Chapter 15

Principles of Electrosurgery and Laser Energy Applied to Gynecologic Surgery

Ted L. Anderson

May S. Thomassee

DEFINITIONS

Active electrode—The electrode in monopolar circuits that carries the radiofrequency energy to the patient operative site.

Active electrode monitoring—A system with a sleeve placed around the active electrode to detect stray energy and to carry the induced energy to ground. Stray energy generally occurs from breaks in insulation or capacitive coupling.

Alternating current (AC)—Sinusoidal energy waveform (60 Hz) used in household electrical appliances and in electrosurgery.

Ammeter—Device that measures the amount of current flowing through a conductor at a specific moment.

Ampere—Quantity of electrons that move through a conductor over time (coulombs per second).

Bipolar—Closed circuit system where the active and passive electrodes are located within the energy device. This system does not use the patient as part of the circuit.

BLEND—Variation of electrical “on” and “off” time, where the current is interrupted at a variation of time, other than the standard CUT and COAG settings. (The current is “on” usually between 25% and 50% and varies with each BLEND setting.)

Capacitance—The buildup of electrical charge surrounding the active blade or even insulator of an electrosurgical device.

Capacitive coupling—Occurs when two conductors are separated by an insulator. Is always present, but not always dangerous. Becomes dangerous when the discharge of electrical energy occurs outside of the surgeon's field of view or when it is not recognized as conducting energy to nearby tissue through electromagnetic current.

Circuit—An electrical network that has a closed loop giving a delivery and return path for electrical current, accomplishing work by routing electrons.

COAG—Function on electrosurgical unit to describe interrupted, modulated, or damped current. The voltage of this waveform is always, higher than it is with CUT waveforms, given the same power output.

Coulomb—Measure of a quantity of electrons.

Current (power) density—Total amount of energy output per unit area of tissue. Affected by size of active electrode, shape, and power output (settings) of electrosurgical generator. Measured in watts (W). The smaller the spot of contact, the greater the density (current concentrated at the surface area of an electrode in contact with tissue during electrical flow) and the greater the heat effect for the same amount of time. Related to the square root of the area of contact.

Current (amperes)—Flow rate of a quantity (coulombs) of electrons.

CUT—Function on electrosurgical unit to describe uninterrupted, unmodulated, or undamped current in a continuous sinusoidal waveform. At the same power settings, the voltage of the waveform is always lower than it is with COAG or BLEND waveforms.

Desiccation—A form of coagulation achieved by “drying out” tissue through making contact with the active electrode. Either CUT or COAG waveforms may be used, but CUT waveform is preferable to reduce depth of penetration. Intracellular temperature stays below 100°C, which leads to cell shrinkage and dehydration.

Direct coupling—Occurs when two conductive materials in the same circuit touch during electrical activation or are close enough that arcing can occur. This can be intentional or unintentional. A break in the insulation of an active electrode that allows sparking to tissue is an example of unintended direct coupling.

Dwell time—Length of time an activated electrosurgical device is held at a specific tissue location.

Edge density—Affinity of electrons to concentrate at the edges of flat or irregularly shaped electrodes as they exit the electrode. This feature enhances the cutting ability of bladeshaped electrodes.

Electricity—Movement of electrons between two oppositely charged poles, positive and negative.

Electrocautery—Use of electricity to heat an object with subsequent direct transfer of energy by heat, such as a hot iron. Electrons do not move into the affected tissue; only heat is transferred.

Electrosurgery—Concentrated transfer kinetic energy (via electrons) from an active electrode to tissue creating a passive transfer of heat, using an electrosurgical generator.

Energy (joules)—Quantity of work produced over time. Energy (joules) equals work (watts) multiplied by time (seconds).

Faradic effect—Stimulation of tetanic muscle contractions, including cardiac muscle, when using electrical current with radiofrequency less than 100,000 cycles per second.

Fulguration—A form of coagulation achieved by arcing or spraying of “sparks” to tissue surface using high-voltage, damped, or interrupted (COAG) function with active electrode not touching tissue. Immediately causes charring and carbonization of the superficial tissue. Used to coagulate bleeding vessel or for treatment of endometriosis.

Heat (thermal energy)—Produced as electrons move from the low resistance of an electrosurgical probe to the high resistance of tissue. This energy may boil (vaporize) or denature (coagulate) tissue, depending on the extent and rapidity with which heat is generated.

Hertz (Hz)—Unit of measurement of electromagnetic sine wave. 1 Hz = 1 cycle per second.

Hybrid laparoscopic trocar sleeve—Conductive trocar sleeve used in laparoscopy that is covered by an outer nonconductive locking sleeve. Not used often anymore.

Impedance (ohms)—Resistance to flow of electrons through a conductor. Although resistance refers to direct current through a uniform wire, such as copper, it is generally substituted for impedance. Impedance is correctly applied with changes in voltage (alternating or fluctuating), frequency (modulating or demodulating), or tissue type (lipid membranes, soft tissue, fibrous tissue, fat, muscle, bone, or artificial appliances). It can measure the combination of tissue resistance and capacitance. Impedance in human tissue is generally 100 to 1,000 V; in the fallopian tube, it is 400 to 500 V.

Isolation ground circuitry—Safety feature that uses transformers not in contact with the parent generator so that the induced flow “floats” its own separate circuit. If a break in the floating circuit occurs, all energy within that circuit stops and does not seek ground.

Kilohertz (kHz)—Equal to 1,000 cycles of electromagnetic radio waves per second.

Kinetic energy—The energy that an object possesses due to its motion.

Monopolar—Type of electrode or electrical system in which the active electrode is small (high current density) and the passive electrode is large (low current density), and they are located remotely from each other. Most monopolar generators are calibrated against a 500-V load of resistance.

Open circuit (open "activation")—State when the electrosurgical instrument is activated prior to touching the tissue. A charge density can build up at the tip of the electrode and spark or stray to an unintended site if activated for a prolonged period of time remote from the site of intended effect. Open circuitry is used to start fulguration.

Return electrode (passive or dispersive electrode)—Large conductive pad (low current density) placed on the patient to complete an electrosurgical pathway and return electrosurgical energy to the generator.

Return electrode monitoring—A system of modern electrosurgical generators whereby the return electrode consists of a dual pad system with internal monitoring capabilities to sound an alarm on the generator if not placed properly.

Radiofrequency—High-frequency electrical current in the range of 3 kilohertz (kHz) to 300 gigahertz (GHz), or 3,000 to 3 billion cycles per second.

Sparking (arcing)—Transmission of electrical energy through gas (air, argon). Used in a noncontact technique with COAG interrupted waveform for tissue fulguration.

Vaporization—Raising the cellular temperature rapidly above 100°C, which causes cell wall rupture, releasing steam. CUT mode is preferred for this with a noncontact technique.

Voltage (volts)—Electromotive force (pressure) that drives current.

Watts (work)—Amount of work produced by electron flow (current). Work (watts) equals force (volts) multiplied by current rate (amperes).

Waveform—The pattern of sinusoidal oscillation of an alternating electrical current from positive to negative.

Waveform frequency—Number of oscillations of an alternating electrical current, usually between 350,000 and 4 million cycles per second in electrosurgery.

INTRODUCTION

The practice of medicine and surgery has increasingly relied on applications of energy since the late 1800s. Indeed, the majority of gynecologic surgical procedures performed today incorporate some form of applied energy. However, the underlying physical principles that govern the desired biologic effects remain marginally understood by most surgeons. The typical resident graduating from an obstetrics and gynecology program has received limited formal training concerning the principles and application of electrosurgery, as was often the case for his or her faculty mentors. Importantly, these limitations in a surgeon's knowledge of electrosurgical principles can permit delivery of unintended energy, resulting in immediate or delayed complications.

Over the past decade, electrosurgical instruments and generators have evolved into complex systems that can interact with biophysical properties of tissues to modulate, limit, and even discontinue energy delivery in response to measured parameters. In some cases, multiple energy modalities can be delivered by the same instrument. Thus, it is imperative that the contemporary gynecologic surgeon has a comfortable working knowledge of energy generation, delivery, and tissue effects in order to use these devices and systems effectively and safely.

Our goal in this chapter is to provide the basic fundamental principles of electrosurgery and laser technology. More specifically, we wish to provide a very practical approach that illustrates how these are applied within the field of gynecologic surgery to promote safe use of the available instruments.

HISTORY AND THE DEVELOPMENT OF ELECTROSURGERY

As early as the 4th century BC, the Egyptians described the treatment of wounds using a device called a "fire drill," which turned rapidly to produce heat along its shaft. In the early writings of the Hippocratic Corpus (approximately 400 BC), followers of Hippocrates described the treatment of various tumors, as well as hemorrhoids, through direct application of heat. During this period, the use of heat was frequently accomplished through specific heating of a metal device and placing it directly on the wound, essentially inflicting third-degree burns without the ability to modulate tissue effect. Accordingly, the word "cautery" arose from the Greek term *kauterion,* meaning "hot iron." Around 1600, the English physician and scientist William Gilbert introduced the term *electricus* meaning "like amber" as he discovered attraction of objects to each other after rubbing them against an amber rod. Once electricity was widely available, this concept was further expanded to "electrocautery." *Electrocautery* is the use of electricity to heat the metal tip of a device and subsequently apply direct heat to the tissue. Thus, up until this point, all applications of heat to medicine were in the form of cautery or electrocautery.

It was actually Benjamin Franklin's eighteenth century experiments with electricity that led to the idea that direct application of electrical current to tissue might be used to advantage in medicine. While John Wesley (England), Johann Kruger (Germany), and Jean-Antoine Nollet (France) experimented with paralytic conditions, Franklin and his Dutch colleague Jan Ingenhousz described a "highly elated state" after several unintended nonlethal shocks to the head and proposed this as therapy for melancholy.

Two significant discoveries paved the way for modern application of electricity in medicine. First was the recognition of electromagnetic induction by Michael Faraday and Robert Todd, leading to the ability to harness and store electrical energy reliably. This gave rise to a pathway for development of electrosurgical generators. The second was an extension of the work of Luigi Galvani, who demonstrated that electricity applied to frog legs induced muscle contraction, when William Morton and Arsenne D'Arsonval recognized application of electricity at a frequency of greater than 100 kHz allowed electricity to pass through the body without inducing pain or burn and without inducing muscle (including cardiac) spasm, the so-called faradic effect. D'Arsonval further noted that the current directly influenced body temperature, oxygen absorption, and carbon dioxide elimination, increasing each as the current passed through the body. Of note, the temperature was determined to increase proportionally to the square of the "current density."

The French surgeon Joseph Rivière in the early 1900s was perhaps the first to use electricity clinically, in the form of an electrical shock to treat a hand ulcer. However, in the 1920s, it was Grant Ward who demonstrated that a continuous sinusoidal electrical waveform was superior for cutting tissue, and an interrupted electrical sinusoidal waveform resulted in more effective coagulation. This led to the now infamous collaboration between Harvey Cushing and physicist William Bovie to produce an electrosurgical unit (ESU) (generator) designed to achieve intraoperative hemostasis during neurosurgical procedures. They published the results of a case series of intracranial tumor excisions in 1928, with an excerpt by Dr. Bovie describing the principles of superficial dehydration (desiccation), cutting, and coagulation as they applied to the tissue. These landmark events led to the era of modern applications of electricity in medicine.

BASIC PRINCIPLES OF ELECTROSURGERY

Electrocautery and electrosurgery are not synonymous. We distinguish between the two terms electrocautery and electrosurgery based on many differences as described in this chapter. *Electrocautery* refers to the application of electric current to an instrument of high resistance, resulting in heating, and then applying this hot instrument for direct transfer of heat to destroy tissue, without the ability to modify the depth of tissue penetration or tissue effect. For example, as described earlier, this would be like burning the skin with a hot iron. Conversely, *electrosurgery* is the employment of kinetic energy in the form of alternating current (AC) radiofrequency to transfer energy to tissue, raising intracellular temperature, which can be modulated to achieve desired tissue effects.

In order to achieve electrosurgery, there are three specific elements we must have. First, there must be a generator or ESU to accept electricity delivered from the electrical outlet on the wall of the operating room, modulate it to a higher frequency, and deliver it in the required conformation. Second, there must be an active electrode to deliver electricity to the tissue of interest in the form required. Third, there must be a return electrode to deliver the electricity away from the tissue to complete the electrical circuit.

