Electrosurgery: History, Principles, and Current and Future Uses

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Within the surgeon's armamentarium, electrosurgical devices stand out as some of the most useful and most-used instruments. Although widely accepted today, the application of electrosurgery was considered a stain on the long-standing traditions of the medical profession until relatively recently. Surgeons who pioneered use of this new technology and developed the instruments were chastised as charlatans. Nonetheless, electrosurgery, and the surgeons who use the instruments, have endured the test of time and are accepted as a welcome part of modern surgery and its history.

Evolution of a tool

Many credit the man for whom the "Bovie" was named with being the father of elecrosurgical devices. But the physical scientific advancements behind these instruments had been known for some time before William T Bovie. Surgeons had used cautery and electricity in medicine well before the early 1920s, when Bovie developed the modern-day instrument and helped bring it to the forefront of the profession. Today there are increasing numbers of applications for electrosurgery in the operating room, but cauterization is unquestionably the most common application of the technology.

The use of cautery dates back as far as prehistoric times, when heated stones were used to obtain hemostasis. Conductive heating of tissue became a well-known tool in medicine used as early as the sixth century BC. The use of electricity in medicine coincided with the earliest scientific discoveries, beginning in the 18th century.[1] Goldwyn described three eras encompassing the development of the modern electrosurgical technology.[2] The first era began with the discovery and use of static electricity. The time frame of this era is unclear. The second era, best called "galvanization," evolved from Luigi Galvani's accidental discovery in 1786. He noted that muscle spasms were induced in frogs' legs hanging from copper hooks as they brushed the iron balustrade in his home. His discovery and subsequent experiments led to the birth of electrophysiology. The third era, dating to 1831, was ushered in with discoveries by Faraday and Henry in England and America, respectively, who almost simultaneously showed that a moving magnet could induce an electrical current in wire.

In 1881, Morton found that an oscillating current at a frequency of 100 kHz could pass through the human body without inducing pain, spasm, or burn (Fig. 1). In 1891, d'Arsonval published similar findings with a frequency lowered to 10 kHz. But d'Arsonval did note that the current directly influenced body temperature, oxygen absorption, and carbon dioxide elimination, increasing each as the current passed through the body.[3] Of note, the temperature was determined to increase proportionally to the square of the current density.

Around the turn of the 19th century, medical uses for electricity began to be realized. Franz Nagelschmidt, in 1897, discovered that patients with articular and circulatory ailments benefited from the application of electrical currents. He coined the term *diathermy* to describe the heating effect discovered by d'Arsonval 6 years earlier. Nagelschmidt's innovation was followed in 1900 by the work of a Parisian physician, Joseph Rivere, who, while treating an insomniac patient with electricity produced by a generator similar to Nagelschmidt's, noted that a spark arcing from an electrode coagulated an area of his skin. He subsequently used this arcing current to treat a carcinomatous ulcer on the hand of a patient. This event has been cited as the first true use of electricity in surgery. During the next decade, the use of electricty in treating lesions of the skin, oral cavity, and bladder, and for coagulation of vascular tumors and hemorrhoids became commonplace.[4]

During the early 1900s, Simon Pozzi used high-frequency, high-voltage, low-amperage currents to treat

