Electrosurgery

David J Hay

Surgical diathermy (electrosurgery) uses a high-frequency electric current to cut or coagulate tissue. The equipment is safe and most injuries are due to poor technique.

Electricity

To understand electrosurgery, one must grasp the concept of electricity (the flow of electrons through a substance from atom to atom driven by a difference in voltage). Higher voltages drive the flow of more electrons. This flow is called current, measured in amperes (amps). The power generated (to do work or create heat) is measured in watts. This is the product of voltage and current and it is expressed:

\[ \text{volts} \times \text{amps} = \text{watts} \]

The flow of electricity may be likened to the flow of water (Figure 1). The power of a water wheel increases by the height of the reservoir above the wheel (voltage) and by the amount of water that can flow to the wheel (current). A high voltage and a small current can generate the same power as a low voltage and a large current. However, high voltages can challenge insulation and can arc to surrounding structures.

**Direct and alternating current:** direct currents in battery-powered appliances flow in one direction only. The alternating current of the UK domestic mains supply changes its direction of flow 50 times per second. This rate of change is called frequency and it is expressed as cycles per second or Hertz (Hz).

Very-high frequency radio waves alternate many thousands of times per second (kHz). Ultra-high frequency transmissions for telecommunications are higher and microwaves are measured in millions of cycles per second (mHz, Figure 2).

Electricity produces heat when it passes through a substance. The amount of heat generated is proportional to the power. In addition to this heating effect, living tissues are affected in other ways, the most important of which is depolarization of the cell membrane because it arrests cell function. This can lead to neuromuscular stimulation, abnormal conduction, myocardial fibrillation and death.

An alternating current > 10 kHz can pass through the body without causing neuromuscular stimulation or depolarization; this is the basis of electrosurgery. It allows the use of high-frequency alternating current (about 500 kHz) to achieve the heating effect at the electrode tip for cutting or coagulation without electrocuting the patient.

**Insulation:** high-frequency alternating current is impossible to insulate completely. All insulation on instruments and cables is relative and some energy always radiates through it. Ultra-high frequencies in the megahertz range are not used in electrosurgery because the leakage or radiation effect is too great.

**Capacitance** – energy passes through the insulation of electrosurgical instruments and cables to adjacent structures by several mechanisms, the most important of which is capacitance (Figure 3).

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**Voltage, current and power**

\[ \text{volts} \times \text{amps} = \text{watts} \]

**Radiofrequency spectrum**

- Long wave
- VHF
- UHF
- Microwaves

- 50 Hz
- 10 kHz
- 500 kHz
- 10 mHz

- Mains supply
- Electrosurgery
- Threshold of depolarization

VHF: Very-high frequency; UHF: Ultra-high frequency.
A capacitor is any two adjacent conductors separated by an insulator (e.g. the side of a metal instrument in contact with body tissues separated only by the insulation). Direct current cannot pass across this insulation, but high-frequency alternating current passes freely. If the tip of the electrosurgical instrument or electrode is in contact with the target tissue, most of the energy passes to the tissue rather than through the insulation.

However, if the electrode is energized when the tip is not in contact with the tissue (non-contact activation), the only path for the energy is through the insulation and into the surrounding tissues. High voltages and prolonged electrical transfer through the insulation can cause it to melt. The full force will arc through the melted insulation to damage adjacent structures, with potentially grave consequences. Whilst the insulation was intact before the instrument was energized, it was not intact afterwards. Glove burn occurs in the same way.

An electrosurgery cable should never be wrapped around a metal towel clip because the current can pass via the clip to the patient. In all these circumstances, the higher the voltage, the greater the danger.

**Tissue effects**

The tissue effect of an electrosurgical current depends upon the size and shape of the electrode and the output mode of the generator. The amount of current that flows through the tissues per unit area (current density) significantly alters the effect on tissue. A needle electrode has a very high current density that causes tissue vaporization and therefore a cutting effect (Figure 4a). A ball electrode has a high current density, but it is spread over a larger area, causing coagulation and desiccation (Figure 4b).

In monopolar electrosurgery, the same current that passes through the active electrode passes through the return or inactive electrode (the patient plate). The area of the patient plate is many thousands of times greater than the area of the active electrode, so the current density is very low (Figure 4c). Nonetheless, a minimal heating effect takes place. If the patient plate is poorly applied (e.g. crumpled or partly separated from the patient) or it is wet, the current density in parts may be high, leading to skin burns. To avoid damage, the patient plate should be applied over well-vascularized muscle close to the site of operation and it should avoid bony prominences, scar tissue and metal prostheses. The area should be shaved only if hirsute. The plate should be checked if the patient is moved during the procedure.

**Generator output modes (Figure 5)**

The output from the electrosurgical generator can be altered in two ways: the voltage can be altered (to drive more or less current through the tissues) or the waveform can be modified (influencing its effect on tissues).