The flow of electricity from an ESU through tissue follows the basic principles of physics. Particles of energy *(electrons)* are forced through tissue in a maximal direction from a positively charged pole to a negatively charged pole, in a sinusoidal waveform. The term circuit is used to describe the path the electrons take. In electric circuits, electricity is typically carried through conductors such as wire. However, electricity can also be carried through ion-containing substances like living tissue. Electron flow through cells creates changes in polarity of the cellular electrolytes (Na^+, Ca^{++}, K^+, Cl^-, etc.). Electromagnetic energy causes the anions to migrate toward the positive electrode and cations toward the negative, which is referred to as the galvanic effect. Importantly, the high-frequency flow of electrons in the radiofrequency spectrum surpasses that required for cellular membrane depolarization and does not affect the opening of sodium or calcium channels. Rather, the frictional forces of these charged intracellular ions create kinetic excitation and subsequent intracellular thermal heating as a result of thermodynamic changes.

The flow of electrons through a conductor is called *current,* which is governed by two opposing forces, namely *voltage* (the force pushing electrons along a circuit) and *resistance* (opposition to the free flow of electrons). This relationship is defined by Ohm law, which is depicted in **Figure 15.1**. You can see from this relationship that in order to increase electron flow (current), you must either increase the electromotive force (voltage) or decrease the impedance to free flow (resistance). It may help to think of this in terms of water flowing through a hose in your garden. If you kink the hose (increase resistance), your water flow (current) is going to decrease. The only way to accommodate for this is to increase the water pressure (voltage) proportionally.

$$\begin{array}{c}\text{Current (I)}\\ \text{(amps)}\end{array} = \frac{\text{Voltage (V) (volts)}}{\text{Resistance (R) (ohms)}}$$

FIGURE 15.1 Ohm law describes the flow of electrons through a circuit.

We can further explore the relationship between resistance and voltage by examining the concept of *power,* defined as the instantaneous energy required per unit time to perform a function, measured in watts. Specifically, power is defined by the electromotive force (voltage) times the flow of electrons (current), or $W = V \times I$. With mathematical substitution of Ohm law ($I = V/R$), we can derive that power (watts) is related to the voltage squared divided by resistance, or $W = V^2/R$. In practical terms, this means that as resistance increases, in order to maintain the power required to perform a function, the electromotive force (voltage) must increase exponentially. As we shall see, it is the voltage that we must harness and control to accomplish electrosurgical tasks effectively and safely. If we go back to our hose analogy, this means that if you increase resistance (kink the hose), in order to maintain the watts or instantaneous energy required per unit time to perform a function of work (to water the garden), the voltage (water pressure) must increase. Therein, we have the basic mathematical and physical basis for applied electrosurgery.

ELECTROSURGICAL GENERATORS

Generators of ESUs deliver AC the surgical field carried by an electrosurgical instrument (active electrode). More specifically, the ESU must take the electrical current supplied from the wall outlet and change it to direct current.

Then, through the use of oscillators, it must be modulated back to AC with higher frequency and the appropriate characteristics needed to produce the desired effects on tissues. The frequency delivered is between 500,000 and 5 million cycles per second and is sufficiently rapid to avoid stimulation of muscle contraction by surpassing the threshold for calcium and sodium channel depolarization. Because this frequency is in the range of AM radio waves, it is often referred to as radiofrequency (RF) current. Frequencies below 100,000 cycles per second are capable of causing tetanic muscle contraction, which is referred to as the *faradic effect.* On occasion, harmonic demodulation can occur, which produces small amounts of RF at less than 100,000 Hz presumably by alteration of current through interactions with the biophysical environment, which produces minor muscle twitches or nerve stimulation. Conversely, usual household appliances, such as hair dryers or blenders, use 60 cycles per second (or 60 Hertz, Hz) and are at much lower frequency than that of electrosurgical instrumentation (**Fig. 15.2**).

Most modern solid-state ESUs are capable of producing over 8,000 V, which is capable of pushing electrons up to 3 mm in room air under standard atmospheric conditions. However, more common outputs in typical use are in the 1,000 to 3,000 V range with a frequency upward of 350,000 Hz. Further, most generators today are calibrated to power output, with the power set reflecting the power available at the start of the electrosurgical application. As tissue impedance increases with heating in response to applied energy, we know from our prior calculations that power decreases. Additionally, many modern ESUs are best described as adaptive generators. Often designed to work in concert with specific instruments, they have the ability to adjust computer-controlled output in real time. They measure tissue impedance at the operative site and modulate output accordingly. Additionally, there are features for limiting maximum voltage, thereby reducing unintended effects of “stray energy.”

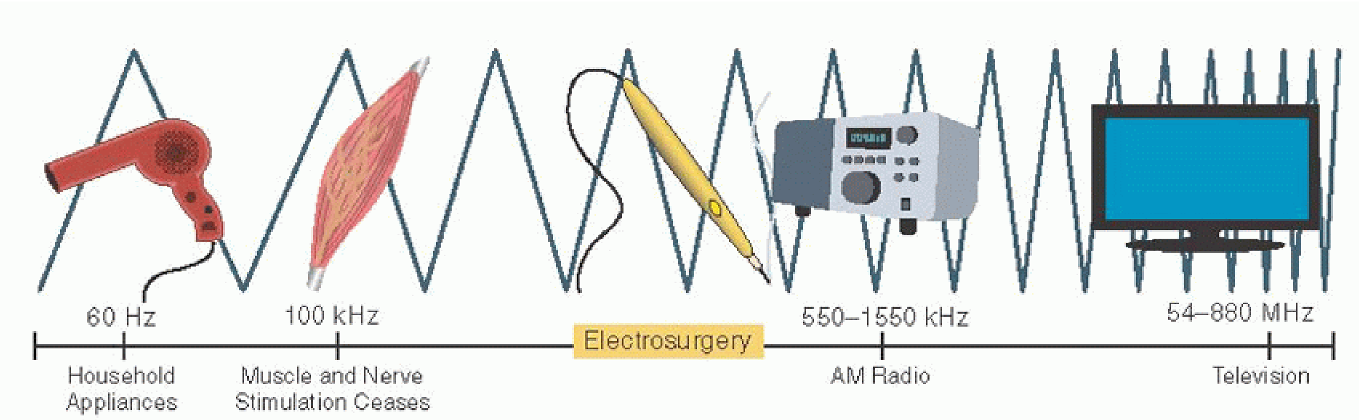

FIGURE 15.2 Radiofrequency spectrum. The frequency produced by electrosurgical generators overlaps with the range of AM radio waves and is thus referred to as “radiofrequency” (RF).

Three fundamental principles that have guided the evolution of the modern ESU are “electricity must complete a circuit or it will not flow,” “electricity goes to ground,” and “electricity follows the path of least resistance.” Older generator models were ground referenced, which means that a “grounding pad” was required to return the electrical current delivered to the patient (complete the electrical circuit). However, given the other principles just mentioned, currents often traveled through alternative grounding pathways, including EKG clips, creating unintended patient thermal injury. Isolated ESUs were introduced in the late 1960s, whereby current delivered by the ESU was returned to the ESU, not to ground, to complete the circuit. Further, the current delivered to the patient was generated in transformers insulated from the ESU frame. Thus, when the electrical circuit is interrupted, the electrons do not seek ground; no current flows. This introduced the concept of “return electrode” rather than “grounding pad,” although the two terms are often (incorrectly) used interchangeably. This advancement dramatically reduced thermal injury hazards associated with earlier grounded systems. However, if return electrodes were not properly or completely placed, or if they began to peel off intraoperatively, burns could occur at these sites due to electrical arching and increased charge density.

Return electrode monitoring was introduced in the 1980s. In this system, still used today, return electrodes consist of two side-by-side conductive pads. Built-in monitors measure integrity of pad contact with skin and balance of contact between the two pads through a low-impedance feedback with the ESU. If there is an imbalance, poor contact, or a breach in contact, an alarm sounds and generator output is automatically discontinued. It should be noted that for these return electrodes to function effectively, both pads should be equal distance from the operative field with the largest edge facing the site.

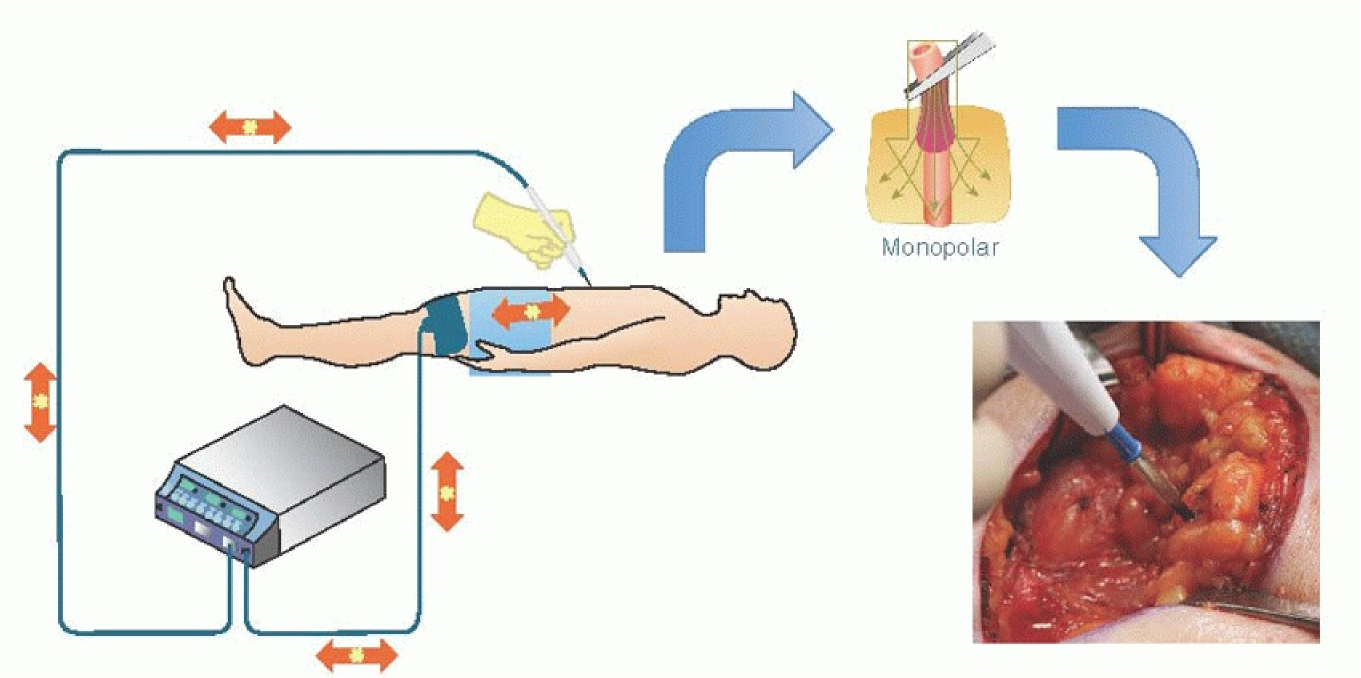

FIGURE 15.3 Monopolar electrical circuit. RF is delivered from the ESU through an active electrode to the patient, is dispersed through the patient, and is returned to the ESU via a remotely placed return electrode to complete the circuit.

MONOPOLAR AND BIPOLAR

All modern ESUs offer the ability to modulate electrical current output. The radiofrequency output can be delivered in *monopolar* or *bipolar* circuits (see Figs. 15.3 and 15.5 below). Further, radiofrequency can be delivered by providing a continuous or interrupted pattern RF energy. By convention, we typically refer to these two patterns as *CUT* and *COAG* (respectively) in homage to the description of tissue effects by Ward and Bovie in the 1920s.

Of course, *monopolar* current is a misnomer, as all electrical circuits must be bipolar. The more appropriate distinction would be the location of the active and return electrodes with respect to each other. With monopolar circuits, the active electrode (instrument delivering RF energy) and the return electrode (sometimes called dispersive or passive electrode) are located remotely from each other. Thus, the RF energy enters the body (conductor) through the active electrode and is dispersed through a myriad of pathways following the path of least resistance to the return electrode to complete the electrical circuit (**Fig. 15.3**). The concentration

of RF energy at the active electrode is responsible for local tissue effect (e.g., burn) at that site. Conversely, the dispersed nature of RF energy through the body and at the site of the return electrode explains why there is minimal, if any, recognizable effect. This concept is known as “current density.” You may notice this concept readily when comparing the tissue effect using a standard electrosurgical spatula electrode with the edge versus the wide face of the blade facing the tissue. This is further illustrated by the increased tissue effect when using a needle tip electrode without decreasing the ESU output (**Fig. 15.4**).

