **massive damage** to underlying soft tissue and bone, necessitating escharotomies, fasciotomies, or amputations.

     The sites of entrance and exit wounds will provide an important clue to the path that a current has taken.

   Secondary burns due to "arcing" or "flash over":

   - Electricity may also traverse (or arc or flash) *over* the skin. The electrical energy converts the air to heat.

     Arc buns occur when electrical energy passes over the skin from a high-resistance contact point to a low resistance point (on the ground in the case of lightning strike where the electricity ionizes air particles to complete the circuit and significant heat is generated - enough to ignite a victim's clothing and cause secondary burns. These arcs may generate momentary temperatures of up to 3000 °C !).

     One particular characteristic form of an electrical arc burn is the "**kissing burn**". A kissing burn is an electric arc generated between two **skin** surfaces facing each other and sandwiching a joint, typically the elbow and knee flexures. The arc crosses the flexor crease and burns the two "kissing" skin surfaces. This injury pattern is important to recognize as it is often associated with significant **deep tissue** damage, (*DermNet New Zealand, Website*), (**see Appendix 2 below**).

2. Skeletal Muscle:

- AC currents at 50 - 60 Hz may produce tetanic contraction.
- Rhabdomyolysis (current and heat damage).
- Compartment syndrome:
  - ♥ This can develop progressively over 6 to 12 hours in significant injuries.

3. Neurological:

Virtually any type of neurological injury may occur including:

CNS:

- Coma
- Confusion
- Amnesia
- Seizures
- Spinal cord lesions/ Hemiplegias/ Paraplegias

Peripheral nerve injury:

- Initial neurological injury often is transient, but permanent sequelae are also possible.
- If a neurological deficit develops late, it has a worse prognosis and is probably secondary to a vascular lesion (i.e. delayed thrombosis).

4. CVS:

- Direct myocardial injury:
  - ♥ Cardiac stunning/ failure
  - ♥ Myocardial infarction has been described.
- Arrhythmias:
  - ♥ Low voltage (less than 1000) low current tends to result in **VF**.
  - ♥ High voltage, high current tends to result in **asystole**.
  - ♥ **AF** may occur, but virtually any arrhythmia (including **ectopics** and **conduction delays**) is possible.

- ♥ Arrhythmias usually occur **at the time of injury** and delayed onset arrhythmias are very uncommon (unless there is clear evidence of myocardial injury **initially**).

  VF or **asystole** are the usual causes of immediate death from electric shock.

- Vascular:

  - ♥ Both large and small vessel, arterial and venous injuries are possible.

    Injury is by spasm or delayed thrombosis leading to ischemia of the affected region.

5. Respiratory:

   Apnea from:

   - Tetanic muscular contraction (e.g. household electrocution).
   - Medullary paralysis, (e.g. seen with lightning strikes).

6. Renal:

   - ARF, secondary to myoglobinuria

7. Ocular:

   - Direct damage, optic nerve, retinal detachments, uveitis, and iritis.
   - Cataracts at time of injury or up to weeks to months post injury. [3]

Associated Injuries:

These include:

1. Musculoskeletal injury from **tetanic** muscular contractions, including:

   - Spinal injury
   - Joint dislocations; especially of the **shoulder**:

     Two unusual patterns of shoulder dislocation are characteristic following a seizure:

     - ♥ Posterior dislocation of shoulder, (though anterior is also possible).
     - ♥ Bilateral shoulder dislocations, (**see Appendix 1 below**).

3. Injury due to secondary trauma:

- Falls.
- Being thrown back from the current source.

4. Injury secondary to thermal burns (igniting clothes)
5. Blast type injuries, (in the special case of **lightning strikes**).

Investigations

These will be guided by the severity of injury, the clinical state of the patient and the presence of any associated trauma.

Blood tests:

Consider:

1. FBE
2. U&Es and glucose
3. Myoglobin levels
4. CK
5. Cardiac troponin levels:
    - Measurement of troponin is not *routinely* required as the clinical significance of an elevated level is not clear and does not necessarily guide disposition decisions.

ECG:

Initial 12 lead followed by continuous monitoring if abnormal.

In survivors who develop ECG abnormalities the following may be seen:

- Sinus tachycardia
- AF - (this usually resolves spontaneously).
- Non-specific ST-T wave changes
- Myocardial infarction had been reported.