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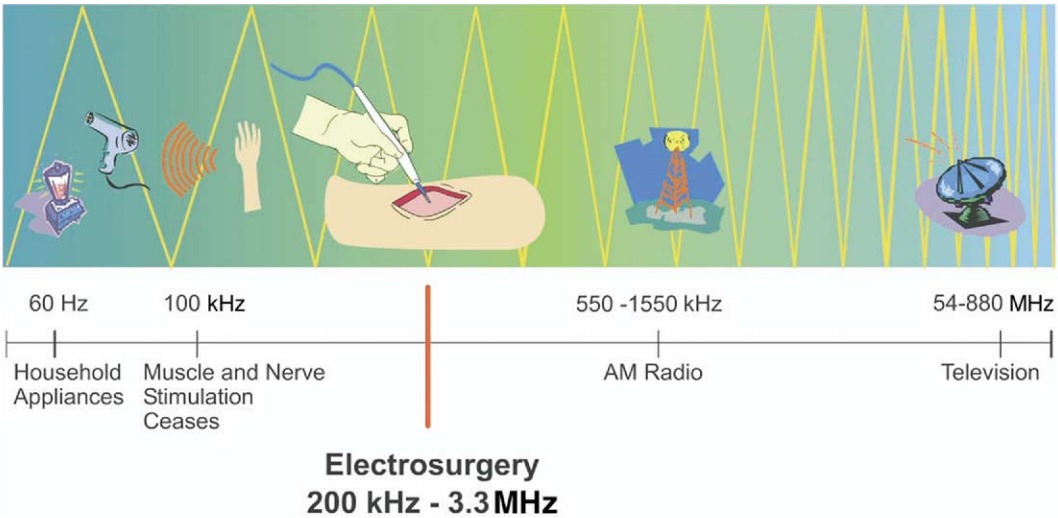

Figure 1. Applications of different current frequencies.

skin cancers, a technique he termed *fulguration.* Doyen improved on this technique by attaching a grounding plate to the generator and placing the plate underneath the patient. He found this helped the current to penetrate deeper into the tissues and had an effect he termed *electrocoagulation*.[2]

Around 1910, William Clark advanced the understanding of the electrical principles behind the electrosurgical apparatus used by Doyen and Nagelschmidt. He altered their apparatus by increasing the amperage and decreasing the voltage generated by the machine, producing a hotter and shorter spark that was capable of penetrating deeper into tissues. Additionally, he substituted a multiple spark gap for the common single one, producing a much smoother current. Under the microscope, he observed that tissues subjected to this current shrunk from dehydration. In 1914, he used the term *dessication* to describe the effect when tissues were destroyed, short of carbonization, by dehydration. He became the first American to routinely use this process to remove malignant growths of the skin, head, neck, breast, and cervix. Clark's alterations to the electrosurgical apparatus of the time essentially set the stage for the work of Bovie and Cushing, leading to development of an early version of the modern instrument used today.

Bovie, basing his electrosurgical unit on the work and discoveries of his predecessors, constructed a diathermy unit that produced high-frequency current delivered by a "cutting loop" to be used for cutting, coagulation, and dessication. The first use of his apparatus in an operating room was at the Peter Bent Brigham Hospital in Boston, on October 1, 1926, when Dr Harvey Cushing used it to remove an enlarging, vascular myeloma from the head of a 64-year-old patient. Cushing had tried to remove the mass by more traditional means several days earlier, but failed because of the vascularity of the tumor.

Cushing, heartened by the success of this operation, began to call on many of his patients previously considered inoperable. Over the course of the next year, Cushing's operative mortality increased significantly, reflecting the increased use of the Bovie apparatus to perform more complex procedures he had not attempted without electrosurgical technology.[4] The Liebel-Flarsheim Co, under the direction of George H Liebel, purchased the patent for the Bovie unit from Bovie himself for $1, and they began producing the unit for use in other operating rooms.[2]

Biophysics

Electrosurgery has been described as high-frequency electrical current passed through tissue to create a desired clinical effect.[5] As the current is delivered, it passes through and heats the tissues. This differs from electrocautery, in which electrical current heats an instrument and a clinical effect is realized when the heated tool is applied to the tissues. Central to the understanding of electrosurgery is an understanding of electrical circuits and Ohm's Law. Circuit is an uninterrupted pathway of flowing electrons and Ohm's Law describes the actions of a given circuit:

$$\text{Voltage} = \text{Current} \times \text{Resistance (Formula 1)}$$

A current is measured as the flow of electrons during a given period of time. Voltage is the force driving a current against the resistance of the circuit. In electrosurgery, voltage is provided by the generator, and current is delivered to the tissues through the electrode tip of the instrument. Resistance to current is inherent within all human tissues. The higher the inherent resistance, the greater the voltage needed for the current to pass. Also, as more superficial tissues are cauterized, they become less electrically conductive, increasing their resistance and requiring higher amounts of voltage for current to penetrate to the tissues beneath.