In cut mode, the alternating current generated is a pure, uninterrupted waveform of a few hundred volts. This creates a tiny arc, which achieves a tissue-cutting effect when used with a needle electrode. If used with a blunt electrode, the current density is lower, enough to gently coagulate or desiccate tissue.

In coagulation mode, the generator output pulses on and off (modulation) many thousands of times per second, allowing the generated heat to dissipate into the tissues, reducing the cutting effect whilst enhancing the coagulation. Modulation reduces the current that flows; therefore the voltage has to be increased significantly to drive the current through the tissues. Coagulation mode employs much higher voltages than cut mode (order of several thousand volts). The highest voltage mode is fulguration or spray, which creates a rain of sparks that flash through the air to the tissue. The voltage may be as high as 4,000–5,000 volts. Under these circumstances, any insulation has only the most
minimal effect. Spray coagulation is regarded as inherently dangerous (particularly in laparoscopic surgery) and it should be used with great caution.

**Blend modes** are less modulated than coagulation modes, and operate at voltages between those of cutting and coagulation. They allow cutting with a degree of haemostasis.

**Types of electrosurgery**

**Argon plasma:** in conventional fulguration, a high voltage strikes an arc in the air between the hand-held electrode and the tissue. With argon plasma, a stream of inert argon gas is passed over the tip of the electrosurgical instrument, confining the electrical current to an ionized stream, allowing precise directional control whilst eliminating oxygen from the target area. This reduces smoke production, gives a clearer field of vision and prevents tissue carbonization. Argon plasma coagulation has particular application in:
- surgery on the liver and spleen
- control of bleeding in the gastrointestinal tract
- palliative ablation of malignant tumours.

**Monopolar (Figure 6):** in monopolar circuits, the current passes from the tip of the instrument (in the surgeon’s hand) to the tissue, to the return electrode and back to the generator. Depending on the positioning of the patient plate relative to the surgical operation, the current can have an effect on pacemakers and metal prostheses. There is also the danger of burning taking place away from the site of surgery.

**Bipolar (Figure 6):** the current passes to one jaw of the instrument held in the surgeon’s hand, through the tissue between the jaws, to the opposite jaw and back to the generator. The patient’s body does not make up part of the electrosurgical circuit. The amount of tissue held in the instrument is very small, so much lower voltages can be used and capacitance effects do not apply. Bipolar electrosurgery does not interfere with cardiac pacemakers. Unlike monopolar current, it can be used safely on tissue pedicles (e.g. in circumcision).

**Feedback-controlled bipolar** (e.g. Ligasure™, Gyrus™): the advantages and safety of bipolar systems have been recognized and the technology developed. The voltage passing between the two jaws of the instrument is lower than in conventional bipolar electrosurgery, but the jaws of the instrument (and therefore the area of coagulating tissue) is larger; therefore a greater current is used. The generator senses the resistance of the tissues in the jaws of the instrument and switches off the electrical flow when coagulation is optimal. These devices are much more effective than conventional bipolar electrosurgery and offer a significant advance, especially in laparoscopic surgery.

**Hazards of electrosurgery**

**Burns:** accidental burns may occur at the patient plate (as outlined above). Since 1980, electrosurgery generators monitor the patient plate or return electrode electronically. Some employ split plates to help detect partial separation. Despite these devices, current can be diverted away from the return electrode and cause accidental burning at other points on the body. These alternative pathways occur when the current finds a different route back to the generator. To circumvent this, the patient’s body should not touch any metal object (e.g. part of the operating table).

**Fire and explosion:** alcohol-based skin preparations should be avoided because they can pool under surgical towels and be ignited by sparks from the active electrode. Electrosurgery sparks can ignite flammable gases in body cavities with disastrous results.

**Surgical smoke:** toxic substances (e.g. carcinogens, viable viral material, particulate matter) have been discovered in electrosurgery smoke, and are a potential hazard. A smoke evacuation system should be used.

**Minimal access surgery:** the dangers of electrosurgery are increased by the confined, enclosed conditions that apply in a laparoscopic procedure. Vision is limited to the immediate operating area. There may be several instruments and much of their length may be outside the surgeon’s field of vision. **Direct coupling** (where the active electrode accidentally touches another instrument) and **capacitive coupling** (where the energy passes through the intact insulation to another instrument or to part of the body) are particular hazards. Insulation may fail due to physical damage or due to the inappropriate use of high voltages with non-contact activation. To be safe:
- consider a bipolar technique
- avoid high-voltage modes
- avoid non-contact activation
- use only enough power to achieve the desired effect
- check insulation (but remember that even intact insulation may fail with high voltages due to capacitance)
- do not reuse single-use electrodes
- In laparoscopy, keep the active electrode in full view.