Delayed lethal arrhythmias are **rare**.

Imaging:

Is done as clinically indicated, in particular:

1. Plain radiology for any suspected bony injury / joint dislocations.

2. CT brain for any altered conscious state.

3. CXR, if aspiration is suspected.

Management

Note that electrical injury may be far more extensive than is apparent from external appearances.

Make the immediate environment safe:

In the prehospital environment, safety of the **rescuer** is paramount.

The victim should not be approached while there is any risk of electrical injury to the rescuer:

1. Switch off any power sources.

2. Avoid wet areas.

3. Wood/ rubber matting are good insulators, (avoid the instinct to grab a victim if they are *still in contact* with the electrical source).

   If the electrical source cannot be turned off, electrical cables can be removed from the victim using a non-conducting material such as timber or rubber.

Then treat the patient:

1. ABC as indicated:

   - Low voltage less than 1000 volts/low current injury tends to induce cardiac arrest via VF.

   - High voltage injury / high current, usually defined as greater than 1000 volts, tends to cause cardiac arrest via asystole.

   Prolonged ALS is warranted in cases of electrically induced cardiac arrest due to the higher likelihood of recovery from cardiac arrest following electrocution relative to other causes of cardiac arrest.

   ALS follows standard protocols.

2. Arrhythmias:

   - These are treated according to standard protocols.

   - Most commonly survivors will have AF if they have an arrhythmia.

     This is often transient and in most cases management is observation until it resolves.

12 lead ECG and continuous monitoring.

- Routine monitoring post *household* electrical shock (ie 240-volt rms, AC at 50 Hz) is not necessary providing the patient is well and the **initial ECG is normal.** [1]

3. Analgesia as necessary.

4. CNS:

   A cerebral CT scan should be done on any patient who has:

   - An altered conscious state.
   - Confusion.
   - A history of loss of consciousness
   - A seizure.

   The electrical injury may have caused primary brain damage or secondary (to trauma or intracranial haemorrhage) brain damage.

5. Tetanus immunoprophylaxis as required.

6. Burns:

   - Treated as for any thermal injury.

7. Musculoskeletal injury:

   Careful primary and secondary survey to look for:

   - Traumatic injuries, (shoulder dislocation in particular).
   - Extent of electrical injury.

   Deep tissue injury must be suspected in anyone with an entry and exit wound.

   Electrical injuries behave more like a severe crush injury rather than a burn.

   - **Rhabdomyolysis may be an issue with severe injuries.**

     Potassium and myoglobin levels should be monitored.

   - **Compartment syndrome will require urgent fasciotomy**

     See also separate document for Rhabdomyolysis

8. Vascular compromise:

- If there is any vascular compromise a Doppler ultrasound or CT angiogram should be performed.

Electric Shock in Pregnancy:

In cases of electric shock in pregnant women:

- Urgent Ultrasound.
- Urgent CTG fetal monitoring
- Urgent obstetric consultation

Note that DC cardioversion and ECT are both known to be **safe** in pregnancy, a major factor being that the fetus *is not in the main current pathway.*

Disposition:

The victim of a brief, low-voltage (household) exposure who has been and remains asymptomatic and has a normal ECG can be discharged directly. [1, 4]

Fatal arrhythmias typically occur *at the time of the electrical insult*, and delayed arrhythmias are uncommon in otherwise healthy patients.

