Electrosurgery and energized dissection

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Abstract

This article outlines the biophysics of electrosurgery and tissue energy sources, including the basic concepts of both modalities. It explores the biophysics of electrodiathermy, including current density, waveforms and electrosurgical circuits. The principles of monopolar and bipolar diathermy are described with reference to the safety issues pertinent to implantable cardiac devices and other implants. Safe application of electrodiathermy in endoscopic and laparoscopic surgery are discussed, exploring potential risks such as direct and capacitance coupling. The principles behind tissue energizers, specifically advanced bipolar energy sources and ultrasonic devices, are also covered.

Keywords Argon plasma coagulation; biophysics; bipolar; coupling; electrodiathermy; endoscopy; ERCP; laparoscopy; monopolar; risks; tissue energizers

Introduction

Electrosurgery is based on the principle of energy transformation from high-frequency alternating current (AC) into heat, thereby permitting the cutting or coagulation of tissues at the point of application. A clear distinction should be made with electrocautery, which refers to the use of direct current to generate heat at the tip of an instrument.

The development of electrosurgery in the 1920s revolutionized the surgeon's ability to achieve haemostasis. The physicist William Bovie, in collaboration with the surgeon Harvey Cushing, was the first to pioneer the routine use of electrosurgery in clinical practice.[1] Electrosurgical units (ESUs) now form the mainstay of the modern-day surgeon's armamentarium. This article aims to cover the basic principles, applications and potential hazards of electrosurgery, as well as provide an insight into the newer energized dissection technologies.

Biophysics

An understanding of the physics underpinning electrosurgery is fundamental to its safe and effective application by the surgeon.

The flow of electrons through tissue between adjacent atoms is defined as electrical current. This process is driven by the difference in electrical potential, or voltage, between the atoms. The electrical energy from the voltage source is converted into heat energy as the tissue acts as a resistor within the circuit. The power generated by this heat energy per unit of time is the product of the current and voltage, expressed as:

$$P(\text{power in Watts or Joules/second}) = I(\text{current in amperes}) \times V(\text{voltage in volts})$$

Ohm's law describes the relationship of current flowing within the circuit as:

$$I = V/R(\text{resistance in Ohms})$$

Therefore, power can also be expressed as:

$$P = V^2/R \text{ or } I^2 \times R$$

Based on these equations, the power generated by an ESU is proportional to the square of the current and voltage.

Current density

The key to achieving the desired clinical effect at the active electrode is based upon the principle of current density (current applied per unit of area). The surface area of the active electrode is small, thus producing a concentrated heating effect at the point of contact on the patient's tissues. Following the same rule, the surface area of the patient return electrode in monopolar circuits is much larger than that of the active electrode. This facilitates dissipation of the current returning to the ESU, minimizing heat production at the return electrode site. The rise in temperature is also governed by the length of time the active electrode is in contact with the tissues, as well as the resistance of the tissues. This forms the basis of Joule's law, which is essentially a derivation of Ohm's law:

$$Q(\text{heat energy in Joules}) = (I/\text{cross} - \text{sectional area})^2 \times R \times T(\text{time})$$

Current waveforms

The alternating current produced by ESUs constantly change the direction in which current flows. The rapid movement of electrons through the cytoplasm of cells causes the temperature to rise. The speed at which this movement of electrons occurs per unit of time is termed the frequency, measured in Hertz (Hz). ESUs operate in the frequency range of 200 kHz to 3.3 MHz (Figure 1). The use of such a high frequency range is crucial in preventing the unwanted neuromuscular stimulation that would otherwise occur at lower frequencies within the body, typically <100 kHz.

The current waveform can be modulated to produce the desired effect on the tissues. A pure cutting waveform is continuous, sinusoidal and unmodulated (Figure 2). Ideally the active electrode is held slightly away from the tissue to create a tiny arc that achieves a cutting effect by vaporization of the tissue over a short time period. The use of the cutting current in direct