The laws governing electricity and electric fields are similar to the laws that describe the behavior of fluids. Electrons, when acted on by an electric field, will be set in motion, forming a current that always seeks to travel the path of least resistance, just as water behaves in a gravitational field. A current can be driven in a circuit by an electromotive force supplied by a generator, just as water can be driven by a pump.

Electrosurgery requires the presence of a circuit for current to flow. In the absence of a complete circuit, the current will seek ground. Before 1970, electrosurgical generators were "ground referenced," ie, the flow of energy was in relation to earth ground. In this situation, anytime the patient came in contact with a potential path to ground, the current would choose the path of least resistance. This could potentially result in current flow through an electrocardiogram pad or through an intravenous pole in contact with the patient. If the current density were high enough at the point of contact, there was the possibility for a patient burn. This potential hazard was eliminated with the introduction of generators that were isolated from ground, confining the current flow to the circuit between the electrode and the patient return electrode, which offers a low-resistance pathway for current to return to the generator from the patient[6] (Fig. 2). D'Arsonval discovered that electricity can cause body temperature to rise. The temperature change was noted to be a function of the current density. The transformation of electrical energy into heat occurs in accordance with Joules Law and can be expressed by the following formula:

$$\text{Energy} = (\text{current}/\text{cross-sectional area})^2 \times \text{resistance} \times \text{time} \quad \text{(Formula 2)}$$

Heat given off is a function of current density (current per cross-sectional area), time, and resistance. It is apparent from this formula that the heat produced is inversely proportional to the surface area of the electrode, ie, the smaller the surface area, the more localized heating energy is produced. By the same token, larger electrodes require longer periods of current application to achieve the same heat production.

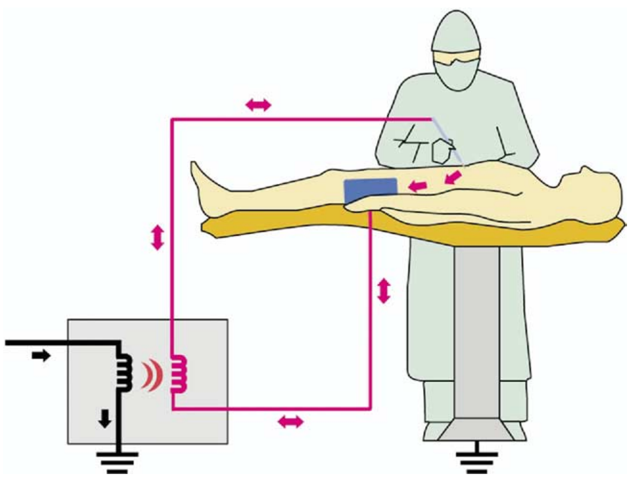

Figure 2. Isolated generator circuit.

The heating effects produced are central to the desired function of the electrosurgical instrument; the rate at which tissues are heated plays a crucial role in determining clinical effect. When an oscillating current is applied to tissue, the rapid movement of electrons through the cytoplasm of cells causes the intracellular temperature to rise. The amount of thermal energy delivered and the time rate of delivery will dictate the observed tissue effects. In general, below 45°C, thermal damage to tissue is reversible. As tissue temperatures exceed 45°C, the proteins in the tissue become denatured, losing their structural integrity. Above 90°C, the liquid in the tissue evaporates, resulting in desiccation if the tissue is heated slowly or vaporization if the heat is delivered rapidly. Once the tissue temperatures reach 200°C, the remaining solid components of the tissue are reduced to carbon.

Electrosurgical generators can apply energy in either a monopolar or bipolar fashion. The monopolar delivery of energy to tissue requires that the current from the generator pass from the active electrode through the patient and out of the body through a dispersive electrode pad connected to the generator to form a complete circuit. Bipolar delivery of energy does not require a dispersive return electrode pad because both the active electrode and the return electrode are integrated into the