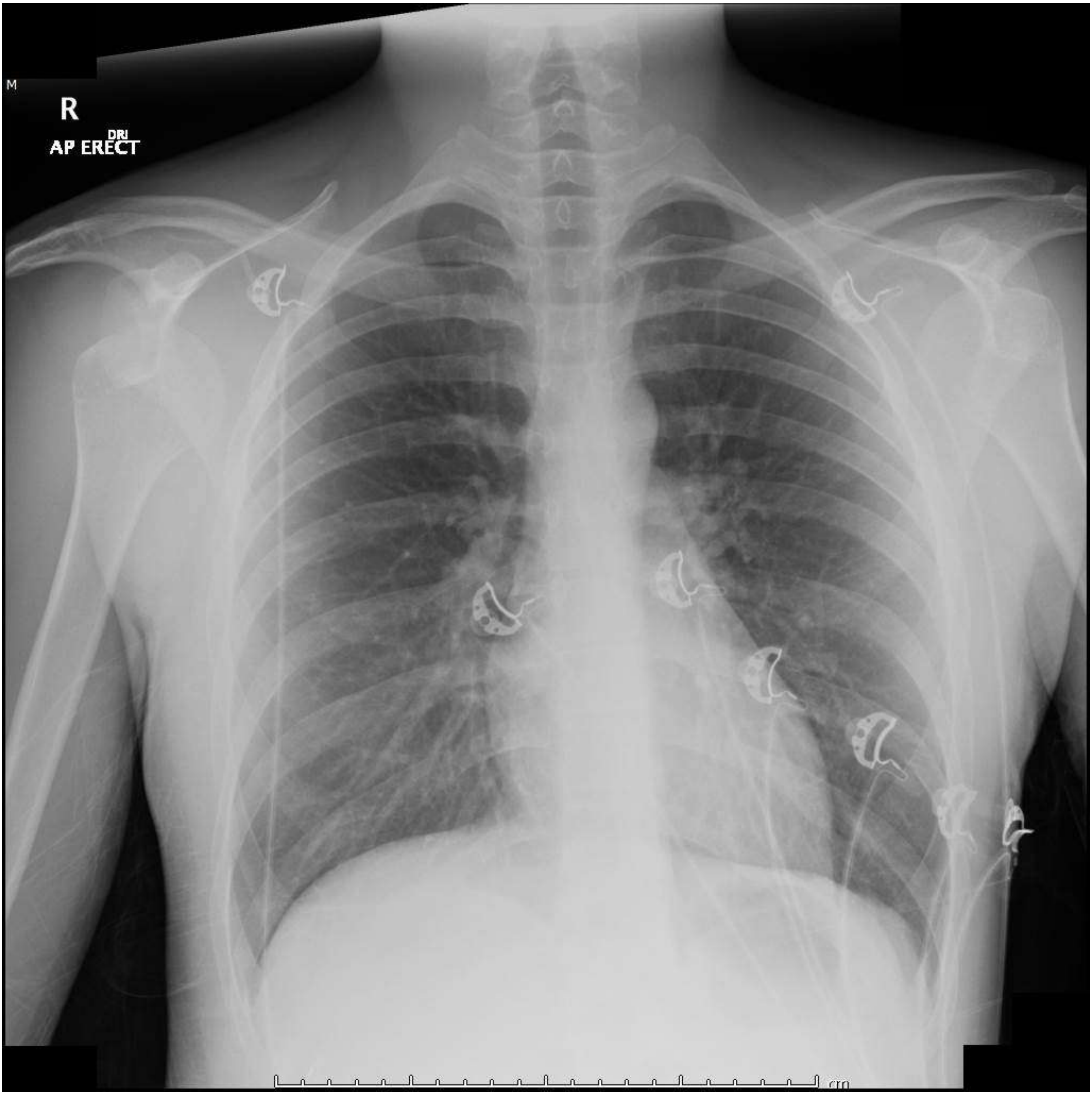
Admission and prolonged (at least 12 hours) cardiac monitoring is only required for patients with: [3,4]

- **High voltage (non-household) exposures (> 1000 volts).**
- **Documented ECG changes such as ischemia or arrhythmias**
- **Seizures or loss of consciousness.**

Patients with a pacemaker or implanted defibrillator devices should have their function checked before they are discharged.

Any patient with suspected deep tissue electrical injury should be admitted to a specialist **burns** or **plastic surgical** unit.