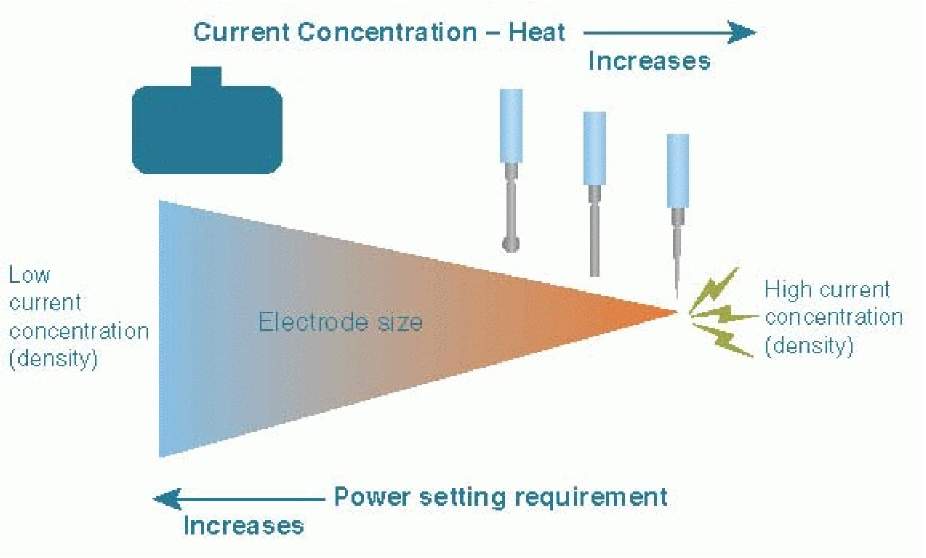

FIGURE 15.4 Current density. The higher concentration of RF energy at the active electrode is responsible for the tissue effect achieved at that site. Increasing the electrode size decreases charge density and lessens the local effect. Further, as electrical current radiates away from the active electrode, the tissue effect is dramatically decreased.

In bipolar circuits, the active and return electrodes are components of the same instrument. The charge density is basically identical at both electrodes. The only part of the patient involved in the circuit is that tissue directly located between the electrodes (**Fig. 15.5**).

In monopolar circuits, RF energy may be delivered either in a continuous waveform or in interrupted pulses electrical current, referred to as *CUT* or *COAG,* respectively, in deference to tissue effect described by Grant Ward in the 1920s. In CUT mode, there is delivery of a continuous uninterrupted sinusoidal waveform through the active electrode (continuous duty cycle). Alternatively, in COAG mode, the RF energy is delivered in pulses whereby over a given time RF energy is only delivered approximately 4% of the time (interrupted duty cycle). During the “off time,” desiccated, cooled, and coagulated tissue with denatured proteins increases resistance and thus increases voltage required for energy delivery. Most ESUs offer a “BLEND” mode in which the duty cycle is increased to 40%, but off 60% of the time, allowing for a mixture of cutting and coagulation properties (**Fig. 15.6**).

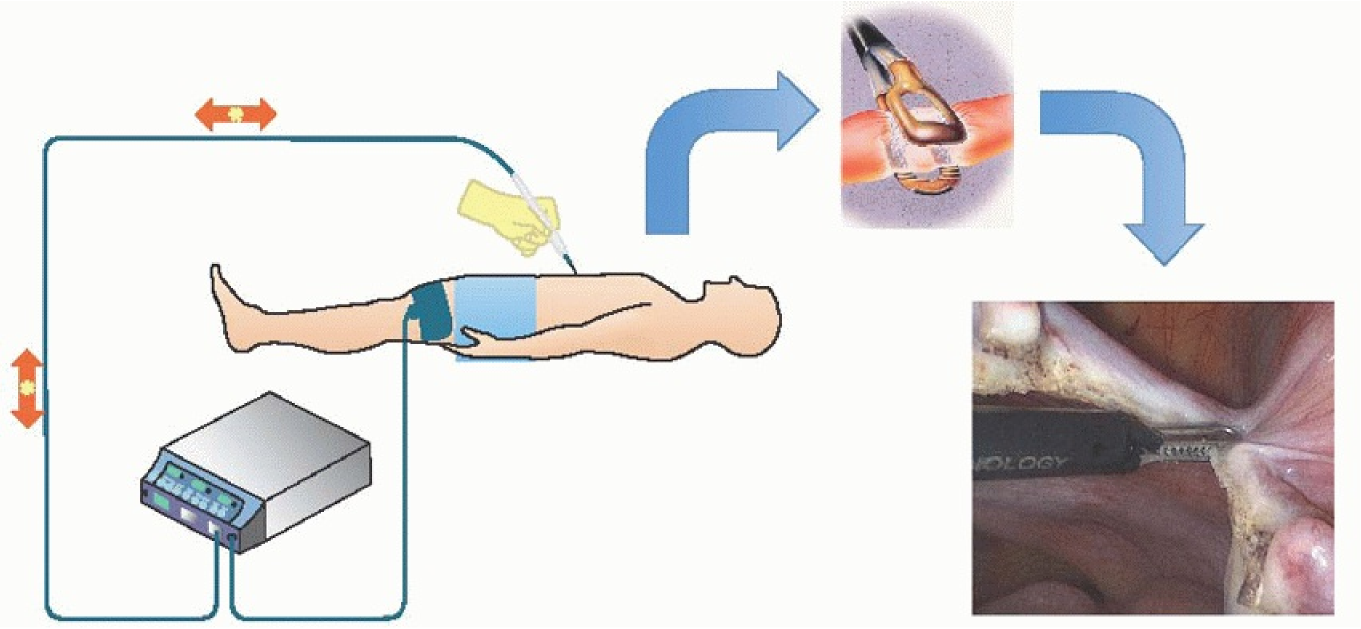

FIGURE 15.5 Bipolar electrical circuit. RF is delivered from the ESU through an active electrode to the patient and is returned to the ESU via return electrode located in the same instrument to complete the circuit. Only the tissue located between the electrodes is involved in the circuit.

In bipolar circuits, RF energy is delivered by the ESU in CUT setting, which is a continuous sinusoidal waveform with low voltage. Modern instruments available to use in the bipolar mode also employ use of compressive force to reduce vascular pulse pressure and subsequently blood flow through the intervening tissue. This further helps the energy to remain concentrated between the electrodes in order to achieve maximal desired tissue effect. Further, there is often the incorporation of feedback mechanisms to determine when the intervening tissue is sufficiently desiccated. This feedback allows an adaptive ESU to recognize increased tissue resistance and discontinue energy delivery when complete tissue effect has been achieved.

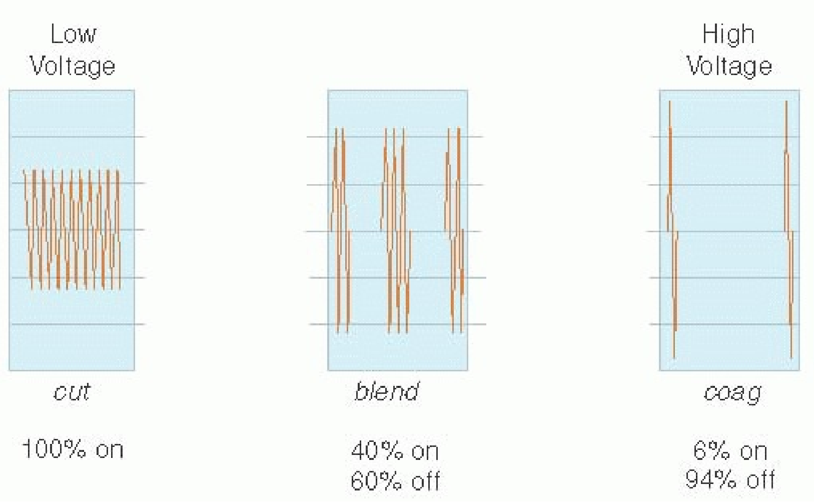

FIGURE 15.6 Continuous (CUT) versus interrupted (COAG) duty cycles differ in the duration that RF energy is delivered over time and by the voltage required to deliver that energy. Most generators offer a BLEND mode that offers some features of both extremes by varying the duration of the duty cycle.

TISSUE EFFECTS

Although the terms “CUT” and “COAG” have become ingrained in our electrosurgical lexicon, it is more useful to think of waveform and technique with respect to the tissue effect achieved. RF energy may be used to cut through tissue via rapid increase in temperature in a noncontact mode (vaporize) or coagulate tissue through slow deep dehydration and denaturation of proteins (desiccate) or by the superficial spray of electrons (fulgurate), often resulting in tissue carbonization (**Table 15.1**). Temperature changes have been identified with each of these effects. Normal resting human physiologic temperature is 37°C. Irreversible damage in tissue occurs at ≥50°C by intracellular protein denaturation and coagulation. Cellular dehydration (evaporation of water) occurs when tissue is heated to ≥90°C, which is referred to as *desiccation.* Rapid temperature rise to ≥100°C will cause cell walls to rupture as liquid water changes to steam by a process known as *vaporization.* At temperatures ≥250°C, tissues begin to char and carbonize leading to a *fulguration* effect.

As mentioned earlier, the CUT mode delivers a continuous sinusoidal waveform alternating from positive to negative at the frequency output of the ESU. This RF, delivered through a small active electrode (high current density), generates rapid and intense intracellular heat, which vaporizes the surrounding cells. The steam vapor occupies a space much greater than the water of the cell, creating two effects. First, it literally explodes the cells. Second, and equally importantly, it dissipates the heat generated to reduce thermal damage to adjacent tissue. Consequently, there is little or no coagulation effect. This mode is used to maximal advantage if the RF energy is engaged immediately before touching the tissue. If the active electrode is moved too slowly, or allowed to dwell in one spot too long, the tissue becomes dehydrated, resistance is increased, and tissue is more slowly dehydrated (desiccated). Therefore, for efficient and effective cutting of tissue, the surgeon should use a continuous waveform (CUT) with a small or thin active electrode that is activated just prior to tissue contact. With a peak voltage of about 200 V, the ionized air facilitates a layer of steam as the electrode glides by exploding cells with minimal surrounding heat or tissue coagulation.

TABLE 15.1 Tissue Effect Can Be Altered by Altering the Waveform and using the Active Electrode with a Contact or Noncontact Technique

	NO CONTACT	CONTACT
CUT (continuous)	Vaporization	Desiccation
COAG (interrupted)	Fulguration	Desiccation

In the COAG mode with a frequency of 500 kHz, bursts of RF energy occur over 31,000 times per second. However, this accounts for less than 5% of the time in pure COAG mode. It is during the “off” intervals that tissue is cooled and denatured (coagulated), which increases resistance. If the COAG waveform had the same peak voltage as the CUT waveform, the average power delivered per unit time would be less because the RF energy is off the majority of the time. In order to deliver the same power, the COAG waveform must deliver the same average voltage as the CUT waveform. To do so, there must be large peak voltages during the percentage of time that the RF energy is being delivered (**Fig. 15.7**). The high-voltage sparks created are more widely dispersed, and, due to the intermittent heating effect, cellular temperature does not increase rapidly or sufficiently to vaporize. Consequently, cells are more slowly dehydrated and do not explode to create an incision in tissue, but greater tissue resistance is the result. Because of the higher peak voltage (greater electromotive force), COAG waveforms can drive current through higher resistances, which permit fulguration (superficial), even after dehydration has occurred, and deeper desiccation of tissue. Fulguration and desiccation are both forms of tissue coagulation. With desiccation, concentration of current is related to the area of tissue contact with the active electrode. This creates deep penetration of heat and minimal charring of the tissue surface. On the other hand, fulguration occurs when (noncontact) superficial sparking occurs. Due to the high peak voltage at high current density, the sparks are sprayed in a random fashion in repeated intermittent cycles, resulting in tissue necrosis and charring. Given equal current density, noncontact fulguration is more efficient at creating surface necrosis and charring. However, contact desiccation yields a greater depth of tissue dehydration.

Coaptive coagulation is a term that refers to grasping of a bleeding vessel with a conductive metal instrument using sufficient pressure to stop blood flow. Subsequently, the active electrode is used to transfer energy through the instrument, causing coagulation and protein denaturation of the tissue. The surface of the tissue is coagulated first, with subsequent desiccation of the deeper tissue. The CUT waveform should always be used during coaptive coagulation since it has lower voltage and will reduce the chance of desiccation of the surrounding tissue.