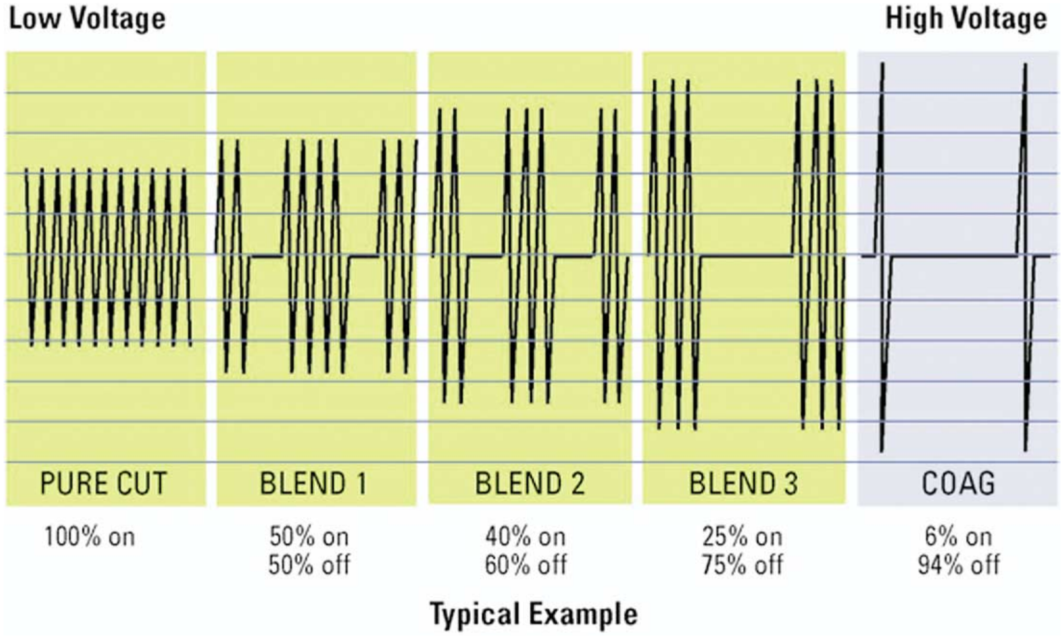

Figure 3. Relationship of instrument settings to voltage and current interruption.

energy delivery forceps with the target tissue being grasped between to complete the circuit.

The current output of electrosurgical generators can be modulated to deliver different waveforms to the tissue, depending on the so-called mode. As the output waveforms change, so does the corresponding tissue effect. In general, electrosurgical generators provide energy delivery in two types of modes: continuous and interrupted. The continuous mode of current output is most often referred to as the "cut" mode and delivers electrosurgical energy as a continuous sinusoidal waveform. The interrupted mode of current delivery is referred to as the "coag" or coagulation mode. In this mode, the time the tissue is exposed to current is significantly reduced to approximately 6% of the time relative to the continuous "cut" mode. To deliver the same amount of power in the interrupted mode as the continuous mode, the output voltage is higher (recall Formula 1, Ohms Law).

Modern electrosurgical generators can offer a wide variety of electrical waveforms. In addition to the pure "cut" mode, there are often blended modes that modify the degree of current interruption (so-called duty cycle), to achieve varying degrees of cutting with hemostasis[7] (Fig. 3).

Because the tissue is exposed to current flow for significantly less time in the interrupted or "coag" mode, it does not heat to the point at which vaporization occurs. Because tissue heating is a function of I^2 (recall Joules Law), the intermittent delivery of current associated with the "coag" mode results in the production of less heat, forming a coagulum as the tissue temperatures rise more slowly. The "cut" mode, on the other hand, with its continuous delivery of current, creates higher tissue temperatures in a shorter time, leading to rapid expansion of the intracellular contents and explosive vaporization.[7]

In addition to output modes and power settings, electrosurgical tissue effects depend on a number of other factors. The size and geometry of the electrodes delivering the energy play an important role in achieving the desired surgical effect. The smaller the contact area of the electrode, the higher the potential current concentration that can be applied to the tissue. This allows the same surgical tissue effect to be achieved with a lower power setting. Time plays an obvious role in the extent of the surgical effect; the duration of the activation of the generator is directly related to the heat produced in the tissue. The greater the heat produced, the more the potential for thermal spread to adjacent tissues.

