Part X: Trauma

Chapter 75: Electrical Injuries

T E Oh

The widespread use of electrical appliances and electronic equipment in homes and hospitals, exposes people, patients, and staff to the hazard of electric shock. The ICU is an area of special risk to patients, due to the use of invasive monitoring equipment and transvenous pacemakers, which not only bypass the resistance of the skin, but may provide a direct route to the heart for electric currents.

Electrical injuries may be in the form of:

1. Electrical flash burns resulting from radiant heat released when an arc forms between an energized source and ground.

2. Flame burns secondary to the ignition of clothing from high voltage injuries.

3. Electrocution.

4. High tension and lightning injuries.

Electricity

Electricity is produced by electrons which carry negative charges. This electricity may be static, such as that seen with some synthetic clothing, or dynamic, where there is a flow of current. An electric current is a flow of electrons through a conductor, from a point of higher concentration or potential, to a point of lower potential. This flow may be a direct current (DC) such as that obtained from a car battery, or alternating current (AC) from mains supply. With direct current, the electrons always flow in one direction, whereas with alternating current, the electrons flow back and forth at a frequency, ie, cycles per second, or hertz (Hz).

Current flow (the volume or number of flowing electrons) is measured in amperes (A). An ampere is a flow of one coulomb per second. One coulomb (C), the unit of electrical charge, is 6.28×10^{18} electrons. In order for current to flow, there must be a difference in the "electrical pressure" (ie, potential) from one higher potential point to a lower point. The unit of electrical pressure or potential is the volt (V). Mains supply in Australia is 240 V at 50 Hz. In USA and parts of Europe, the household current is 110 V at 60 Hz. Resistance to current flow is measured in ohms. The relationship of voltage, current and resistance is signified by Ohm's Law:

$$\mathbf{V = I \times R}$$
$$\mathbf{or\ I = V / R.}$$

where I = current in amperes (A)
R = resistance in ohms (Ω)
V = voltage in volts (V).

An electric current will flow if a circuit is completed either from positive to neutral wires, or from positive to earth. From Ohm's Law, amperage increases with larger voltages and lower resistances.

Physiological Considerations

For a current to flow through the body, the body must complete an circuit, and the current must overcome the resistance of the body. Most of this resistance is in the skin. If the skin is dry, there is a resistance in excess of 100.000 Ohms. Skin resistance will be markedly reduced if the skin is wet, or if conductive jelly has been applied. The resistance of the current pathway from one extremity to another with intact, but moist skin, is approximately 1000 Ohms. Hence, a current of 240 milliamps (mA) from household and hospital electrical supply at 240 V, can easily flow through the body from electrical source to ground, whenever a circuit is completed, if the skin is moist or wet.

Electrocution

The pathophysiological processes of true electrical injuries are poorly understood. Risk of electrocution depends on any of the following:

1. the amount of current passing through the body;

2. the duration of the current; and

3. the tissues traversed by the current.

Obviously, amperage is most directly related to the extent of injury, but usually only the voltage is known. In general, lower voltages cause less injury, although voltages as low as 50 V have caused fatalities.

The electric current passing through the body produces these main effects.

1. Tissue Heat Injury

Body tissues in decreasing resistance are skin, bone, muscle, nerves, and vessels. It is not known whether electricity flows through the body homogenously, or follows pathways of lower tissue resistance. Skin entry burns depend on the area of contact and skin resistance. Oral commissure burns in toddlers biting through electrical cables, and burns at (lower resistance) wrist and antecubital areas, are other typical patterns of skin electrical injury. Organs may be injured by generated heat if they lie in the path of the current from entry to ground. Other electrical heat generated tissue injuries include coagulation ischaemia and necrosis, and vascular thrombosis.

2. Depolarization of Muscle Cells

An alternating current of 30-200 mA will cause ventricular fibrillation. Currents in excess of 5 A cause sustained cardiac systole. (This is the principle used a defibrillator.) Apart from ventricular fibrillation, other arrhythmias may occur. ST and T-wave changes may be seen on ECG. Global left ventricular dysfunction may occur hours or days later despite initial minimal ECG changes. Myocardial infarction has been reported, and the diagnosis is often difficult, because of the elevated creatine phosphokinase levels (even the MB isoenzyme levels), due to the extensive muscle injury.

Skeletal muscle is responsive to tetanic depolarization at household frequencies of 50-60 Hz and with currents greater than 15-20 mA. Hence, voluntary release from the electrical source may be prevented during electrocution.

3. Neurological Injuries

These injuries may involve the central nervous system, spinal cord, and/or peripheral nerves, and clinical manifestations may range from confusion and agitation to paresis and paralysis.

4. Renal Failure

Acute renal failure may follow due to myoglobinuria secondary to extensive muscle necrosis.

5. Other Injuries

Fractures and dislocations caused by falls, and damage to eyes, lungs, gastrointestinal tract as well as other organs may result from electrical injury. Intrauterine foetal death has been known.

Microshock

The above domestic/industrial electrocution is known as macroshock, when current flowing through the body passes through the heart. In the ICU there is potential for another form of electrocution, microshock. Microshock occurs when there is a direct current path to the heart muscle. The pathway may be provided by a saline-filled monitoring catheter or transvenous pacemaker wires. A current required to produce ventricular fibrillation in microshock is extremely small, in the order of 60 microA. Currents of 1-2 mA produce tingling of the skin and is barely perceptible. Hence a lethal macroshock current may be transmitted to a patient via a staff member who may be unaware of the conducted current. Such a small current is potentially lethal because a high current density is produced at the heart.

