Editorial

Contemporary Electrosurgery: Physics for Physicians

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Electrosurgery as we know it was first introduced in the late 1920s by William Bovie and Harvey Cushing. They invented the first electrosurgical generator (ESG), which produced high-frequency electrical energy (current) for cutting and coagulating biological tissue. ESGs produce high-frequency alternating current (greater than 300,000 cycles per second, or Hertz [Hz]). Lower frequencies, particularly those less than 100,000 Hz, stimulate muscles and nerves; very low frequencies electrocute. Most ESGs today operate at frequencies between 300,000 and 3,800.00 Hz (3.8 MHz). These frequencies lie within the radio frequency portion of the electromagnetic spectrum. Because of this, electrosurgery has on occasion been referred to as *radio frequency surgery.*

Understanding Electricity

Two fundamental principles that apply to electricity are of major importance in surgery: (1) electricity always flows to ground, and (2) electricity follows the path of least resistance. For safe electrosurgery, these two axioms and the following four concepts need to be understood.

Current

Current is basically charged electrons moving in a stream. The path they take is called a "circuit." The strength of a current is the amount of charges per unit of time passing a point. Average current is the average amount of charge passing a given point in a circuit per second. The unit of charge is the coulomb and time is in seconds. Current is expressed in amperes (A), which are coulombs per second, or more appropriately for surgery, milliamperes (mA), one thousandth of an ampere.

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Volt

The volt is a measure of pressure or electromagnetic force for pushing the electrons along in the stream. To produce sparking to tissue from a metal electrode, which is how electrosurgery is intended to work, a minimum of approximately 200 peak volts (V_p) is necessary. Less than that will not cut tissue. The length and intensity of sparks generated increase in proportion to the volts. Greater voltage intensifies the thermal effect and enlarges its zone of injury around the cut. Ideal voltages for electrosurgery range from 200 to 500 V_p. Higher than 600 V_p results in tissue carbonization.

Resistance

Resistance is a measure of the electric conductability of a substance. Some materials slow down the current stream, causing it to lose energy and creating heat in the conductor. Resistance within tissue to the flow of electrons through the wire is what creates the envelope of steam that cuts tissue. Resistance is measured in ohms (Ω).

Power in Watts

A watt, the amount of energy produced or consumed over time, is reflected as heat output. In conventional electrosurgery, the practitioner generally cannot affect volts or current, and tissue resistance depends on the surgical site. All one can do is change the power settings on the generator, which are usually displayed on the unit's front panel digital display. Some manufacturers have hard-wired several power settings from which to choose. Others allow for the selection of specific watt levels. Still others automatically adjust the power to match the changing tissue resistance, keeping the volts constant during the cutting process. The actual watts delivered to tissue vary according to tissue resistance. As it desiccates, tissue resistance increases, which may result in fluctuations in actual current transmitted to tissue.

Mechanism of Cutting and Coagulating

Cutting occurs when sparks come in contact with tissue. The sparks are electromagnetic energy. Current flows through the tissue electrode and is resisted by the tissue. This creates a small envelope of steam around the electrode. The steam vaporizes the tissue. Moving the tissue electrode creates the cut. The best cut with the least thermal effect is made using a pure sine waveform of the electromagnetic energy. But as a corollary to this, it has the least hemostasis. To add some thermal effect to produce hemostasis, the pure sine wave can be modified. The resulting modulated wave has intermittent coagulation waveforms added to the cutting sine wave. The relative amount of coagulation vs cut is reflected in a measure called the "crest factor." The lower the crest factor, the less the thermal damage and the cleaner the cut, but also the less the hemostatic effect. Higher crest factors cut less cleanly with greater tissue damage but with more hemostasis. The crest factor is a ratio of peak voltage to average (called RMS) voltage.

Most ESGs have several waveform combinations to choose from. They sometimes consist of a pure sine wave for cutting and several blended waveforms (with different combinations of cut and coagulation that have different crest factors and, therefore, different hemostatic properties). Some do not have a pure sine wave at all. One manufacturer keeps the voltage constant in each mode setting so that its units have the lowest crest factor for all cutting modes. An increase in thermal effect, when needed, is achieved by increasing sparking to tissue.

Coagulation can be performed in two ways. One is called desiccation. It occurs when the ball electrode is touching the tissue. Few sparks fly from the electrode to the tissue (when voltage exceeds 200 V_p) and when they do, it is out to the side of the contact electrode. However, a large amount of heat is created along the tissue surface that is contacted. This results in coagulation but can produce deep tissue damage. More superficial coagulation is caused by fulguration, which uses sparking to the tissue to control bleeding. This occurs when the electrode is held just above the tissue surface. The powers needed to coagulate depend on the waveform and on the size of the ball electrode (or, more accurately, its surface area). The higher peak voltages are produced in the coagulation-modulated or damped waveforms. If voltage is insufficient to create sparking, an attempt to fulgurate may result in desiccation.

Types of Electrosurgical Systems

There are basically four types of generators: grounded, isolated, balanced, and return-electrode monitoring systems. They have important differences in safety, features, performance, and cost. Many of the available units are evaluated in the accompanying article by Dr Ferris and colleagues (page 160).

Grounded Systems

Grounded generators use ground (earth) to complete the circuit. These units can produce high voltages with excellent sparking to tissue. However, the current can divide in the patient's body, seek ground through any grounded object touching the patient (most objects in the operating room are grounded), and produce burns at sites away from the surgical site. Burns also can be caused beneath the dispersive plate since the adequacy of its contact is not measured. Loss of plate contact causes electricity to seek ground through any path available. In addition, if the grounded return electrode can attract other ground-reference voltage produced by other devices in the operating room, the patient can be electrocuted.