Desired tissue effects can vary based on multiple factors and are not as simple as using CUT current when “cutting” is needed and COAG current when “coagulation” is needed. In 1928, Bovie described three distinct tissue effects of electrosurgery: *superficial dehydration, cutting,* and *tissue coagulation.* Superficial dehydration involves using the active electrode at a very short distance above the tissue, not in contact with, and causing electron "spraying" across the surface for dehydration of a thin layer of tissue. The cutting mechanism involves using current to separate the tissues ahead of the active electrode without using the electrode as a manual cutting device. This technique relies on an arc of electrons ahead of the electrode tip, prior to contacting the tissue. This method can be altered to perform coagulation by "damping" or interrupting the waveform to produce a coagulation effect in highly vascular tissue, while current remains the same. Lastly, he described tissue coagulation ("electrocoagulation") in which an electrode cannot perform the same effects as that of cutting. This type of tissue manipulation is based on two factors, the current density at the electrode tip and the dwell time of the activated instrument. The larger the area of tissue to be

coagulated, the weaker the current needed with a longer dwell time. If a stronger current is used, the superficial tissue becomes quickly dehydrated or carbonized, causing cessation of flow to the surrounding tissue. If the dwell time is activated for longer than necessary to achieve the desired effect, there is possibility of unintended stray current to nearby tissues.

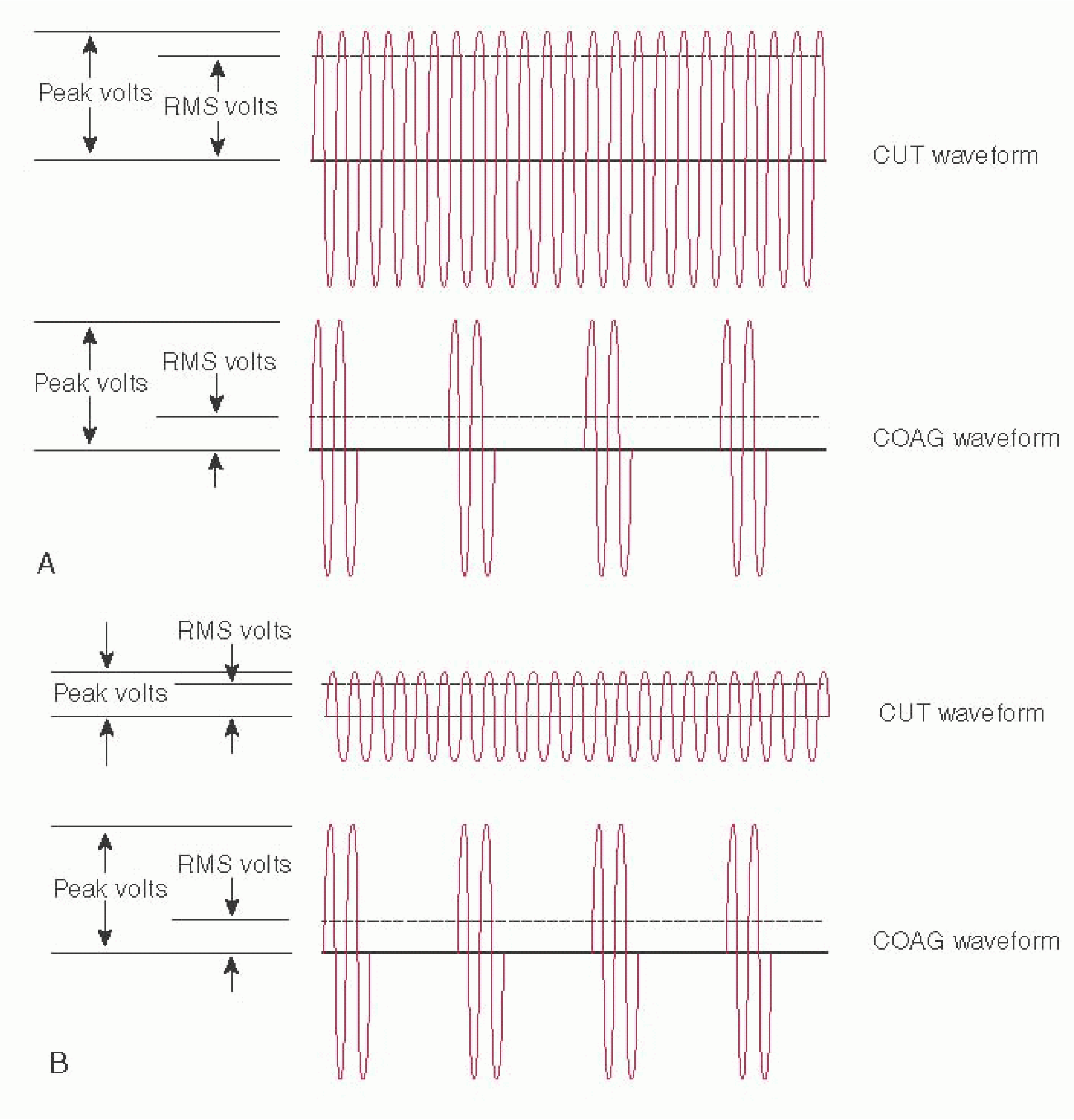

FIGURE 15.7 When the voltage is the same between pure CUT and pure COAG current, the amount of power delivered in COAG is only one third that of CUT. Conversely, when the power is the same between pure CUT and pure COAG current, the peak voltage of COAG is about three times greater than that of CUT. (RMS, root mean square.)

To achieve numerous desired tissue effects, the surgeon can use a combination of waveforms, current waveforms, active electrode characteristics, and surgical technique (**Fig. 15.8**). We have already discussed the effects achieved by electrode contact versus noncontact (**Table 15.1**) and different waveforms (**Figs. 15.6** and **15.7**). Additional manipulation of tissue effects may be accomplished by altering the size of the electrode, which controls current density. A needle tip electrode will yield greater current density than the broad surface of an electrosurgical bladed electrode. Therefore, at a given power using a continuous waveform, the needle tip electrode will produce quicker higher temperatures favoring vaporization (cutting), whereas the broad blade will result in a lower current density and slower and lower rise in temperature, favoring tissue desiccation. The speed with which the active electrode is moved can also contribute significantly to tissue effect. Recall that at an ideal speed, the active electrode glides through a path of vaporizing cells to cut tissue with minimal collateral effects. On the other hand, moving the electrode too slowly (increased dwell time) will generate increased heat in surrounding tissues resulting in a proportional degree of tissue coagulation. Once the superficial tissue is fulgurated, it acts as its own insulator. Dwelling over the same tissue longer than is required for the fulguration effect has potential to cause deeper tissue injury with potential for stray paths of electron flow. Similarly, moving the active electrode too fast will result in a continuous waveform contact mode (desiccation) as it overshoots the microenvironment of ionized air that creates a layer of steam from vaporized cells.

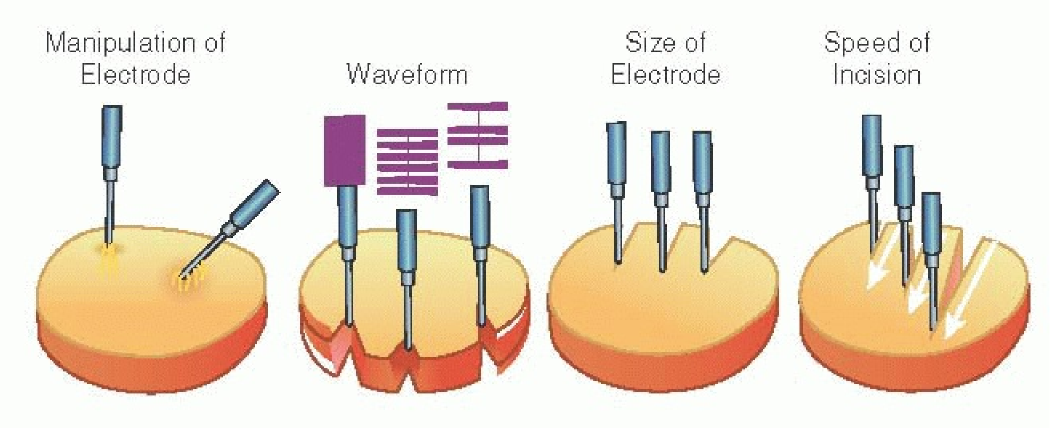

FIGURE 15.8 Variables that moderate tissue effects include electrode manipulation (contact versus noncontact), waveform (CUT versus COAG or BLEND), size of electrode (current density), and speed of active electrode movement.

Finally, in order to achieve a desired tissue effect, the surgeon must take into consideration the constitution of the target tissue.

Tissue impedance (resistance), which primarily depends on water content, will also affect the electrosurgical outcome. Impedance is high in desiccated tissues, moderate in adipose tissues, and very low in vascular tissues with higher water content. The impedance of tissue is dynamic during electrosurgery. Moreover, the power needed to accomplish a particular electrosurgical effect may vary from one patient to another. Lean, muscular patients are better overall conductors of electricity. Obese or emaciated patients may provide more tissue impedance to the electrical current and so may require more applied power to achieve the same effect. Power requirements to achieve a given electrosurgical effect will be higher whenever an electrode is applied to an area of higher impedance. With higher resistance, there is increased possibility of stray current seeking alternative sites of action. For example, as water evaporates and tissue coagulates, impedance rises—at times to the point that current is inhibited from flowing through the tissue. If the surgeon reflexively increases the power setting and consequently the output voltage, the current is more likely to overcome the tissue resistance and seek an alternative pathway of least resistance to the ground, which may lead to unintended thermal injury. Therefore, it is always advisable to use the lowest power setting to achieve the desired tissue effect.

ELECTROSURGERY AND PATIENT SAFETY

As we have seen, the principles of Ohm law along with the rules “electricity must complete a circuit or it will not flow,” “electricity goes to ground,” and “electricity follows the path of least resistance” provide the basis of predictable use of RF energy in surgical applications. However, these same principles illustrate the potential dangers of unintended energy paths. Complications arise when electrosurgical principles are not thoroughly understood and devices are not properly used. Injuries from electrosurgical devices have been reported anywhere from 2.2 to 5/1,000. Of note, these are recognized injuries at the time of surgery. Electrosurgical injuries do not always present at the time of surgery and can frequently present complications between 3 and 7 days postoperatively. It is believed that there are a larger number of unrecognized injuries, some of which do not become substantial and are thus underreported. Unintended thermal injury to tissue can be related to many factors, including direct and indirect application of energy. We discuss here examples of the most common sources of unintended energy application, potentially leading to patient injury.

Open Activation

Intentionally activating the active electrode prior to contact with tissue (open activation), the surgeon can create a fulguration effect (discussed earlier). Perhaps the best example of this is the use of a ball electrode to fulgurate the bed of a cervical loop electrosurgical excision procedure (LEEP). However, this becomes a potential hazard when the active electrode is at a sufficient distance away from the target tissue (e.g., activating the RF energy in a laparotomy incision when the active electrode is a few inches away from the target). The energy charge builds up at the tip of the electrode as it encounters the very high resistance of air. With sufficient power, the electromotive force (voltage) can cause the RF energy to discharge the energy across the resistance of the insulator to the nearest (often unintended) site, much like a lightning bolt discharge.

Direct Coupling

Direct coupling occurs when an active electrode comes into contact with a conductive instrument that channels RF energy to another site (tissue) with which it is in contact. An intentional use of this principle would be passing current from an active electrode through a pair of forceps that is grasping a vessel at the operative site. A common example of untended direct coupling in laparoscopy occurs when activated monopolar scissors touch adjacent bowel graspers, causing direct transfer of RF energy to the unintended site (bowel). Alternatively, this may occur when the active electrode touches the laparoscope, which is in contact with bowel.

Insulation Failure

This type of “stray energy” perhaps occurs more frequently in laparoscopy than in laparotomy. It is frequently unrecognized, owing to the fact that less than 15% of the operative field is typically seen when using a video camera and laparoscope. Laparoscopic instruments are covered by an insulator to direct current to the active electrode at the tip of the instrument. When there is a break in the insulated shaft of an instrument, which can occur through a variety of mechanisms such as moving the instrument repeatedly through a trocar or when cleaning and processing for reuse, RF energy can discharge through these breaks with effects like that described in open activation. The bowel is a frequently affected target of stray RF energy form insulation failure. Usually, blanching of sigmoid wall (or other tissue) occurs, and the surgeon should assume that tissue destruction is deeper than is visible. This type of tissue injury (pale, blanching) has a higher likelihood of breaking down in the future. However, this may be more indirect if, for example, the RF discharge were to the laparoscope, which is in turn in contact with bowel. Should such injury to the bowel occur, the correct method of action for the bowel is excision or resection and reanastomosis.

Capacitive Coupling

Capacitance refers to the ability of an object to store an electrical charge. Capacitance coupling may occur when two conductors in proximity to one another are separated by an insulator. It is best described as a mechanism whereby electrical current in the active electrode induces a current in another nearby conductor (unintended) despite otherwise intact insulation. For example, when using an operative laparoscope, the insulated active electrode (scissors, for example) is passed through a channel within the operative scope. This produces the ideal situation for capacitive coupling of the laparoscope by the active electrode (**Fig. 15.9**).