Perhaps the most important factor in achieving the desired surgical effect with electrosurgery lies in the surgeon's manipulation of the electrode. Whether or not vaporization or coagulation occurs can be a function of how the surgeon holds the electrode with respect to the

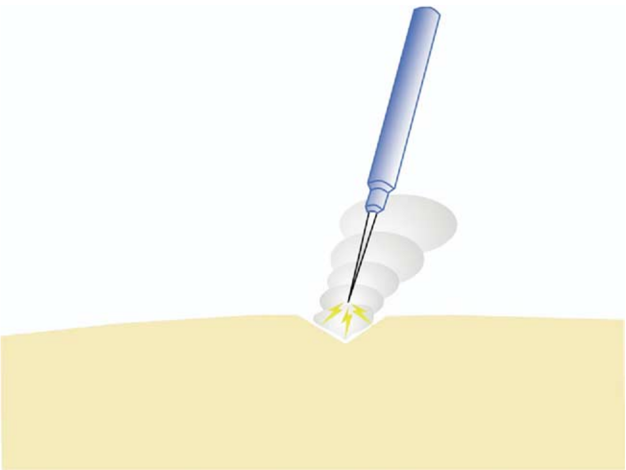

Figure 4. Use of continuous current "pure cut" mode.

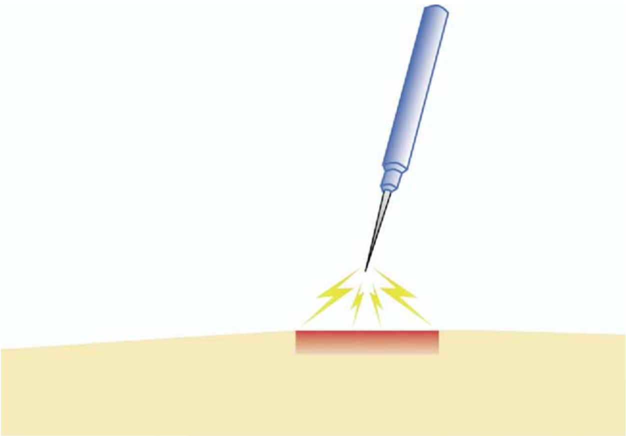

Figure 5. Use of interrupted current "coag" mode resulting in fulguration.

tissue. Allowing arcing of current by holding the electrode in close proximity to the tissue versus activating while in direct contact allows the surgeon to achieve a wide variety of effects at a given generator power output and mode.

Tissue effects that can be achieved with electrosurgery can be roughly divided into three basic groups: cutting, fulguration, and desiccation. Electrosurgical cutting divides tissue with electric sparks that direct intense heat to the tissue over a very limited surface area, producing maximum current density and delivering the greatest amount of heat over a very short time. This causes tissue temperature to rapidly exceed 100°C, vaporizing the intracellular contents of the tissue. The surgeon can most easily achieve this effect by using the continuous or "cut" mode of the generator while holding the electrode slightly away from the target tissue to create a spark (Fig. 4).

Fulguration is most often used in the context of sparking to tissue using the interrupted or "coag" mode of the generator. Because the interrupted mode delivers energy for about 6% of the activation time, less heat is generated and the sparks create a coagulum rather than vaporize the tissue. The higher voltage of the "coag" waveform coagulates and chars the tissue over a larger area than the lower-voltage "cut" mode does (Fig. 5).

Electrosurgical desiccation occurs when the active electrode is in direct contact with the tissue. Contact with the tissue reduces the current concentration, leading to less heat production. This results in the tissue drying out and a coagulum being formed (Fig. 6).

It is possible to cut in the interrupted "coag" mode by using a combination of surgical technique and appropriate adjustment of the generator power output. The benefit of using the continuous current of the "cut" mode is that the desired surgical effect can be achieved with less voltage. As was mentioned earlier, voltage in electricity can be compared to height in gravity. The higher the voltage, the greater the potential energy and subsequent force that the electrons "feel" in a circuit. This corresponds to the potential for increased or uncontrolled thermal spread (Fig. 7).

