

winding causing the relay to break the circuit. A difference of as little as 30 mA can trip the COELCB in a very short period of time (milliseconds). This greatly reduces the possibility of a serious electrical shock.

## Surgical diathermy

Surgical diathermy equipment uses the heating effects of high frequency (kHz–MHz) electrical current to coagulate and cut tissues. There are two basic types – monopolar and bipolar.

### Monopolar diathermy

Monopolar diathermy generates electrical energy at 200 kHz to 6 MHz. The energy is applied between two electrodes (neutral and active). The neutral electrode has a large conductive surface area producing a low current density with no measurable heating effect. The active electrode has a very small contact area resulting in a very high current density. The heating effect beneath the active electrode is considerable producing deliberate tissue damage. Cutting diathermy employs a sine waveform whilst coagulation uses a modulated waveform.

### Bipolar diathermy

Bipolar diathermy operates with a much lower power output. The output is applied between the points of a pair of specially designed forceps producing high local current density. No current passes throughout the rest of the body.

### Accidents with diathermy

Accidents may result from electrical burns, fires and explosions or by their effect on pacemakers.

#### Burns

Electrical burns may be due to inadvertent depression of the foot switch. Keeping the forceps in a protective quiver and the

installation of a buzzer which is activated when the switch is depressed may prevent this. Burns may also result from poor contact between the neutral plate and the patient resulting in increased current density. Some diathermy machines produce an audible warning if the plate is not plugged in or the lead is broken. If the electrical circuit is completed via the operating table, or other points through which the patient may be earthed, a burn may result at this site.

#### Fires and explosions

Fires and explosions may be caused by sparks igniting flammable materials, *e.g.* skin cleaning solutions, bowel gas.

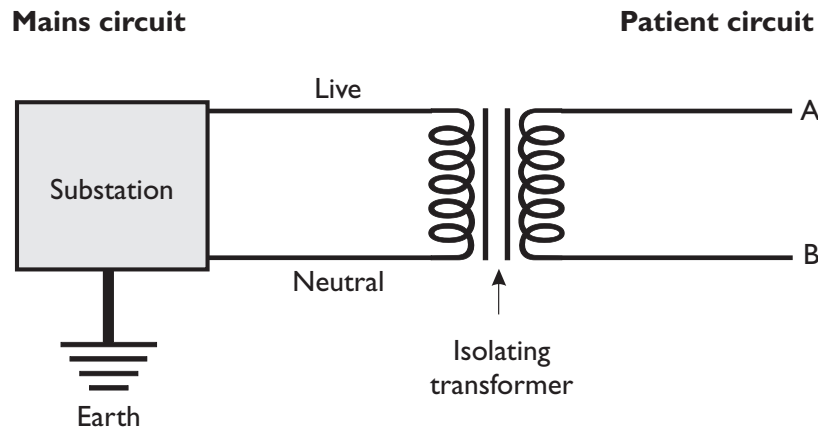
#### Pacemakers

Unipolar diathermy can inhibit or permanently damage pacemakers. If diathermy is essential, the bipolar variety should be used. However, bipolar diathermy should be applied well away from the pacemaker and its wiring.

## Key references

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See multiple choice questions 10–13.



**Fig. 2** Isolated patient circuit.

### Type designation

We have seen that the class to which a piece of equipment belongs describes the method by which it protects against electrocution. The degree of protection for medical electrical equipment is defined by the type designation and is based on the maximum permissible leakage currents:

#### Type B

The equipment may be of Class I, II or III but the maximum leakage current must not exceed  $100 \mu\text{A}$ . It is therefore not suitable for direct connection to the heart.

#### Type BF

As for type B, but uses an isolated (or floating) circuit (see below).

#### Type CF

These provide the highest degree of protection, using isolated circuits and having a maximum leakage current of  $< 10 \mu\text{A}$ . They are suitable for direct cardiac connection, *e.g.* ECG leads, pressure transducers and thermidulation computers.

### Equipotentiality

Different pieces of equipment may be at different potentials relative to earth. If they are in close proximity, a connection may be made between them by the user. A current may then flow from the higher to lower potential via the user. To avoid this, the terminals of each piece of equipment in a stack can be connected to each other bringing them all to the same potential.

### Isolated (floating) circuits

Isolated or floating circuits (Fig. 2) provide a circuit whereby a connection between the electrical source and earth does not allow current to flow. They are created by the use of an isolating transformer which consists of 2 coils electrically insulated from each other. When alternating current flows through the mains or primary coil, it produces a changing electromagnetic field around it. This induces a current in the patient or secondary coil. The mains circuit is earthed but, importantly, the patient circuit is not earthed (hence floating). Therefore, to form part of this circuit one must connect wires A and B (Fig. 2). Even if you are earthed, contact with wire A or B alone does not complete a circuit and so current cannot flow.