Some degree of capacitive coupling occurs with all standard monopolar electrosurgical instruments, but it is not always a hazard. Whether the “stray energy” of capacitive coupling causes clinical injury depends on (a) the total amount of current transferred, (b) the ability to prevent arcing discharge of the built-up energy to an unintended tissue target, and (c) concentration of the current (i.e., the current density) as it makes its way back to the patient return electrode. Higher voltages increase capacitive coupling. The low-voltage CUT mode exhibits less capacitive coupling than COAG does. Thin insulation decreases the effective separation of the electrode from the surrounding conductor and will increase the amount of induced current.

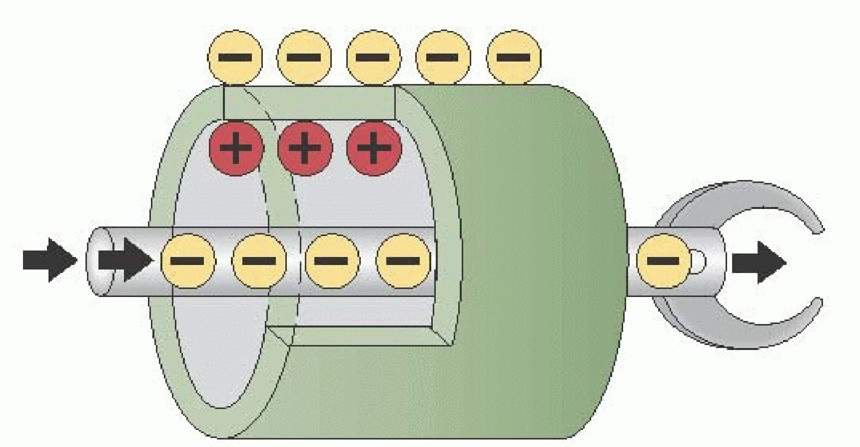

FIGURE 15.9 Capacitance coupling is the induction of electrical current between two conductors separated by an insulator. The active electrode carries active current and induces a separate current in the nearby conductor.

Common conditions exist where capacitive coupling can cause sufficient current to cause an injury. When a metal trocar is used, it can be capacitively coupled to the active electrode. Additionally, when a conventionally insulated electrode is passed through a metal suction-irrigator, approximately 70% of the current may be induced in the suction-irrigator. The same situation can occur when an active electrode is passed through the operating channel of a laparoscope. An all-metal cannula through the abdominal wall will “bleed off” stray current through the abdominal wall as the RF energy is discharged over a larger surface area on its way to the return electrode with minimal or no effect. However, if the metal trocar is anchored by a plastic sleeve in the first example, or if a plastic trocar is used, then RF energy can build up until it overcomes the impedance of surrounding air to discharge through the path of least resistance to an often unintended tissue target. Another common and rarely recognized example occurs when the wire of a monopolar electrosurgical instrument is wrapped around a hemostat attached to a surgical drape for stabilization. With prolonged use of the electrosurgical instrument, the hemostat may become charged through capacitive coupling and that electrical energy may discharge seeking ground through the path of least resistance causing a drape fire or a burn to the patient (**Fig. 15.10**).

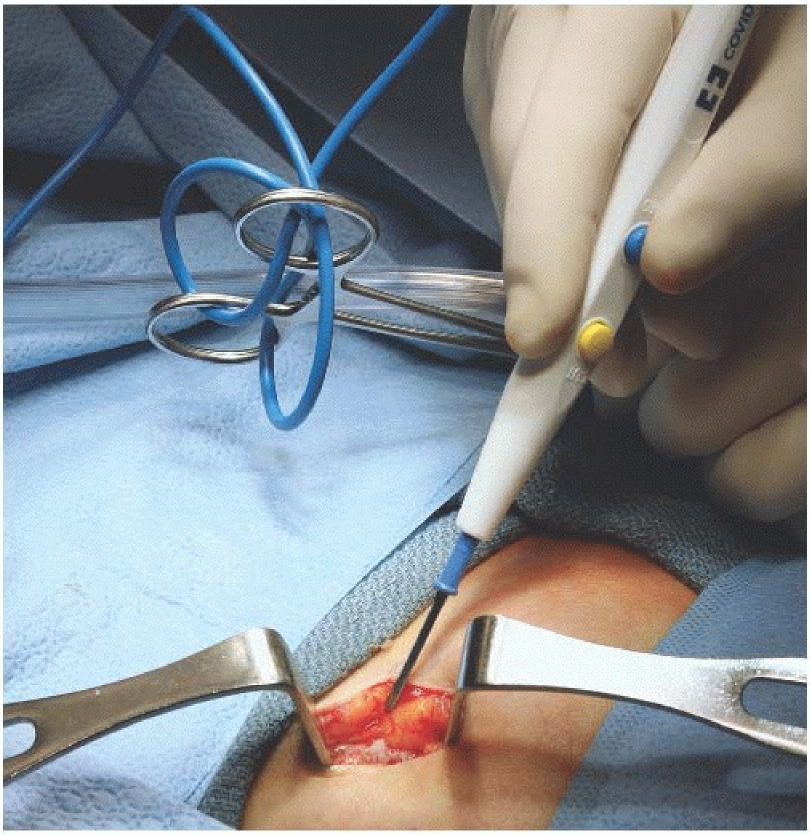

FIGURE 15.10 Securing the wire of an electrosurgical instrument to the drape with a hemostat provides an opportunity for capacitive coupling and discharge of built-up energy to create a drape fire or a patient burn.

Bipolar Instruments

Bipolar electrosurgical instruments became popular in the mid-1970s as an alternative to monopolar instruments with hopes to avoid complications of stray current as described above. Although bipolar electrosurgical instruments are safer than monopolar instruments with respect to stray RF injury, they are not without possibility of complication. It is important to remember that the zone of thermal damage may extend beyond that of the electrodes at the instrument tip. Once the tissue is sufficiently desiccated, further application of electricity can propagate heated water and subsequent steam to adjacent tissue, causing a thermal spreading effect. In order to reduce this potential, the surgeon should cease desiccation once vapor is no longer visualized and when the tissue becomes white in color.

Excessive desiccation can cause stickiness of the tissue as a result of carbonization, often referred to as an “amalgam.” Additionally, the active electrode can become adherent to the tissue, due to molecular breakdown of the cellular contents into sugars if the COAG function is used improperly or for a prolonged period of time. When deep tissue desiccation is required, the CUT function should be used to ensure deep penetration of tissue. If the COAG function is used instead, in tubal sterilization for example, it can cause immediate surface char and cessation of the flow of electrons while increasing tissue impedance, increasing lateral thermal spread, and preserving patency of the underlying tubal lumen. Use of the CUT mode allows a more precise and controlled spread of energy within the tissue due to its continuous, low-voltage waveform.

When using bipolar instruments, the use of an “in-line ammeter” is recommended to help monitor the increase in tissue resistance indicating complete tissue desiccation.

ADVANCED MONOPOLAR AND BIPOLAR DEVICES

Unique instruments are now widely available that dramatically reduce the potential for injury though unintended RF energy discharge in monopolar instruments. Further, with the advent of bipolar electrosurgical devices in the mid-1970s, there came a recognized need for more versatile instruments, including the ability to offer both tissue desiccation and cutting abilities in the same instrument. Having these functions within one instrument provides more efficiency to the surgeon and avoids the need to change out surgical instruments for various tissue effects. There was a simultaneous desire to reduce the thermal spread, tissue carbonization resulting in instrument sticking, and increased “plume” formation of conventional bipolar instruments. Several instruments are now available that can be used to grasp, dissect, seal vessels up to 7 mm in diameter, and transect tissue. These tissue-sealing devices all employ the three components of pressure, temperature, and time to coapt tissue; denature and mobilize collagen and other proteins within the tissue at elevated temperatures; and fix or reorganize the collagen fibers to form a tissue seal. Then, some mechanism is used to transect the sealed tissue.

Active Electrode Monitoring

The potential for injury from capacitive coupled currents can be reduced with an understanding of the biophysics but can be eliminated by active electrode monitoring systems that “collect” stray current and confine capacitive coupling to the surgical instrument. Such a device is commercially available that eliminates the risk of capacitance regardless of the type of trocar sleeve used (Encision, Inc., Boulder, CO). This device

consists of a shroud over the active electrode shaft that shunts all capacitance-coupled current back through a return electrode to the electrosurgical unit, which avoids unintentional RF energy discharge. Additionally, if there is any breech in the insulation of the active electrode that could promote direct coupling to other metal instruments or adjacent tissue, the surgeon is alerted with an audible alarm (**Fig. 15.11**).

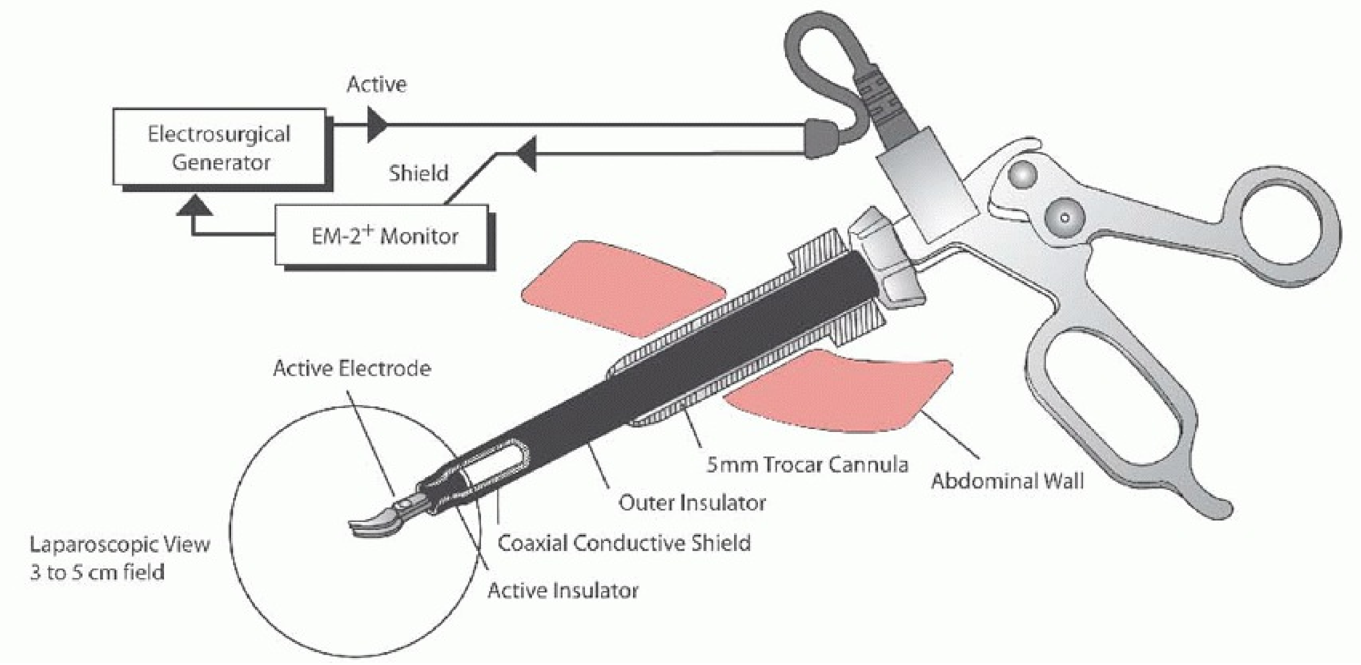

FIGURE 15.11 The Encision (formerly Electroshield) system eliminates the threat of unintentional capacitance injury when using monopolar instruments during laparoscopy by returning capacitance-induced current back to the generator. If an insulation breakdown occurs, the surgeon is alerted.

Argon Beam Coagulator

The argon beam coagulator is a monopolar active electrode housed inside an insulated cannula through which argon gas is dispelled at up to 12 L per minute (laparotomy) or 4 L per minute (laparoscopy). This instrument is superior for controlled noncontact superficial fulguration of tissue, owing to two unique properties of argon gas. First, electrons prefer to follow a stream of argon gas rather than pass through room air or carbon dioxide (CO_2), as each of the latter has a higher resistance to electron flow. Accordingly, because electrons choose to flow the path of least resistance, they stay collimated (parallel alignment) in the flow of argon, so sparks can be directed with efficiency. Second, the ionization properties of argon gas flowing over the active electrode enhance the distance the spark can travel to complete the circuit to the tissue surface. These properties create a bright bluish hue to the sparks, which makes them easy to see and aim at the bleeding surface (**Fig. 15.12**). The gas, expelled under pressure, blows the pooled blood away from the surface bleeders, making coagulation more discrete and efficient. To create the planned fulguration effect, the wand must move like a paintbrush to prevent deep tissue damage.