Types of electrosurgical instruments

Electrosurgical technology offers essentially two types of devices for energy delivery: monopolar and bipolar. The monopolar instrument, the Bovie being the most common example, delivers current through an active elec-

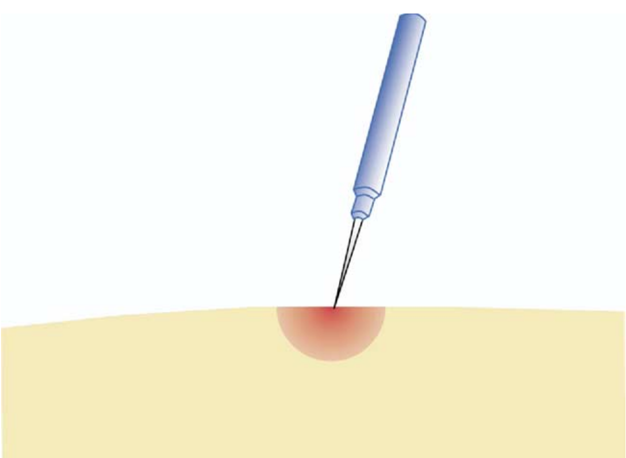

Figure 6. Electrode tissue contact results in desiccation.

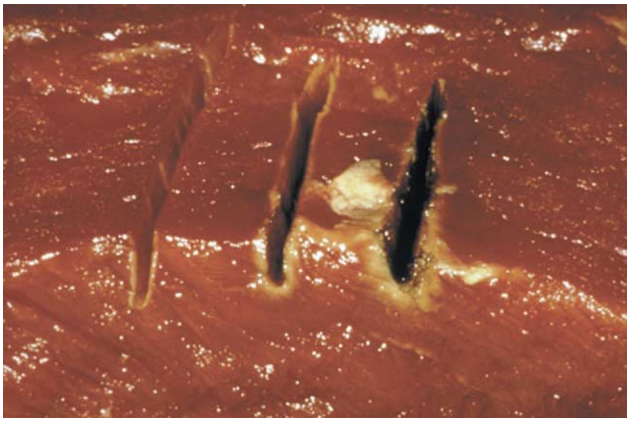

Figure 7. Relative voltage and thermal spread at different generator settings.

trode, which then travels through the patient and back to the generator through a conductive adhesive grounding pad applied to the patient before beginning the procedure. Bipolar instruments resemble surgical forceps, with both the active electrode and the return electrode functions being performed at the surgical site. The electrosurgical energy does not travel through the patient but is confined to the tissue between the forceps. Because of this configuration, bipolar delivery of energy clearly offers very little chance for unintended dispersal of current.

Electrosurgical delivery of energy using monopolar instruments can be enhanced by incorporating a stream of argon gas to improve the surgical effectiveness in maintaining hemostasis over larger surfaces. The argon beam, as it is sometimes called, owes its development largely to liver transplantation, where coagulation of large, oozing hepatic, retroperitoneal, and diaphragmatic surfaces is required. Traditional Bovie electrosurgical pencils do not function in a liquid (blood) environment because the current is dispersed. The argon beam unit overcomes this problem by adding a column of argon gas passing over the electrode, in line with its tip. The argon gas becomes fully ionized by the electrosurgical energy and also acts to displace (blow away) the blood. Because argon is a noble gas, it allows the current to arc from the electrode to the underlying tissue, following the path of the column of gas, creating a diffuse superficial coagulation ideal for obtaining hemostasis over large surface areas. The argon beam units use a standard generator and grounding pad, but typically use a higher current in coagulation mode to desiccate the target tissues.

Figure 8. Obliteration of blood vessel lumen by "vessel-sealing" instrument.

Bipolar electrosurgical instruments have evolved from being used in the coagulation of tissue to the creation of complete fusion of the intimal layers of vascular structures. With recent improvements in computing technology being integrated into electrosurgical generators, the use of sophisticated closed-loop feedback control algorithms has created the ability to fuse vascular structures up to 7 mm in diameter. This allows the surgeon to create an "autologous clip" to achieve hemostasis without suture, staples, or traditional clips. These "vessel-sealing" devices were first introduced in 1998 (Fig. 8).

