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The electrosurgery device market is lucrative and highly competitive. Several device manufacturers exist, and many creative techniques are used to differentiate products. Some device manufacturers make claims in marketing campaigns that are difficult to reconcile with the laws of physics or basic physiology. The variety of claims may be confusing to surgeons desiring to purchase new electrosurgical products. Understanding a few basic principles of electrosurgery physics can allow a surgeon to be a more informed consumer of electrosurgical products. This article discusses the basic physics of electrosurgery and then addresses several common misconceptions about electrosurgery and electrosurgical devices. (Otolaryngol Head Neck Surg 2000;123:450-5.)

Electrosurgical devices are used in nearly every operating room today. A wide variety of these devices are available for purchase, and there is intense competition among manufacturers for market share. In an effort to differentiate their products from those of competitors, several electrosurgical device manufacturers make claims that are difficult to reconcile with the laws of physics, accepted terminology, or current physiologic thought. The purpose of this article is to elucidate the basic concepts of electrosurgery and allow the reader to become a better informed consumer of electrosurgical products.

NOMENCLATURE

The terminology of electrosurgery adds a level of complexity to the device marketplace that can easily confuse those who use these products daily. The terms *electrosurgery, electrocautery, radiosurgery, diathermy, endothermy,* and *radiofrequency heating* have all been used to refer to tissue application of radiofrequency electricity to obtain a desired effect. Several of the terms originally had specific meaning, but over the years the words have been used interchangeably, and their individual definitions have blurred. Many examples of improper terminology in the literature lead to imprecision in the language. In present day vernacular, the terms listed above should be considered synonymous unless contextually specified.

The most common terminology error involves the word *electrocautery.*[1,2] In its classic meaning, *electrocautery* is defined as the use of electricity to heat an object, which is then touched to the tissue to singe vessels. This "hot iron" cautery (used in devices such as the Thermal Scalpel) differs from electrosurgery. Electrosurgery uses radiofrequency electricity to generate heat in the tissue itself rather than applying heat from an outside source. Readers can easily be confused when authors use the word *electrocautery* and do not specify whether they mean hot iron cautery or electrosurgery.

All electrosurgical devices currently available use radiofrequency electricity to heat tissue. The term *radiofrequency* is purely descriptive. The frequency of an electrical signal, in simple terms, is the rate at which the signal's voltage rises and falls. Frequency is measured in cycles per second, and the unit of measurement is Hertz. Electricity from a wall socket in the United States is at 60 Hz, whereas electrosurgical devices deliver electricity between 0.1 MHz and 4 MHz. In the electromagnetic spectrum, radio waves fall approximately within the range of 0.01 to 300 MHz. The electricity delivered by electrosurgical devices is well within the radio wave spectrum and therefore is called *radiofrequency electricity.*

PHYSICAL PRINCIPLES

In the most general sense, heat is simply energy in transit. Molecules and atoms absorb and retain heat through 4 mechanisms. The kinetic molecular theory suggests that energy is realized through translational motion, the movement of molecules or atoms through space. Three other mechanisms that allow atoms and molecules to absorb and retain energy are increased vibration, increased rotation, and excitation of electrons into higher energy states.[3] Increased particle translational, vibrational, and rotational energies are released mostly as radiant heat, whereas electron excitation energy is released as electromagnetic radiation (eg, light) when the electron returns to its usual energy level.

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Heating tissue with radiofrequency energy uses these mechanisms of energy absorption in 2 distinct ways: ohmic heating and dielectric heating. When an electric field is applied to matter, the charge carriers and dipoles (such as water) absorb some of the energy from the field. Ohmic heating, dominant below 500 MHz, increases the translational motion of the affected particles in tissue. Dielectric heating, dominant above 500 MHz, increases vibrational and rotational motion of the affected particles.[4] Ohmic heating is the mechanism of tissue heating by electrosurgical devices; dielectric heating is the mechanism of tissue heating by lasers and microwave ovens.