Plasma Kinetic Technology

The PlasmaKinetic platform (Olympus America, Center Valley, PA) employs an advanced solid-state adaptive generator with software to deliver pulsed RF energy with continuous tissue impedance. This vapor pulse coagulation generates less heat overall but ensures reaching temperature for effective collagen denaturation without rapid desiccation. As the generator delivers a pulse of RF energy, tissue impedance is measured and voltage is altered (decreased) to match the impedance. In between pulses, the tissue cools, allowing for renaturation (fixing) of the collagen. This cycle continues until complete tissue sealing and desiccation has been accomplished. Instruments for use with laparoscopy, laparotomy, and vaginal surgery are available with this technology. Several related devices are available using this platform. The HALO device (Olympus America, Center Valley, PA) includes a knife blade that can be advanced after desiccation to cut the tissue. The newest device in this line (ThunderBeat) offers the option of advanced bipolar technology or a combination of advanced bipolar together with ultrasonic technology for simultaneous sealing and cutting of tissue.

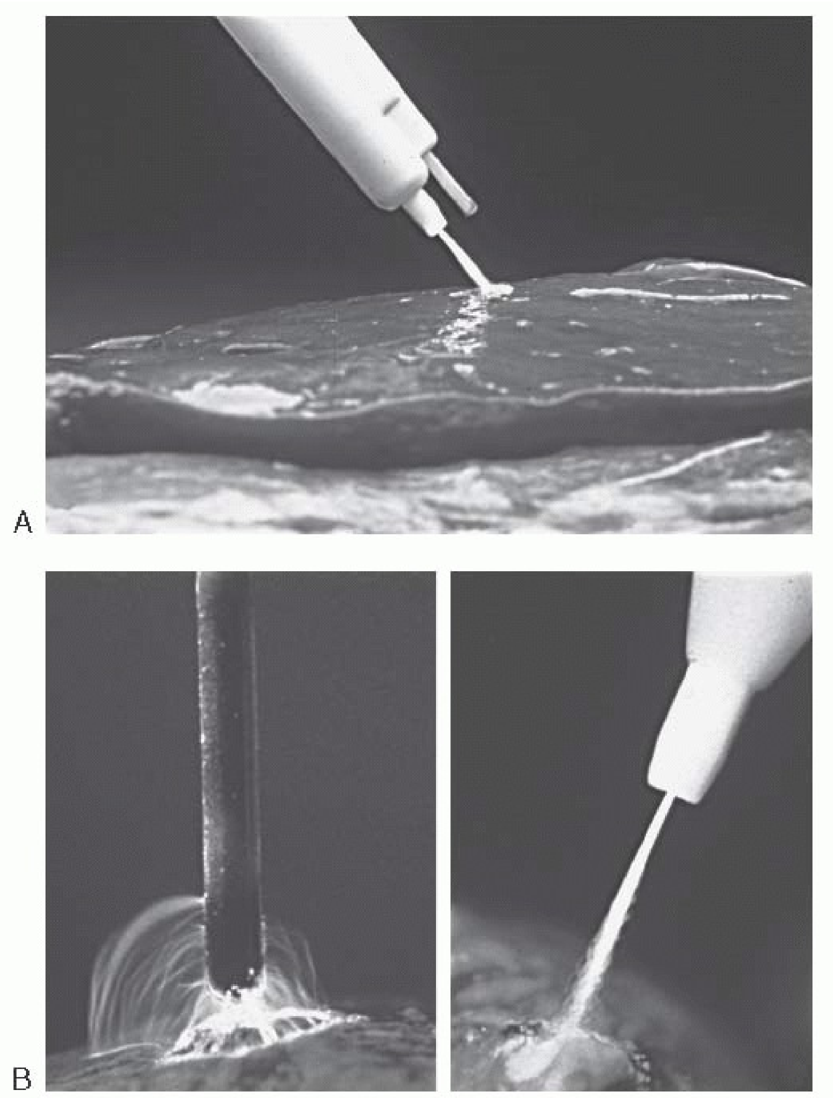

FIGURE 15.12 Argon beam coagulator. The ionized gas has its own unique blue hue that makes the sparks easily visible for accurate fulguration. **A:** The argon beam coagulator at work. **B:** Sparking effect of standard electrode (**left**) compared with argon beam coagulator (**right**).

LigaSure

The LigaSure device (Covidien, Boulder, CO) achieves true tissue fusion using a combination of pressure and pulsed energy to denature collagen and elastin in tissue bundles, vessel walls, and lymphatics to reform into a permanent plastic-like seal that resists deformation with tensile strength up to three times the normal systolic pressure. The tissue to be sealed is grasped in the jaws of the instrument, and a calibrated force is applied to the tissue during energy delivery. Using proprietary adaptive generator technology and software, the type of tissue held in the forceps is recognized and tissue impedance is monitored while delivering the appropriate amount of RF energy required to seal the tissue. During the process, elastin and collagen are denatured, creating a permanent seal that resists deformation. A cutting blade is then deployed to cut the sealed tissue. Instruments for use with laparoscopy, laparotomy, and vaginal surgery are available with this technology.

EnSeal

The EnSeal Laparoscopic Vessel Fusion System (Ethicon Endo-Surgery, Cincinnati, Ohio) uses a set of high-compression plastic jaws embedded with nanometer-sized spheres of nickel through which the temperature of the tissue pedicle is predetermined by local conductivity. A patented positive temperature coefficient system utilizes a carbon crystalline matrix to limit tissue temperature along the seal line. This creates a conductive polymer chain at temperatures less than 100°C that dissociates at temperatures greater than 100°C, thus limiting energy delivery and lateral thermal spread. The device has a central mechanical blade used to compress the tissue to force water out of the cells and reduce lateral thermal spread by reducing excess steam within the tissue being desiccated. This feature also serves as the cutting function of the tool.

ULTRASONICS

Ultrasonic devices generate tissue effects similar to advanced bipolar devices. However, the source of thermal energy generation is ultrasonic vibration of the active shaft of the device at greater than 20,000 vibrations per second. An ultrasonic generator delivers AC to the handpiece to achieve excitation in pizoelectrodes interspersed between metal cylinders. This process results in mechanical energy by vibrating the cylinders at frequencies between 23 and 55 kHz. The shaft of the instrument, which is the active element or nonarticulating jaw, is in contact with the cylinders and oscillates linearly at the same frequency.

Different tissue effects can be achieved by variation in the oscillation distance of the shaft. The higher setting (100 μ) is better for rapid tissue transection while minimizing lateral thermal spread, but the effectiveness in coagulation of tissue and vessels is decreased. Alternatively, a shorter oscillation (50 μ) is superior for tissue and vessel sealing, yet results in greater potential for lateral thermal spread and cavitation. Cavitation occurs when steam released from vaporized cells expands tissue planes. Although this does occur to some extent with monopolar vaporization, it occurs at lower temperatures with ultrasonic energy due to the oscillating tip. Thus, ultrasonic devices are similar to advanced bipolar devices in that they both sequentially convert electrical energy to mechanical energy to thermal energy to facilitate tissue effects. However, with bipolar devices, the source of friction is intracellular (molecular), whereas ultrasonic devices create extracellular friction from the oscillating shaft followed by intracellular heating without the passage of electrical current through the tissue.

There are multiple ultrasonic devices currently available, including the Harmonic Scalpel and Harmonic ACE (Ethicon Endo-Surgery, Cincinnati, OH), Autosonix and Sonicision (Covidien, Boulder, CO), and SonoSurg (Olympus America, Center Valley, PA). A recently available device by Olympus, ThunderBeat, combines both advanced bipolar and ultrasonic technology in the same device in a manner, allowing the surgeon to use the different energy sources independently or sequentially.

SPECIAL SURGICAL SITUATIONS

Pregnancy

No data indicate that using electrosurgical techniques in a pregnant patient has any untoward effect on the fetus at any stage of development. Owing to the dispersion effect, the fetus, bathed in electrolyte-rich amniotic fluid, is protected from any concentration of electrical current. Just as the output frequency of all electrosurgical generators is above the faradic effect (the level that stimulates muscle contraction) for adult electrosurgery, the same is true for the fetus.

During a cesarean section, the only concern is the accidental touching of an activated electrode to the fetus, which causes tissue heating. This does not mean that the usual technique of making an incision in the uterus would preclude using an electrosurgical incision, but rather that a “backstop” under the incision line, between the amniotic membrane and the muscle wall, should be in place. Although using a nonconductive material, such as a plastic suction tip, may seem wise, a metal ribbon retractor also can be used because it has a large surface area serving to diffuse the current density. Caution should be exercised when using the gloved finger of the surgeon as a backstop because if open activation is used, the increased voltage may create a hole in the glove.

Body Piercing and Prosthetic Implants

There have been no documented electrosurgical injuries reported in the literature in relation to body piercing. Nonetheless, faulty instrument insulation can theoretically transmit current from the surgical active electrode to the metal object, causing a skin burn. Therefore, conventional wisdom indicates that removal of umbilical and labial piercings prior to a surgical procedure is prudent when possible. It is not necessary to remove piercings or other metal jewelry distant from the operative site. These objects are too far away from the active electrode to receive substantial electrical current. If removal of rings and/or piercings is

not desired or possible, then taping the metal object down to the skin to create the greatest surface area contact will decrease current density and minimize any potential risk.

The same principles apply to metal-implanted prosthetic devices. The large surface area would minimize the potential of patient burn, and there have been no reported adverse patient events related to prosthetic devices and electrosurgery. It is noteworthy that the overlying scar has more potential for affecting the electrical circuit through increased resistance, and that is minimal as well.

Implantable Devices

Any implanted cardiac pacemaker, implantable cardioverter-defibrillator, resynchronization device, or ventricular assist device is referred to as a cardiac implantable electronic device (CIED). The nature of any device type and patient reliance on that device must be investigated preoperatively. Failure to do so can lead to adverse outcomes. The potential for electromagnetic interference with CIEDs depends upon the distance from the active and return electrodes, the RF frequency used, and the current pathway. Attention must be paid to place the return electrode in a location so that the path between the active and return electrodes does not travel near the CIED generator or leads. If so, then the risk of interference is low, although there is at least some potential for interference as the RF circuit does not travel linearly between the active and return electrode.

Possible adverse effects of CIEDs with electrosurgery include permanent damage to the device, inability of the device to function properly, resetting of the device, or inappropriate delivery of implantable cardiac defibrillator (ICD) therapy leading to patient effects of hypotension, tachyarrhythmia or bradyarrhythmia, myocardial tissue damage, and myocardial ischemia or infarction. When planning a surgical procedure in a patient who is heavily dependent on the CIED, alternative monopolar instruments should be replaced whenever possible with bipolar instruments where current is limited to tissue between the tips of the forceps and stray RF energy is rare.

Preoperative management of the CIED may include reprogramming or disabling algorithms and suspending antitachyarrhythmia functions. Clinical magnets positioned over the CIED can change pacing to an asynchronous mode in pacemakers and suspend tachycardia therapies in implantable cardiac defibrillators. However, magnets should not be routinely used over an ICD. Temporary pacing and defibrillation equipment should be immediately available before, during, and after the procedure.

Although continuous monitoring by EKG is critical, that signal can also be subject to electromagnetic interference, which can complicate detection of CIED malfunction. Thus, peripheral perfusion by pulse oximetry or invasive arterial waveform should also be monitored.

There are noncardiac devices using electric current that could potentially be affected by RF energy during electrosurgery. These include neural stimulators and gastric neurostimulators used to treat gastroparesis. Minimizing interference with these devices is desirable. However, the consequences of malfunction are not immediately life threatening, as with CIEDs.

ELECTROSURGICAL APPLICATIONS IN OPERATIVE HYSTEROSCOPY

The same electrosurgical principles that have been discussed previously in this chapter apply to hysteroscopy as well, with one notable exception, that is, the need to create distension of the uterine cavity and provide an electrically insulated environment (replacing the insulation of air during laparotomy or CO_2 gas during laparoscopy). This is accomplished through the use of nonionic fluids such as glycine, mannitol, or sorbitol.

These media are absorbed to varying degrees, depending on factors such as operative time, intracavitary pressure, and vascular nature of the resected tissue. With excessive absorption come the hazards of fluid and electrolyte imbalances and complications from metabolism of the medium itself (e.g., glycine is metabolized to water and ammonia). However interesting and important, these issues are beyond the focus of this chapter.