Appendix 1

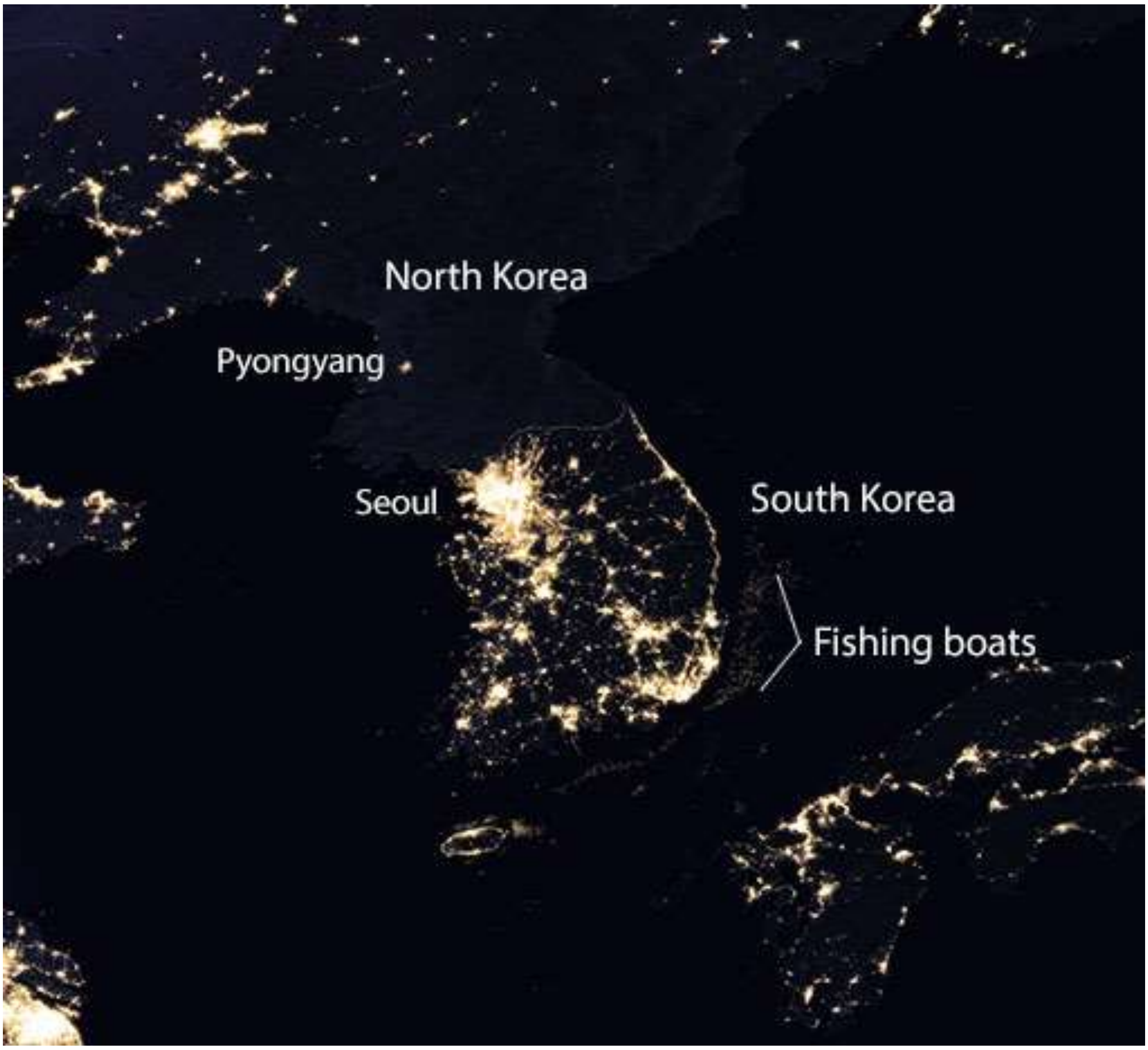


Bilateral shoulder dislocations in an 18 yr old male secondary to generalized seizure, (Clinical photograph, courtesy Dr Kin Wong).

Appendix 2

Typical appearance of a direct electrical burn, note that the watch band should be removed ! (eMedicne Website)

Typical appearance of "kissing" electrical burns at the wrist - with suggestion of same at the elbow flexure and axilla. (Rosen 2006).



Nocturnal satellite image of the Korean Peninsula, (2017).

If an advanced alien intelligence many light years distant, were to survey the Earth at night, then they could very quickly glean a comprehensive overview of which geographic regions of the planet, were the most technologically "advanced", prosperous, and/ or populous, merely by examining the distribution of artificial light. The exact reasons for the peculiar patterns of distribution would undoubtedly. present a mystery. Perhaps they would surmise that the North Korean peninsula was a barren uninhabitable desert, very abruptly demarcated by some natural mountainous barrier extending the entire width of the landmass. It is interesting to ponder whether, the thought would occur to them that some social or political reason - known only to the species inhabiting the planet - could account for such a startling discrepancy!

Alessandro Volta (1745-1827), Volta courtyard, University of Pavia, Lombardy, Italy.

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Reviewed December 2017.