PLASMA

In recent years we have witnessed an increase in the marketing of “plasma” products. Plasma is a high energy state of matter beyond the gas phase; it is a fourth state of aggregation—solid, liquid, gas, and plasma. A plasma is defined as an ionized gas. The physics of plasma are very complex and only superficially treated here. The reader is referred to the literature for a more detailed introductory discussion.[5,6] Plasmas are most easily formed in a near vacuum, but recently a form of plasma known as a *glow discharge* has been developed in 1 atm and has growing interest for research and industrial applications.[7]

To create plasma, energy is added to a medium (by laser, microwave, radiofrequency electricity, etc) until the electrons become sufficiently excited to escape the attractive forces of the nucleus and move freely about. The amount of energy required to maintain a plasma is related to the number of collisions that the electrons will make in the medium.[8] Consider an automobile traveling at 100 mph. How far do you think it would travel in New York City at rush hour before colliding with other cars, as compared with traveling at the same speed on an open road in Montana? Plasmas are created in gases and low pressures where the molecules are spread far apart, allowing longer paths for the freed electrons to move before collision.

A common example of plasma in nature is lightning. When the voltage difference between the sky and the ground is high enough, the air “breaks down” and forms an ion channel for the electricity to pass through, equalizing the charge. Once the charge is dissipated, the ion channel collapses. This ion channel is a plasma. A similar effect occurs in the arc seen in routine electrosurgery and argon beam coagulation.

In the glow discharge, no arc is formed, but electrons are freed from atoms and are able to move about. This is a relatively low-energy plasma that is seen in nature as aurora borealis and in everyday life in neon signs and fluorescent lighting. The same limits to electron motion apply to glow discharges, so it is difficult to create this type of plasma outside of a vacuum. A considerable amount of work is being done in 1 atm glow discharges for industrial purposes, and there are new surgical equipment sterilization devices that use this technology.[9] Currently available plasma sterilizers, however, still operate in a near vacuum.

TISSUE EFFECTS

Electrosurgical tissue effects result from 2 patterns of tissue destruction: boiling and coagulation. If tissue is heated rapidly, the cellular water boils and steam is formed. This causes the cells to burst, forming the familiar plume of steam and cellular debris. If tissue is heated slowly, cellular proteins coagulate before the water boils. The tissue turns white, slowly desiccates, and if current application continues, eventually chars to carbon and smoke. This effect is similar to heating the albumin of an egg.[10]

The rate of tissue heating is determined by the relative rate at which energy is applied to the tissue. Remember that energy per unit time is power, measured in watts (watts = joules/second). If application of electricity at low power heats an amount of tissue slowly, electricity applied at a higher power to the same tissue will heat that tissue much faster. By the same logic, if electricity applied at a specific power setting heats a unit of tissue slowly, electricity at the same power level applied to a much smaller unit of tissue will heat that smaller tissue unit much faster. This is seen routinely in surgery when tissue is “buzzed” between the tines of a forceps. If there is a sizeable amount of tissue between the tines, it takes longer to achieve the desired effect with the same output settings than if only a small amount of tissue is grasped. This result is not affected by the type of energy applied. The same principle is seen in laser surgery when the spot size is reduced to achieve a more intense tissue response at a specific power setting and in the kitchen when a large pot of water takes longer to boil than a small pot on the same stove setting.

The same amount of total energy can be delivered to tissue with very different effects. For example, the same amount of energy is delivered to tissue if 50 W are applied for 2 seconds or if 20 W are applied for 5 seconds (100 J for each application). Different tissue effects from the two application methods are a result of tissue characteristics and rate of energy delivered rather than total amount of energy delivered. Would you rather be patted on the shoulder 10 times gently or slugged once forcefully to receive the same amount of energy? The rate at which energy is delivered to tissue is the key to obtaining the effects of cellular water boiling or protein coagulation.

Because the rate of energy delivered is critical, it is worthwhile to investigate methods of controlling this parameter. The rate at which energy is delivered to a given mass of tissue from electrosurgical devices can be controlled in 3 ways:

1. Changing the power output of the device.
2. Changing the amount of time the energy is applied to the tissue.
3. Changing the cross-sectional area of application.