Some surgeons employ endometrial loop resection, some use ball ablation, and some employ both techniques sequentially. Further variability is noted in watts used, speed of the electrode, and even pressure applied by the rollerball to the uterine lining (more pressure results in greater active electrode contact and decreased current density). Some surgeons use only COAG waveform, while others use CUT or even some sequential or spatial combination of the two. However, we do know that by using the CUT waveform, there is less bubble generation and accumulation on the anterior surface of the cavity. At the end of the ablation procedure, some surgeons switch to a COAG waveform at 75 W. With the increased peak voltage of this waveform, electrons driven by higher electromotive force “seek out” undertreated areas of lower impedance, ensuring complete tissue coagulation.

There are three common, if not unique, electrosurgical complications associated with operative hysteroscopy, aside from the fluid management issue described briefly above. The first is due to uterine perforation by an active electrode during RF energy application. This can be minimized by (a) never advancing the hysteroscope with the active electrode extended and (b) only energizing the active electrode while retracting the active electrode toward the hysteroscope. If this type of complications does occur, then laparoscopy or laparotomy (depending on skill level) must be undertaken to evaluate possible pelvic or abdominal organ injury. The second is accidental burns to the vagina or perineum through capacitive coupling of the outer sheath of the resectoscopic hysteroscope. Because the inner and outer sheaths of the resectoscope (conductors) are separated by air (insulator), capacitive coupling can occur. Relatively high current density in the outer sheath touching small areas of genital tissue can create a burn injury. Finally, injuries can also occur from defects in electrode insulation, especially when interrupted COAG current is used and the cervix is overdilated and is in contact with less than 2 cm of the outer sheath. The high electromotive force created by prolonged activation along already desiccated tissue (increased resistance) and subsequent current diversion is responsible for this type of injury.

BIPOLAR HYSTEROSCOPIC SURGERY

A family of instrumentation is available for hysteroscopy that uses bipolar technology to attain the desired electrosurgical effect. Two advantages of bipolar electrosurgery include the ability to use in a saline environment, mitigating the potential hazards of nonionic fluid absorption. Additionally, isolation of the electrical circuit occurs between a set of closely separated electrodes separated by a ceramic insulator. Performance is similar to its monopolar counterpoint, providing tissue vaporization and desiccation while retaining all of the inherent safety features of bipolar electrosurgery.

The VERSAPOINT system (Ethicon Women's Health and Urology, Somerville, NJ) consists of a dedicated bipolar electrosurgical generator and a variety of specialized hysteroscopic bipolar electrodes for different tissue effects. A key feature of the system is its ability to adjust automatically to an optimal power setting depending on the type of electrode.

The VERSAPOINT adaptive generator varies the output power in response to local impedance changes at the active electrode. A high-impedance vapor pocket is created that surrounds and insulates the active electrode from completing the circuit through the normal saline until tissue contact is made. Once contact occurs, current flows through the tissue and, by seeking the path of least resistance, returns through the saline to the proximal return electrode and finally back to the generator. Similar bipolar resectoscopic systems are also available through Karl Storz Endoscopy America (El Segundo, CA) and Richard Wolf Medical Instruments (Vernon Hills, IL).

BIPOLAR ENDOMETRIAL ABLATION

Nonresectoscopic bipolar endometrial ablation is possible using the NovaSure Global Endometrial Ablation System (Hologic, Marlborough, MA). This system includes a single-use, three-dimensional bipolar device and adaptive RF generator that produces a controlled destruction of the endometrium in an average of 90 seconds. After inserting the device transcervically into the uterine cavity, it is seated by retracting a protective sheath to deploy a fan-shaped bipolar electrode that conforms to the uterine cavity. During deployment, the measured endometrial cavity length and width are entered into the generator, which calculates the power output required to ensure ablation of the uterine cavity. During activation, a vacuum is used to ensure good electrode tissue contact, as well as to remove blood, endometrial debris, and steam, eliminating any uncontrollable steam ablation effect. The term “global” refers to the fact that the entire cavity is treated simultaneously (**Fig. 15.13**).

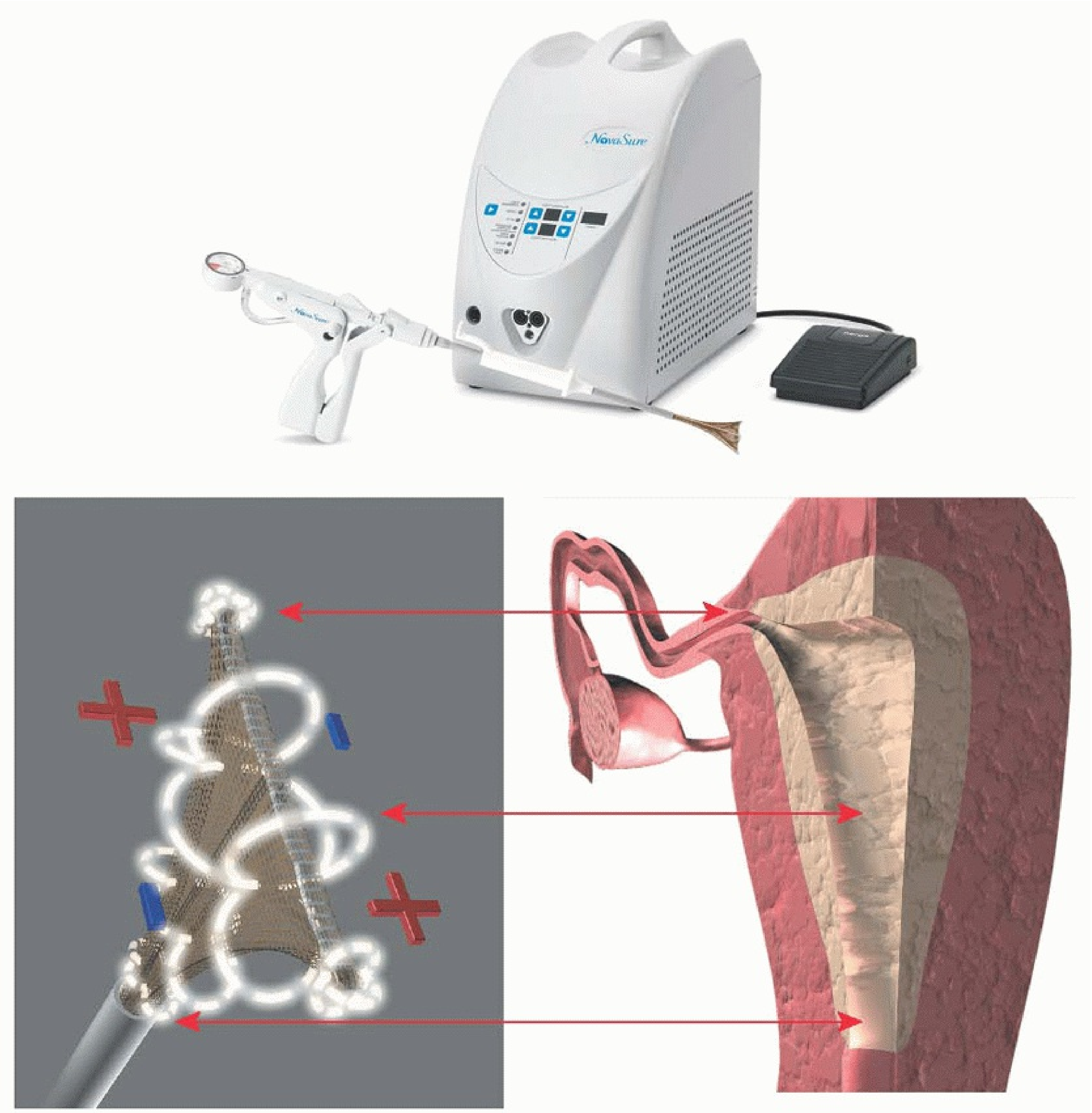

FIGURE 15.13 The NovaSure Global Endometrial Ablation System is a bipolar device for endometrial ablation using a metalized mesh electrode, vacuum for firm tissue contact, and an impedance-controlled generator

designed to create a shallower depth of desiccation at the cornual area and lower uterine segment, with a deeper ablation in the uterine midbody. (Courtesy of HOLOGIC, Inc. and affiliates.)

Using a constant power output generator, the maximum power delivered is 180 W. The depth of ablation is controlled by monitoring tissue impedance during the procedure. A

shorter center-to-center distance between electrodes provides a more shallow depth of desiccation at the areas and lower uterine segment. A wider center-to-center distance between electrodes provides for a deeper ablation in the uterine corpus. The endometrium does not require pretreatment or thinning prior to treatment. RF energy delivery continues until monitored tissue impedance reaches 50 ohms (representing a distinction between the lower resistance of the endometrium and the higher resistance of the myometrium) or after 2 minutes, at which time the NovaSure System discontinues energy delivery.

LASER TECHNOLOGY

Historical Perspective and Background

Although the basis of laser technology was first described by Albert Einstein in 1917, working lasers did not appear until 1960 and were not applied to medicine until about 5 years later. LASER is actually an acronym for “light amplification by stimulated emission of radiation.” Energy from lasers is derived by the ability to generate light emissions that are both highly collimated (parallel rays) and coherent (in phase, noninterfering wavelengths) and that can be delivered to the surgical site by a series of mirrors or fibers without measurable degeneration of these properties. In doing so, virtually any surgical procedure requiring vaporization, cutting, or coagulation of tissue can be performed using lasers. Laser energy can destroy tissue layer by layer, without touching it, with minimal thermal damage.

Lasers generate light energy through the release of photons from excited atoms in a medium contained within an optically resonant chamber. The nature of the active lasing medium, a collection of atoms usually in the form of crystals or gas, is how the type of laser derives its name. When the medium is stimulated by an external source (e.g., electricity), the atoms circulating the nucleus of the medium are stimulated into a higherenergy orbit. As the electrons decay to resting levels, light energy in the form of a photon is released. This process is known as spontaneous emission. Not only can electrons be stimulated by an external energy source, they can be bombarded by photons, which causes decay and emission of a photon that is identical in phase (coherent), in wavelength, and in color (monochromatic) and travels in the same direction without divergence (collimated). This process is called stimulated emission.

The optical cavity in which the electrons reside, and where the photons are produced, is lined by mirrors. All of the mirrors are completely reflective, except for a semitransparent mirror at one end of the linear axis of the optical cavity. The direction in which photons are emitted is totally random. They are focused by the mirrors so that most resonate back and forth along the axis of the optical chamber. Photons that are aligned with the optical axis of the chamber are released when the laser is “fired,” emerge through the semitransparent mirror, and are emitted from the laser as the monochromatic parallel coherent laser beam.

Laser generators have focusing attachments for delivery of the light energy for superficial use (e.g., colposcopy or lower genital tract), for laparotomy, and for laparoscopy. Historically, all lasers have been able to transmit energy via a flexible quartz fiber except for the CO_2 laser, which was transmitted along rigid tubes reflected by mirrors. However, a hollow-core flexible fiber delivery system recently has been developed for delivery of CO_2 laser energy (OmniGuide, Cambridge, MA) with adapters for external, laparoscopy, and robotic use.

Laser Tissue Interactions

Just as the surgeon can manipulate the active electrode to modify the effects of RF energy at the surgical site, there are three parameters that impact the amount of laser energy delivered. The first variable is wattage. For most applications, energy in the order to 5 to 10 W is sufficient; it is rarely necessary to exceed 20 W.

The second parameter is time. Simply put, the longer the laser remains focused on one spot, the more energy is applied to that area. This can be modified either by moving a continuous wave beam around within the desired treatment area or by delivering the laser energy in pulses. In pulsed modes, laser energy can be delivered as a single pulse or a series of pulses. Generally, a single pulse is less than 0.25 second. Timed pulses of short duration can be useful in controlling delivery.

The third parameter that can be controlled is the spot size of the beam. This is analogous to altering the current density of RF energy at the tip of the active electrode to alter tissue effects. Power density, expressed in watts/cm^2, is inversely proportional to the area of the spot size, such that doubling the beam diameter reduces power density to one fourth. Conversely, decreasing spot size in half results in a fourfold increase in power density.

As previously mentioned, laser energy emerges from the generator in a coherent and parallel fashion. This could hypothetically travel in this form to infinitely. However, the laser light is focused to a fixed focal length, depending on the application of the device (external, laparotomy, or laparoscopy use). The surgeon can further alter the focus with additional lenses or mechanical devices. By focusing or defocusing the laser energy, it is used as a cutting or coagulating tool.