Tension and Lightning Injuries

High tension electricity is a supply greater than domestic supply. The voltage is usually many thousand volts. Tissue damage is mainly due to generation of heat. The heat generated, according to Joule's Law, is proportional to the amperage squared times the resistance ($A^2 \times \Omega$). Thus, tissues traversed by the current, but which are poor conductors, will suffer the greatest degree of thermal insult. Witnesses have described tissues actually exploding.

Lightning carries 12.000-200.000 A and voltage in the millions. Exposure to lightning is essentially the same as exposure to any other high tension electricity. Entry skin burns are described as having spidery, arborescent, and pine tree patterns. Asystole is more likely to be prodcued from myocardial injury than ventricular fibrillation. However, good recovery has been reported despite presenting signs of hopeless neurological function (eg, fixed dilated pupils).

Management of Electrical Injuries

1. *First aid and resuscitation* - It is imperative to make the immediate environment safe for rescuers. Power sources should be switched off and wet areas should be avoided wherever possible. Instinctive attempts to grab the electrocuted victim must be avoided until it is safe to do so. Cardiopulmonary resuscitation is carried out when indicated.

2. *Investigations* - are indicated to detect organs damaged and the degree of damage, and include serial ECG, echocardiography, biochemistry, X-ray, and CT examinations. Arteriograms may be indicated.

3. *Hospital and ICU management* - are directed towards treatment of burns, ischaemic and necrotic tissues, and injured organs. The principle of management of the electrical burn is early complete excision. Fasciotomies and amputations may be necessary. The outcome in approximately 50% of high tension injuries is amputation of affected limbs. Tetanus toxoid and antibiotics, especially penicillin are given if indicated.

Electrical Hazards in ICU

The ICU has the potential to inflict both macroshock and microshock injuries to staff and patients. Potential sources of these electrical hazards are:

1. Major Electrical Faults

If the earthwire is disconnected from a piece of electrical equipment, the active wire shorting of the casing will produce mains voltage at the casing. Mains current can then flow through any person who comes in contact with the faulty equipment. Obviously, any handling of exposed "live" electric wires also exposed the person concerned to mains voltage. As mentioned above, the outcome of the resulting electric shock will depend largely on whether the skin in contact is dry, and whether the body offers a low resistance path to earth.

2. Microshock Currents

(a) *Earth leakage*

There exists capacitance between the power supply of equipment and the casing. The capacitance allows a current to flow to earth. This earth leakage current can be very important if the earth wire is not of low enough impedance. Such a leakage current may still occur even with the apparatus' electrical mains supply switched off. In the microshock situation, an earth leakage current of 100 microA can be fatal. As mentioned above, a staff member may unknowingly provide the completion of a circuit from the equipment to the patient.

(b) *Different earth potentials*

When different pieces of equipment are earthed in different receptacles, there may be a significant potential difference between the earth terminals. A current may then pass from one earth terminal to another. The path to earth is still present with the instrument switched off. Again, as a current of only 60 microA may be fatal, the risk of microshock is very real.

Protection Against Electrical Hazards in ICU

All ICUs should take every necessary precautionary measures against macroshock and microshock injuries to both patients and staff. Some such measures are:

1. Electrical Systems

(a) *Core balance relay*

This monitors the current in the active and neutral wires. A short circuit will create a difference between the two wires, and activate a circuit breaker. The sensitivity of this system is not totally adequate for microshock protection, as the activating current is in mA rather than microA. However, this device can be designed to trigger after only 10 milliseconds, which limits the duration of a potentially lethal current, thus providing protection against macroshock.

(b) *Earthing*

All electrical equipment should be earthed at the same potential. A very low resistance wire should be used to achieve this. External equi-potential earth points can be used to earth equipment.

(c) *Mains isolated equipment*

Battery operated equipment, or equipment with a transformer in the patient circuit separate from the mains circuit, offer increased safety.

(d) *Isolation transformers*

The use of a 1:1 transformer to convert the supply of the ICU (or a bank of outlets) into a floating supply, with the incorporation of an earth-linkage alarm system, offers the safest protection.

2. Equipment Checks

The purchase of new equipment should be strictly controlled by a qualified person, and circuit diagrams should be provided with all new equipment. All pieces of apparatus should be checked for both function and current leaks prior to being used in the ICU. There should be regular checks on all equipment as machines which may have complied with safety regulations can deteriorate with age. Dated stickers should be applied on all equipment, and no piece of electrical apparatus without a current sticker should be used.

3. Personnel

Staff must take care when using any electrical or electronic equipment. Cords with frayed wires should never be used. Plugs should not be disconnected by pulling on the cords. All plugs should be clear plastic so that wire connections can be viewed. Extension cords should be avoided. Trolleys should not be wheeled over electrical cords. All staff involved in using equipment should be aware of the principle of microshock. Two pieces of equipment should not be handled at the same time, nor should equipment be adjusted while in touch with the patient or the bed.

All hospitals should have an electrical safety committee which meets regularly to make hospital pollicies. There should be a qualified electrical safety officer who should regularly check all equipment, including leakage current when the apparatus is switched off. The requirements for equipment in the ICU should be strictly enforced. Australian Standards (AS 3003 and ASS 3200) set minimum requirements for Australian hospitals. AS 2500 has much useful information regarding the safe use of electricity in patient areas. Other countries have their own standards and safety regulations.