Most surgeons choose power output settings to provide the tissue effects desired for a specific procedure. In the surgeon's hands, the time of application of any waveform is an on/off phenomenon controlled at the activation switch. Change in the cross-sectional area of application allows the surgeon precision in achieving tissue effect. The amount of tissue to which the energy is applied is easily varied by use of the flat or knife-edge of a paddle tip, use of a needle tip or ball probe, or application of direct contact or arc. Grasping tissue in an instrument and applying the electrosurgical current to the instrument is also a common way to change the area of application.

Although the rate of energy delivered to any unit area of tissue is the key factor in achieving tissue effects, it is often described in the literature in terms of "current density." Essentially, current density is the amount of electricity passing through any unit area of tissue; it is a description of the cross-sectional area of application. It remains the most fluid and easily controlled parameter of electrosurgical energy application in the hands of the surgeon.

COMMON MYTHS

Medical product marketing is very competitive; anything that increases market share may be very lucrative. To that end, some sales personnel and printed materials present information in a manner that may stretch what is considered accurate. This concept is not new to the medical literature. A study of product information presented by a small group of pharmaceutical sales representatives revealed their information not always to be consistent with manufacturer published data.[11] These results cannot be extrapolated to surgical device manufacturer representatives, or even to all pharmaceutical sales representatives, but they serve as a reminder that physician decisions influence a multibillion dollar industry. Although many sales staff are very knowledgeable regarding their products, physicians should be acutely aware that the job of the sales force is to sell the product.

Several common misconceptions about currently marketed electrosurgical devices are discussed below. Although the fundamental operating principles of all electrosurgical devices are identical, various factors have allowed some devices to achieve a mystique within the medical community, and several common myths perpetuate without substantiation.

Myth 1: Radiofrequency Devices Are Different From Conventional Electrosurgery Devices

All electrosurgical devices on the market today are radiofrequency devices. Most conventional devices found in hospitals and offices operate at a frequency of approximately 500 kHz. However, a variety of electrosurgical frequencies are found across the market. For example, ENTech's (Arthrocare Inc, Sunnyvale, CA) Coblation devices operate at 100 kHz,[12] Somnus' (Somnus, Sunnyvale, CA) devices operate at 460 kHz,[13] ERBE's (ERBE USA, Marietta, GA) constant-voltage devices operate between 0.33 and 1 MHz,[14] and Ellman's (Ellman International, Hewlett, NY) Surgitron FFPF operates at 3.8 MHz.[15] Although there is a greater than 10-fold variation in output frequency of the electrosurgical devices mentioned (0.1-3.8 MHz), the entire range is within a small band of the radiofrequency spectrum.

The range of frequencies described is also well below the 500 MHz point where dielectric heating becomes a significant tissue-heating factor. All of the currently marketed electrosurgical devices heat tissue by the same mechanism—ohmic heating. This principle applies whether they are called *radiofrequency devices*, *radiosurgery devices*, or *electrosurgery devices*. The physical principles of heating are the same for all electrosurgical devices.

A recent article using the Somnus device in turbinate surgery states,

> "RF [radiofrequency] is advantageous over resection, electrocautery, or laser surgery because of the applied biophysics of RF tissue ablation. RF generates frictional heating of the tissues around the electrode as a result of ionic agitation induced at the cellular level because the ions tend to follow a change in direction with the alternating current generated. The heat thus emanates from the tissue and not the electrode."[16]

This statement actually provides a very nice description of the mechanism of heating for all electrosurgical devices—translational motion of charge carriers and dipoles (ie, ohmic heating). A similar description is given in a previous article using the Somnus device.[17] The reader is cautioned to note the use of the word *electrocautery* in this context can be understood only in its classic meaning of using electricity to heat an object that is then applied to tissue (hot iron cautery). The applied biophysics of electrosurgery are the same as the applied biophysics of radiofrequency tissue ablation because all electrosurgical devices use radiofrequency electricity to heat tissue. The description does not differentiate radiofrequency heating of tissue from electrosurgery; the two terms are synonymous.

Myth 2: Collateral Damage From Electrosurgery Is Frequency Dependent

The depth of destructive heating from electrosurgical devices is not a function of frequency. Depth of heating is a function of power output level and duration of power application. More technically it is also related to electric field geometry and tissue conductivity. The amount of unintended tissue damage is limited when minimum necessary power levels are used and excessive application of energy is minimized.