Isolated Systems

In isolated systems, the therapeutic current is isolated from the power current by a transformer and returns to the generator unit itself, not ground, to complete the circuit. Because there is no reference to ground, no current flows to ground. If the circuit is broken (because of loss of return electrode contact with the patient, for example), no current will flow. This kind of system in general eliminates current division and alternate site burns. Although their high voltages can leak current that will seek a grounded object and may cause a burn, they do not attract stray grounded voltage from other sources. These systems do not monitor the dispersive plate contact, so burns at the plate can occur.

Balanced Systems

These units have a self-monitoring device with isolated circuitry. The amount of energy coming out of the active tissue electrode must balance with (or equal) the amount picked up by the dispersive plate. A return fault monitor disables the generator immediately if there is any imbalance. These units create significant voltage producing superb sparking to tissue. They detect current division, but since the current density at the dispersive plate is not monitored, burns at the plate can result when there is reduction in surface contact.

Return Electrode-Monitored Systems

These generators have built-in circuitry that continuously monitors the contact between the patient's body and the return electrode dispersive plate. A switch in the generator becomes activated by a pin in the special dispersive plate connector cable plug. For the return-electrode monitoring mechanism to function, the generator must have its part of the circuit and the plate must have the rest. Although other kinds of dispersive plates may be used with these generators, the special monitoring will not work and burns at the plate may occur. This special monitoring detects a reduction in surface contact of the plate by constantly measuring its impedance. When impedance increases in the good-contact portion of the plate and exceeds a safe range, the system disables itself and sounds an alarm. These are the most complicated and consequently the most expensive systems, but they are also the safest ones.

Safety

All users of generators should read and understand the manufacturer's operating manual. Unfortunately, some of the manuals are poorly written and inadequately illustrated. All practitioners should have a basic understanding of electricity and the working mechanisms of the unit they are using. The tissue effects and surgical feel of power settings on one make and model may not necessarily be the same on another unit. The systems must be checked by biomedical engineers before being used in the clinical setting. To take advantage of features, appropriate electrodes should be used for that unit.

Clinical Applications

Contemporary applications for electrosurgery include endoscopic procedures such as laparoscopic cholecystectomy, gynecologic pelvic surgery, and hysteroscopic endometrial ablation. Electrosurgery has virtually eclipsed laser surgery in these applications. There are many other general surgical and dermatologic applications, but electrosurgery has had the most dramatic impact on treatment of cervical preinvasive cancer and human papillomavirus (HPV)-induced benign lesions of the cervix.

Cervical Intraepithelial Neoplasia and HPV

Originally developed in the United Kingdom and referred to as large loop excision of the transformation zone (LLETZ), electrosurgery of the cervix is more commonly referred to, especially in North America, as loop electrosurgical excision. One generator manufacturer trademarked the term "LEEP," which is not really a generic acronym but is widely used to represent the loop electrosurgical excision procedure. Excision of the abnormal epithelium on the cervix or in the endocervical canal using small wire loop electrodes is the main application for electrosurgery of the lower female genital tract. Needle electrodes are sometimes used for cylindrical excision of endocervix and ball electrodes to control bleeding.

One advantage of electrosurgery using wire loop electrodes to excise cervical lesions is having a specimen for histologic examination. Other forms of conservative, ambulatory treatment (like cryotherapy and laser vaporization) are destructive and require considerable expertise in colposcopy so as not to miss an invasive cancer. While it is desirable for everyone who evaluates and treats patients with abnormal cervical cytology to have colposcopic training, not everyone becomes an expert. Without a consistently large volume of patients to evaluate, one's skills decline. Having a specimen histologically evaluated is a reassuring fail-safe for many clinicians. Unless the wrong areas are sampled, any existing invasive cancer should be picked up.

Overzealous proponents of electrosurgery, from salespeople to practitioners who are paid "consultants" of manufacturers, have touted this as an easily mastered skill. Some have recommended that every patient with abnormal cervical cytology "be looped" in a "see and treat" strategy; but major problems have occurred with this approach. As many as 25% of patients who have had excisions actually are found to have no disease, meaning that they have been unnecessarily subjected to a surgical procedure. Another problem is that because of poor training, inadequate skills, or incorrect ESU settings, the specimens are uninterpretable. When this happens, it remains unknown whether the patient has invasive cancer, warts, cervical intraepithelial neoplasia, or nothing. Most thoughtful and experienced specialists in preinvasive cervical disease agree that traditional colposcopic triage should precede loop excision of the cervix.

A technical problem arises when generators that are intended for major surgical procedures in the hospital are used on the cervix. Some of these have very high open circuit voltages (well above 1000 V_p). Because higher voltage results in greater thermal damage, specimens are damaged so that histologic interpretation is impossible. Epithelium is stripped off, squamous epithelial cells are distorted, and excessive carbonization and coagulation necrosis make specimens uninterpretable.

A further problem is that this procedure is recommended as a cost-saving office procedure. However, the majority of patients being treated with loop excision are still being treated under general anesthesia in a hospital or surgery center. The advantage of office treatment is negated when patients require treatment in a hospital. They would be better served with cryotherapy in the office if their lesions fit the criteria for destructive therapy.

Finally, because current follows the path of least resistance, it can travel into the mucus, producing cervical glands (crypts lined with columnar epithelium) and causing so-called glandular distortion and an inability to distinguish between an adenocarcinoma in situ and an adenocarcinoma arising in the crypt. This can compromise management of the patient.

Conclusions

There are certainly many advantages to electrosurgery for cervical lesions when this technique is incorporated into a proper colposcopic triage protocol: good cure rates, convenient and cost-effective outpatient treatment, low initial capital cost of equipment with ease of use, and low morbidity. However, proper training and some skill are prerequisites, and continuing education and practice are necessities.

Recommended Reading

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