Applications of Lasers

The first gynecologic application of laser technology was reported in 1973 when Kaplan and colleagues used CO_2 laser to treat cervical lesions. Potassium titanyl phosphate (KTP) and neodymium:YAG (Nd:YAG) lasers became increasingly popular for laparoscopic applications, especially related to treatment of endometriosis and infertility patients, partially because of their specific properties but equally because a flexible fiber delivery system was comparatively easier to use than the rigid mirrored system of the CO_2 laser. However, because of increasing cost consciousness and availability of superior advanced RF-based devices in the late 1990s, laser technology for all but external lower genital tract disease dramatically decreased.

There are three zones of laser tissue damage: (a) the area vaporized, (b) the area of tissue death that results from the heated tissue short of vaporization, and (c) the area of tissue damage caused by conduction of the heat away from the lased site. Because it removes tissue with vaporization and evacuation, the suctioned plume allows the tissue base to heal without a devitalized tissue covering. Postoperative pain is reduced because nerve endings are sealed by the beam.

In gynecologic surgery, the most commonly used lasers are CO_2, argon, KTP, and Nd:YAG (**Table 15.2**). The argon and KTP lasers produce light waves of a specific wavelength, giving a characteristic color. The Nd:YAG and CO_2 lasers have wavelengths in the nonvisible spectrum. Accordingly, a helium-neon laser (632 nm, red) is typically coupled with them to use as a beam aiming guide and to aid in focus.

CO_2 Laser

The CO_2 laser is the most versatile and most widely used laser. Laser energy is absorbed, scattered, or affected by the thermal conductivity and local circulation of the tissue. Soft tissue is about 80% water by volume, which absorbs CO_2 laser energy readily, limiting penetration. Indeed, it has a shallow depth of penetration (up to 0.5 mm), and minimal lateral thermal damage is limited to about 0.5 mm. The CO_2 laser is therefore relatively safe and can be used in critical areas where RF energy application would be more dangerous, such as near the bladder, on the lateral side wall near the ureter, and on the bowel serosa. A sharply focused laser beam produces narrow tissue vaporization comparable to an incision made by a scalpel. However, defocusing the beam enlarges the spot, and using the same settings, power density is reduced to treat a thin surface rapidly. The CO_2 laser provides excellent vaporization and cutting by increasing the power density and excellent coagulation with slight defocusing of the beam. The amount of damage caused by heat conduction is directly proportional to the amount of time spent in lasing.

TABLE 15.2 Laser Characteristics

TYPE	LASING MEDIUM	WAVELENGTH (NM)	COLOR	DEPTH OF PENETRATION
Argon	Argon gas	488-512	Blue-green	0.5 mm
KTP	Potassium titanyl phosphate	532	Green	1-2 mm
Nd:YAG	Neodymium-doped yttrium aluminum garnet	1,064	Near infrared	3-4 mm
CO_2	CO_2 gas	10,600	Infrared	0.1 mm

Disadvantages of the CO_2 laser include focusing of the helium-neon beam as well as production of smoke referred to as “plume,” which needs frequent evacuation to allow adequate visualization of the target.

Nd:YAG Laser

Similar to CO_2 lasers, Nd:YAG lasers emit an invisible beam requiring a helium-neon spot for guidance. However, this energy penetrates tissue to greater depths of 3 to 4 mm, and, because the Nd:YAG energy scatters in tissue, its thermal damage is greater than that of CO_2. Poorly absorbed by water, it is not as good for vaporization, but it has much better coagulation properties. Because of its depth of penetration and its performance in a liquid environment, it was used to advantage in the early days of hysteroscopic procedures, including endometrial ablation. Although this laser fiber is typically used in a noncontact technique, adding a sapphire tip to the end of the fiber, the laser energy can be focused and converted into heat and used in a contact mode. This improves its vaporization abilities, but the tips need to be cooled with gas or liquid through the fiber.

KPT and Argon Lasers

The KTP and argon lasers have similar wavelengths in the visible light spectrum and are delivered via a fiberoptic fiber. The advantages of these lasers over the CO_2 laser include selective absorption by hemoglobin and other pigmented tissues and less plume production. These lasers produce a moderate scatter, 100 times that of the CO_2 laser, resulting in significantly reduced cutting ability but substantially increased coagulation effectiveness.

The main disadvantage is the need to wear special glasses that distort the view of the pelvis and make it difficult to visualize small implants of endometriosis.

LASER SAFETY

Lasers have been used in gynecologic surgery for nearly 40 years. Although there has generally been good safety record, there is great potential for injury. It is recommended that surgeons wishing to use laser technology undergo both didactic and practical training in laser use. There are also a few guidelines that should be kept in mind related to use of laser technology:

- Place an appropriate warning sign on the door of the operating room indicating when lasers are being used.
- All operating room personnel should wear protective safety glasses, matched for the wavelength of the laser used.
- When the laser is not actively being fired, it should be placed in standby mode.
- Drapes near the operative field should be flame resistant and kept wet if possible.
- Adequate suction should be available to collect all plume produced by laser use. Understand their specific tissue interactions of the laser being used. It is much easier to cause damage to a vessel or ureter when using deep penetrating energy such as that produced by the Nd:YAG laser than when using the CO_2 laser energy.
- Fibers used to transmit laser energy are delicate and can break, deliver laser energy at the break point, and potentially injure the patient and/or operating room personnel.

SUMMARY

When electricity is used in surgical applications, it follows Ohm law and three general rules: (a) Electricity must complete a circuit or it will not flow, (b) electricity goes to ground, and (c) electricity follows the path of least resistance. An understanding of these concepts, continuous and interrupted waveforms produced by electrosurgical generators and electrical circuits, and the tissue effects produced by active electrode characteristics and manipulation, the surgeon can use radiofrequency energy to advantage in the operating room. Conversely, a lack of understanding by the surgeon can result in poor surgical outcome and unnecessary complications. Just as physicians are expected to understand and prescribe drugs in a precise and logical manner, so should they have a working knowledge of the energy sources they choose to use in surgery.

BEST SURGICAL PRACTICES

Fundamental Principles of Electrosurgery

- Ohm law describes the underlying electrical principle of electrosurgery. Current (flow of electrons) is directly related to voltage (electromotive force) and inversely related to impedance (resistance to flow of electrons).
- Three rules explain the flow of electrons in tissue: (a) Electricity must complete a circuit or it will not flow; (b) electricity goes to ground; and (c) electricity follows the path of least resistance.

- An electrosurgical generator produces sinusoidal waveforms, variants of current, and voltage as a continuous (undamped) output current called CUT, a highly interrupted (damped) output called COAG, or a moderately interrupted (damped) output called BLEND.
- Electrosurgery creates a desired tissue effect by delivering high-frequency AC with active electrodes that

manipulate electrons to sufficient concentration (current density) in living tissue.

- In most circumstances, the CUT waveform should be used to cut and desiccate tissue, reserving the COAG waveform for surface fulguration to control small open bleeders and for superficial coagulation.
- Specific tissue effects can be achieved by using specific waveforms, using contact or noncontact techniques, altering the size and shape of the active electrode, and altering the movement speed of the active electrode (dwell time). The educated surgeon can integrate these variables to achieve the desired result.
- The lower-voltage CUT waveform should be used to incise tissue and for coaptive sealing of larger blood vessels. The higher voltage of the COAG current produces rapid tissue desiccation and carbonation, resulting in increased tissue resistance limiting coagulation to superficial small vessels. The BLEND current may provide a satisfactory combination for cutting through fatty tissues, such as the subcutaneous tissue or omentum.
- Coaptive sealing of the uterine and ovarian vessels using any type of monopolar current may be ineffective if the blood flow remains uninterrupted. Unless a vessel is sufficiently squeezed before electricity is applied, current density is dramatically reduced by conduction in blood, as any heat is dissipated by convection. Bipolar cautery is recommended for these larger pedicles.

Fundamental Principles to Reduce Risk during Electrosurgery

- Place electrode pencils in their safety holster when not in use. This will avoid accidental activation delivering unintended RF energy.
- Inspect each instrument's insulation before use.
- Any alcohol preparation near the field of surgery should be completely dried before initiation of an electrosurgical device to avoid fire.
- With monopolar systems, use a monitored return electrode system (frequently referred to as a REM system). Place return electrodes close to the operative site on a clean, dry, shaved area, avoiding bony prominence and scar tissue. The longest edge should face the operative site, and REM pads should never be cut.
- Cords to electrosurgical devices should be secured using a nonconductor (or plastic) clamp. The cord should never be wrapped around a metal clamp, as this has potential for direct coupling with high output of power or if there is an insulation failure in the device cord.
- Activate CUT for all desiccation-coagulation procedures; use COAG for fulguration procedures.
- Activate the electrode in short bursts (about 3 seconds) to minimize capacitive coupling. Use the manufacturer's recommended connection cables. Inspect instrument insulation before each use. If the usual power settings seem inadequate, do not increase the power until the circuit is checked, especially the return electrode.
- Select the lowest voltage that will create the desired effect. For any given power setting, CUT current produces a lower peak voltage than COAG current.
- If open activation occurs at a site remote from the intended area, the charge has potential to build at the tip of the instrument and discharge via arcing to an alternate site. Moreover, this can cause unrecognized injury out of the operative field of view if performed during laparoscopic procedures. If the surgeon desires true fulguration or vaporization of tissue, the instrument should be activated as near to the tissue as possible without actually touching it.
- Consider using bipolar methods. Bipolar systems deliver current as an uninterrupted CUT waveform calibrated

against a lower resistance than monopolar systems. As such, it is wise to use a current flow meter to confirm complete desiccation of tissue, especially during tubal sterilization. In some tissues, the thermal effect will be limited such that monopolar application will be preferable.

- Consider using bipolar energy for patients with pacemakers and other implanted cardiac devices. If monopolar must be used, follow safety advice from the implant manufacturer.
- The degree of thermal necrosis on tissue that is electrically incised is dependent on the velocity of passage as well as electrode size and shape and the electrosurgical waveform.
- As one electrode is changed to another, the surgeon should keep charge density, waveform, and electrode characteristics in mind and adjust the generator output to match the task at hand.
- The most common complication during electrosurgery is return electrode burns, owing to improper application of the electrode. Prophylactic measures include proper skin preparation and site application. Alternate site burns, such as to cardiac leads, usually result from improper grounding, use of too much power, and high-voltage application.

Fundamental Principles of Electrosurgery Techniques

- Before taking any electrosurgical action, determine the source of bleeding and its proximity to vital anatomy using mechanical tamponade with active hydrolavage. If the bowel, bladder, or ureter is in close proximity to the bleeder, mobilize that structure sufficiently before applying energy.
- Because the output voltage of COAG current is very high, contact coagulation is generally limited to superficial layers. That is because of the accelerated buildup of tissue resistance from rapid desiccation and superficial carbonization. Conversely, electrode contact using the lower-voltage CUT current heats tissue more gradually, leading to deeper and more reliable penetration.
- Preferentially use BLEND or COAG current for a wider zone of hemostasis during incision of vascular tissues and to facilitate dissection of tissues with greater impedance, such as fatty or desiccated pedicles and adhesions. On the other hand, it is more prudent to use the lower-voltage CUT current via the edge of an electrode whenever lateral thermal spread may pose extra liability to adjacent tissues.
- If bleeding in the vicinity of the bowel, bladder, or ureter cannot be controlled with pressure alone, carefully direct short bursts of noncontact COAG current with a broadsurface electrode to attain hemostasis with the least possible amount of electrosurgical penetration. Still, visceral bleeding is best controlled by mechanical means, using the patience of pressure or suture ligation.
- Although the flow of current is restricted to the tissue between the poles during bipolar electrosurgery, this does not eliminate the risk of thermal injury to tissue that is distant from the site of directed hemostasis. As current is applied between the poles, the intervening tissue gradually desiccates until it becomes thoroughly dehydrated.

- Unwanted thermal damage can be minimized by terminating the flow of current at the end of the visible vapor phase, applying current in a pulsatile fashion to permit tissue cooling, and securing pedicles by a stepwise process that alternates between partial desiccation and incremental cutting.
- Because the rate of temperature generation is a direct function of the volume of tissue being desiccated, thermal spread can also be reduced by using the sides or tips of a slightly open forceps to press or lift, rather than coapt for hemostasis.
- As with contact monopolar coagulation, tissue between the electrodes of a bipolar instrument may become

adherent during desiccation. Repeated attempts to shake the tissue free may lead to traumatic avulsion of a key vascular pedicle. A stuck vascular pedicle can usually be unglued by energizing the opened device while immersed in a conductive irrigant, such as saline.

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