The amount of energy needed to heat a given amount of tissue is not different for one frequency versus another. Tissue follows the same laws of thermodynamics as all matter. The amount of energy necessary to heat tissue is based on the mass and thermal characteristics of the tissue, not the form or frequency of energy applied.

Myth 3: Tissue Healing Is Frequency Dependent

There is a belief that tissue healing may be less fibrous and contractile when a higher frequency electrosurgery device is used to cut tissue than when a conventional electrosurgical device is used. When asked about this claim at a previous American Academy of Otolaryngology–Head and Neck Surgery meeting, an anonymous booth representative provided an article discussing tissue margin analysis in cervical cone biopsy specimens.[18] There is no discussion of healing with or without fibrous tissue throughout the article. A computerized literature search at the time of this writing revealed no articles demonstrating any change in tissue healing due to the surgical application of radiofrequency electricity of any frequency. Healing is a function of tissue physiology. Gentle tissue handling, proper edge approximation, and minimal wound tension remain the cornerstones of minimal scar formation.

Myth 4: A Noncontact Dispersive Pad Functions as an Antenna

A common misnomer in electrosurgery is referring to a noncontact dispersive pad as an antenna. The “antenna,” often available on the vendor floor at Academy meetings, generally functions as a capacitively coupled dispersive pad, first introduced by the Birtcher Corporation in 1960.[4] The basic idea is that the electricity passes from the patient to the pad by a property known as capacitance. Capacitance is the ability to store a charge and exists when any 2 conductors (the patient and the conducting surface of the pad) are separated by an insulator (the insulating coating on the pad and possibly a surgical drape). The importance of this capacitance is that the ease of passing electricity through it is directly proportional to the frequency of the electricity being passed. In the case of higher frequency machines, the electricity is more easily passed, so it is possible to have the insulated pad simply pressed against the patient’s skin rather than adhered like more common gelled adhesive pads. It does not function as an antenna that can be hung in the room like a radio antenna. The noncontact pad does, however, eliminate any risk of reactions to the adhesive gel, as rare as they may be. Anecdotal reports exist of an electrosurgical device that uses an actual antenna as a return path for electricity, but I have never seen documentation or a demonstration of such a device.

Myth 5: Constant-voltage Devices Produce Less Char and Therefore Improved Healing

Constant-voltage waveform devices provide some unique characteristics. For instance, constant-voltage waveforms provide significant safety advantage in laparoscopic procedures,[19] but their benefits in open procedures are less clear. Another effect of the low-voltage waveform is decreased tissue carbonization. Some believe less carbonization allows for improved healing, but this is not definitively shown in the literature. Articles exist showing delayed healing when constant-voltage machines are used.[20] Clearly, there are articles demonstrating results on both sides of this issue, so a blanket statement cannot be made.

Myth 6: Voltage-limited Devices Require Higher Power Settings and Therefore Are More Dangerous

Machine settings for constant-voltage electrosurgical devices are slightly different than those on conventional devices, but this does not affect safety. With a conventional device the power control at the machine sets the actual amount of power delivered. The voltage and current adjust automatically depending on the tissue characteristics, to keep constant the specified amount of power delivered. In a constant-voltage device the current level rises and falls depending on the tissue impedance, but the voltage stays constant. Because power is voltage multiplied by current, the actual power delivered varies with each specific tissue application, so the machine setting is really a power limit. Some users are concerned when first using constant-voltage machines because higher settings are needed to achieve tissue results similar to those of conventional machines. The higher settings are not dangerous, they simply reflect the limits of power delivery rather than the actual power delivered.