These floating circuits can be used to isolate an entire operating theatre. However, if a fault occurs in one piece of equipment, power may be lost to the entire theatre. In the UK, a floating circuit is generally used to isolate individual instruments.

### Circuit breakers

Current-operated earth leakage circuit breakers (COELCB), also known as an earth trip or residual current circuit breakers, consist of a live and neutral wire with the same number of windings around the core of a transformer. A third winding connects these to the coil of a relay that operates the circuit breaker.

If the current in the live and neutral conductors is the same, the magnetic fluxes cancel themselves out. However, if they are different (due to excessive current leakage) there is a resultant magnetic field. This induces a current in the third

## How can we prevent electrocution?

Methods of reducing the risk of risk electrocution can be broadly classified as: (i) general measures; (ii) equipment design; (iii) equipotentiality; (iv) isolated circuits; and (v) circuit breakers.

### General measures

Several simple measures can reduce the risk or effect of electrocution. These include adequate maintenance and regular testing of electrical equipment, ensuring the patient is not in contact with earthed objects and the wearing of antistatic shoes, whose high impedance will reduce any current flowing through the body.

### Equipment design

In the UK, all medical equipment used in the patient environment should meet the requirements of the *British Standard 5724: Safety of Medical Equipment*. This was revised in 1989, making it identical to the corresponding international standard (International Electro-technical Committee standard in IEC 601). British Standard Symbols used on medical equipment are shown in Figure 1.

These protective methods can be best considered by describing the classification of equipment according to their means of protection.

#### Class I

Any conducting part of Class I equipment accessible to the user, such as the metal casing, is connected to earth by an earth wire. This wire becomes the third pin of the plug connecting the equipment to the mains socket.

If a fault occurs which allows the live supply to come into contact with an accessible part, current flows down the earth wire. This new circuit has a lower resistance, resulting in an increased current which melts the protective fuses and breaks the circuit, removing the source of potential electrocution. In addition to the fuse in the mains socket, Class I equipment should have fuses at the equipment end of the mains supply lead, in both the live and neutral conductors so that this protection is operative even if the equipment is connected to an incorrectly wired socket outlet.

#### Class II

Any accessible conducting parts of Class II equipment are protected from the live supply by either double or re-inforced insulation. This should prevent any possibility of an accessible part becoming live and so an earth wire is not required.

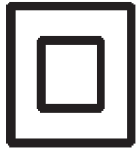















 Class II Equipment	 Type B Equipment	 Type BF Equipment	 Type CF Equipment
 Defibrillator Safe Type B Equipment	 Defib. Safe Type BF Equipment	 Defib. Safe Type CF Equipment	 Equipotentiality
 Alternating Current	 Direct Current	 Dangerous Voltage	 Earth
 Non-ionizing Radiation	 Attention-Consult Accompanying Documents	 Off / On (Mains)	 Off / On (for part of equipment)

Fig. 1 British Standard Symbols used on medical equipment.

#### Class III

Class III equipment provides protection against electric shock by using voltages no higher than safety extra low voltage (SELV). SELV is defined as a voltage not > 25 V AC or 60 V DC. In practice, such equipment is either battery operated or supplied by a SELV transformer.

It is unlikely that these voltages will cause electrocution. However, the danger of microshock persists and the latest standards relating to medical electrical equipment do not recognise Class III, since limitation of voltage alone is not sufficient to ensure the safety of patients.

into the myocardium (or in very close proximity to it), for any given current, the current density will be much greater. In these circumstances, a substantially smaller current (50  $\mu$ A at 50 Hz) can cause ventricular fibrillation. This is known as microshock. Examples of equipment that may allow microshock include central venous catheters, intracardiac pacemakers with an external lead and, to a lesser extent, a temperature probe placed in the oesophagus immediately behind the left atrium.

#### *Type of current*

Direct and alternating currents have different effects on the body; alternating current at 50 Hz is the most dangerous. The myocardium is most susceptible to the arrhythmogenic effects of electric currents at this frequency and muscle spasm prevents the victim letting go of the source.

As the frequency increases to > 1 kHz, the susceptibility decreases dramatically. At higher frequencies (MHz range), use can be made of its heating properties (diathermy).

#### *Current duration*

Finally, damage caused by electrocution is dependent upon the duration of time for which the current flows. The shorter the duration, the higher the current required before damage is done.

#### **Burns**

When an electric current passes through any substance having electrical resistance, heat is produced. Whether or not this produces a burn depends on the current density. Skin (especially when dry) has a high electrical resistance compared with the moist tissues beneath. Thus, electrical burns are generally most marked on or near the skin.

#### **Fires and explosions**

Sparks caused by switches or plugs being removed from wall sockets can ignite inflammable vapours. This is prevented by the use of spark proof switches and electric socket outlets which prevent the plug from being withdrawn whilst the switch is turned on.