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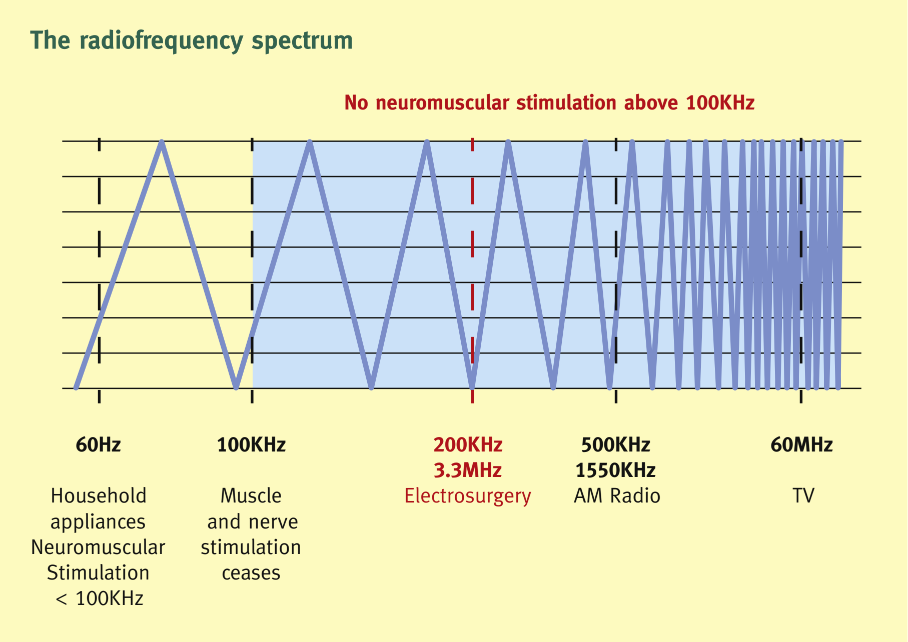

Figure 1

contact with the tissue is referred to as desiccation. Direct contact reduces the current density, causing cells to dry out and form a coagulum rather than vaporize.

At the opposite end of the spectrum, pure coagulation waveforms are modulated (intermittent ESU output) reducing the proportion of time that tissue is exposed to current to approximately 6% (Figure 2). This allows for more thermal spread within the tissues, which reduces the cutting effect but enhances the ability of the tissues to form a coagulum. It is important to remember that coagulation modes require much higher voltages than cut modes to deliver the same amount of power as the flow of current is interrupted. Fulguration, or spray, refers to electrical arcing in the coagulation mode with the aim of coagulating or charring tissue over a wide area. Extreme care must be taken when fulgurating tissue, as this mode requires the highest voltage setting in order to overcome the resistance generated by

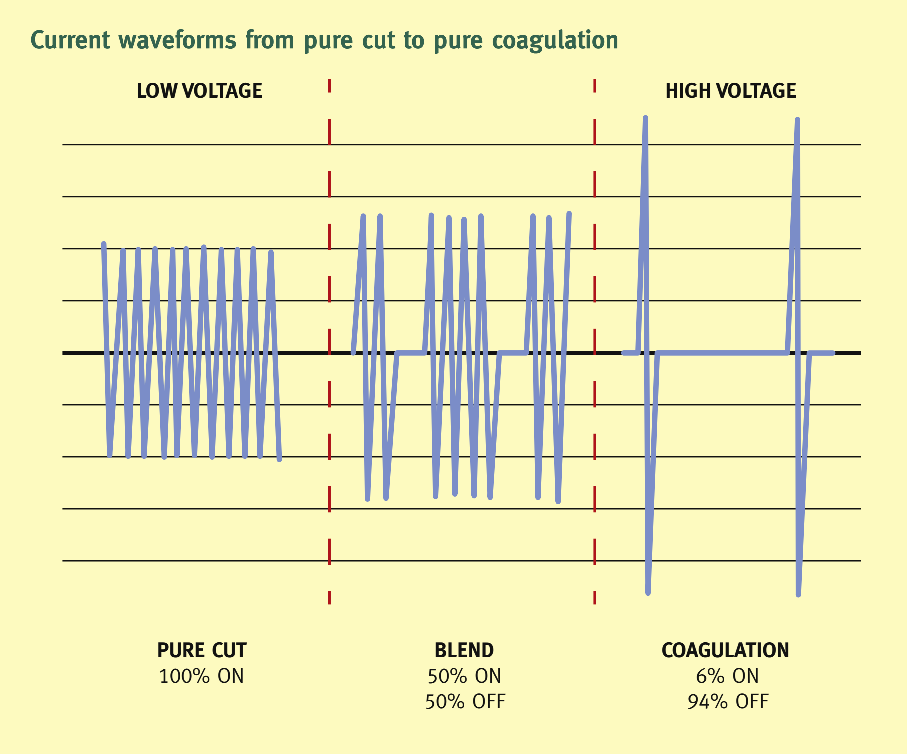

Figure 2