Myth 7: Nonarcing Plasma Can Be Generated With Sufficient Energy to Lyse Tissue Molecular Bonds

An industry white paper describes a device that produces tissue ablation as follows:

> ". . . by employing an electrically conductive fluid (eg, isotonic saline) in the physical gap between the electrode and the tissue. Upon applying a sufficiently high voltage difference between these two structures, the electrically conductive fluid is converted to an ionized vapor layer, or plasma. As a result of the voltage gradient across the plasma layer, charged particles are accelerated toward the tissue. At sufficiently high voltage gradients, these particles gain adequate energy to cause dissociation of the molecular bonds within these tissue structures."[21]

Although this description is fascinating, it appears to be based on speculation. Correspondence with one of the white paper's authors suggests there are neither experimental plasma energy level measurements nor computer simulations of plasma energy levels for the device described (Eggers P, personal letter, March 25, 1999). In fact, in his correspondence the author refers to what he calls the "hypothesized plasma." The supporting reference articles supplied mainly involved high-power and very-high-voltage experimentation significantly different from electrosurgery. The calculations provided were rudimentary and assumed a perfect situation that does not account for many real-world factors that would markedly change the result.

The device emits a faint orange glow when activated in saline solution, and spectrographs of the glow are consistent with the sodium spectrum; therefore it seems to be at least moving electrons through energy level transitions, and it may even create a glow discharge. However, the likelihood of creating a glow discharge with electron energies sufficient to lyse tissue bonds is extremely low considering plasma laboratories around the world cannot achieve particle energies in 1-atm glow discharges close to those needed to lyse tissue bonds.

Professor Jan Hugill of the University of Manchester Institute of Science and Technology Plasma Physics Group in the United Kingdom and Dr Rami Ben Gadri of the University of Tennessee Plasma Science Laboratory both study 1-atm glow discharges. They each find it difficult to achieve average electron energies of 2 electron volts while levels of 5 electron volts would be needed to lyse tissue bonds (a substantial difference). Both found the calculations provided by the white paper author to be markedly rudimentary and insufficient to provide a realistic estimate of electron energy for the device.

A possible mechanism of action for the device not mentioned in the white paper is the simple application of radiofrequency electricity to the tissue. The device operates with a voltage-limited 100-kHz waveform in a bipolar fashion. The electricity flows through the saline solution from one portion of the electrode to the other, not between the electrode and tissue as suggested in the device description above. When the electrode is brought in proximity to tissue, the electricity can flow tangentially through the tissue. The vapor layer may act like a "cushion" of electricity, so the current density cannot be too high at any one specific area. Collateral tissue heating is further minimized by the cooling effect of the surrounding saline solution.

Myth 8: Fine-wire Electrosurgical Tips Change Basic Operating Characteristics

Needles and fine wires are used as application tips with various electrosurgical generators. They solely affect the cross-sectional area of application by concentrating the current at a very fine point. The devices maximize the concept of current density. Lower power output may be used to achieve desired effects because less tissue is heated than with a larger application device. There may be less collateral damage,[22] which may be clinically significant in certain situations.[23] A popular example of these devices, the Colorado needle (Colorado Biomedical, Evergreen, CO) is made of very stiff tungsten and is honed to a very sharp point, which allows a level of precision that some surgeons find beneficial. The surgeon must decide whether the added cost of a specialized tip is outweighed by the unique tissue effects or precision gained.

Myth 9: Argon Beam Coagulators Are Not Electrosurgical Devices

There is a popular belief that the argon beam coagulator is a laser device. However, it is actually a monopolar electrosurgery device that passes electricity to the patient across argon plasma rather than through a metal electrode. Argon gas breaks down (ionizes and becomes conductive) at a lower voltage than air, so it is relatively easy to strike an arc across a gap of argon.[24] Standard monopolar coagulating waveform electrosurgical current is passed across the plasma to the tissue. Besides providing a conducting medium for the electricity, the gas blows away blood and fluids from the area being coagulated. As a conductor, the plasma provides a uniform distribution of the energy throughout its cross-sectional area so that the tissue is evenly heated and superficially coagulated.

CONCLUSIONS

The surgeon's ultimate goal using any electrosurgical device is to achieve the desired tissue effect with minimum risk and maximum efficiency. None of the machines described in this article are inherently dangerous. They are all designed with patient safety in mind, and many successful surgeons around the world use each of them. They all have unique properties and features, but the basic concepts and physical principles of tissue heating apply to all the devices. Despite each device's having unique features, some manufacturers feel compelled to make marketing claims beyond what may be reasonable. Understanding the basic principles of electrosurgery physics will allow surgeons to be informed consumers of electrosurgical products.

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