### **How might electricity flow through the body?**

There are two ways by which the body can form part of an electrical circuit – resistive or capacitive coupling. When the body provides a direct physical connection, this is said to have been made by resistive coupling.

#### **Resistive coupling**

The body can act as a connection if it comes into contact with the source of electricity and the earth directly or by touching an earthed object such as drip stand. There are two potential sources of this electricity – faulty equipment and leakage currents. Faulty equipment may allow contact with a live wire if it touches the equipment casing. Leakage currents arise because electrical equipment is at a higher potential than earth. Given an adequate connection, some current will flow to earth, even if the equipment is well insulated, since there is no such thing as perfect insulation or infinite resistance. Although these currents are normally small, they can be fatal (microshock). Modern equipment is designed to limit this hazard.

#### **Capacitive coupling**

The body can also form a connection between an electrical source and earth by acting as one plate of a capacitor (capacitive coupling). In their simplest form, capacitors consist of two conducting plates separated by an insulating material (dielectric). They allow the storage of electrical charge. The amount of charge a capacitor can store is described in terms of its capacitance, which is measured in the unit farad.

If direct current is applied to a capacitor, current flows for only the very brief period until the positive plate is charged to the same potential as the electrical source. Thereafter, the current ceases. If alternating current is applied across a capacitor, its plates change polarity at the same rate as the alternating current. The capacitor will then continually charge and discharge and the electrons rush back and forth from plate to plate causing a current to flow in the circuit. This is the reason why the term impedance should be substituted for resistance when discussing alternating currents. The impedance of a capacitor can be expressed by the equation:

$$\text{Impedance} = \frac{\text{Distance between plates}}{[\text{Current frequency} \times \text{Plate area}]}$$

Thus, the connection becomes increasingly likely as the frequency of the electrical source and area of the plates increase and the distance between them decreases.

An example of capacitive coupling in the clinical setting occurs in the MRI scanner. The scanner creates a changing electromagnetic field that can induce currents in conductors such as the wires or metal of a standard pulse oximeter probe. Although the patient may not be in direct contact with these conductors, capacitive coupling allows the patient to become part of an electrical circuit which may cause a burn.

# Electrical safety in the operating theatre

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## Key points

Electricity can damage the body by electrocution, burns or ignition of a flammable material.

Damage is dependent upon the density, type and duration of current.

Current as small as 50  $\mu$ A can cause ventricular fibrillation (microshock).

Patients must never be in contact with earth.

Isolated circuits prevent an earth connection completing an electrical circuit.

The operating theatre is unusual as there are numerous examples of the deliberate application of electrical equipment to the human body. This article will review the potential dangers associated with this, how they occur and how they can be prevented.

## Electrical supply

In the UK, mains electricity is supplied as an alternating current, which oscillates at a frequency of 50 Hz. It travels from the substation to its destination in two conductors – the live and the neutral wire. The live wire is at a potential of 240 V, whilst the neutral wire is connected to the earth at the substation and is thus kept at approximately the same potential as earth. These are analogous to the positive and negative wires used with direct current.

If a connection is made between the live wire and earth, electricity will flow through that connection to earth. The problems arise when this connection is a patient or member of staff.

## How does electricity damage the body?

Electricity can cause morbidity or mortality by one of three processes: (i) electrocution; (ii) burns; and (iii) ignition of a flammable material, causing a fire or explosion.

### Electrocution

The effects produced by electrocution are dependent upon 4 factors: (i) the amount of electricity that flows (current); (ii) where the current flows (current pathway) and its density; (iii) the type of current (direct or alternating); and (iv) current duration.

### Current

The word 'current' comes from the Latin *currere*, meaning to run or flow. In electrical terms,

it means the flow of electrons. It is measured in the SI unit ampere (A); 1 A represents a flow of  $6.24 \times 10^{18}$  electrons (1 coulomb of charge) past a specific point in 1 sec.

The size of any current is determined by two factors (Ohms law):

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

Thus, the current will be greatest if the voltage is high or the resistance is low. Strictly speaking, Ohms law applies to the voltage and direct current across a resistor. Alternating current not only flows through resistors but also across capacitors. To take account of this, the term impedance is substituted for resistance.

### Current pathway and density

The pathway that current takes through the body will determine which tissues are damaged. For example, current passing through the chest may cause ventricular fibrillation or asphyxia due to tetany of the respiratory muscles, whilst a current passing vertically through the body may cause loss of consciousness and spinal cord damage.

The effect of the size of current and current pathway can be considered together as current density. This is the amount of current flowing per unit area. For example, a 50 Hz alternating current flowing between each hand would have the following effects:

- 1 mA Tingling sensation
- 15 mA Muscle tetany, pain and asphyxia
- 75 mA Ventricular fibrillation

In this example, the current has passed through the whole of the trunk with only a small part of it passing through the heart, *i.e.* the myocardial current density is relatively low. However, if the current flows directly

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