Current uses

Electrosurgical instruments are undoubtedly some of the most useful and most-often used tools at the surgeon's disposal. But there are potential applications for which these instruments are not commonly used. For example, there is a pervasive dogma in surgery that skin is to be opened using the traditional scalpel, and deeper tissues may then be opened using the electrosurgical tool. The theory behind this proposition is that use of the Bovie causes worse cosmesis at closure and predisposes surgical wounds to postoperative infection. It is believed that electrosurgery devitalizes tissues at the wound edges, leading to approximation of dead tissue at closure.

There is literature that supports use of electrosurgical instruments to open both superficial and deep tissues during laparotomy. As discussed previously, in cutting mode, the electrode rapidly heats cells to the point of vaporization. The excess heat is dispersed as commonly noted smoke and steam, but is not passed to the tissues adjacent to the incision site. So an electrosurgical incision is not a true cutting incision, and this may further explain the lack of tissue char and minimal scarring on wound healing.[8] Kearns and colleagues[9] showed that an electrosurgical incision can be used with good results during laparotomy as compared with scalpel incisions. In this study, patients opened with monopolar electrosurgical pencil electrodes (Bovies) had comparable rates of wound infection to those opened with scalpel and lower pain scores immediately postoperatively on days 1 and 2. Pearlman and associates[10] published data that support the use of electrosurgery as compared with scalpel or CO_2 laser in opening tissues after skin incision with the scalpel. Open cholecystectomy wounds carried deeper with electrosurgery had significantly faster incision times and significantly less incisional blood loss as compared with those done with scalpel or laser, with no significant difference in subjective or objective patient pain. The benefits of such data supporting the exclusive use of electrosurgery at laparotomy in this era of increased rates of surgical exposure to hepatitis C-, hepatitis B-, and HIV-infected patients should be evident.

The recent application of bipolar electrosurgery in the sealing of vessels has seen growing clinical acceptance. Electrosurgically sealed vessels demonstrated clinically equivalent bursting pressures when compared with vascular staples, titanium clips, and sutures, and significantly higher pressures when compared with the harmonic scalpel in vessels in the 4- to 7-mm diameter range.[11-14]

Vessel sealing with electrosurgery has found favor in a variety of general surgical procedures, including splenectomy, thyroidectomy, hepatic lobectomy, pulmonary resection, hemorrhoidectomy, gastric resection, and nephrectomy. Romano and coworkers[15] reported success using the LigaSure Vessel Sealing System (Valleylab) in performing laparoscopic splenectomy on 10 patients. This study demonstrated a 10% conversion rate for bleeding, lower than other published studies. In addition, operative time was significantly lower, as was average amount of intraoperative bleeding. Head and neck surgeons have shown very favorable results when using the LigaSure electrosurgical vessel sealing in thyroidectomy, demonstrating reduced operating times and incision length.[16,17] The LigaSure has also been successfully used in hepatectomy.[18] In a series of six patients (three right, two left, and one partial hepatectomy), the LigaSure was used with rapid and effective results, demonstrating minimal blood loss from the cut surface and without morbidity or mortality. Similarly, we have demonstrated a low complication rate and low operative blood loss using vessel-sealing techniques.[19]

Complications

Although the use of electricity in surgery is highly useful and effective, it is not without possible complication. From the 1970s through the 1990s, the reported incidence of electrosurgical injuries has remained at roughly 2 to 5 per 1,000.[20-22] Regardless, the exact incidence of electrosurgical complications is difficult to pinpoint and, in many cases, is operator dependent. But these types of injuries do constitute a significant amount of morbidity associated with surgery. Understanding the scientific and physical properties of electrosurgical instruments can help the surgeon and operative team reduce the incidence of complications and increase the efficiency of use.

Users of monopolar electrosurgery in patients with pacemakers or implantable cardioversion devices should consult with the manufacturer of the devices before operating to avoid interference with the implants and the potential for current concentrations in the tips of the lead wires. When using monopolar electrosurgery on patients with prosthetic conductive joints, every effort to place the conductive joint out of the direct path of the circuit should be made. If a patient has a left hip prosthesis, for example, the return electrode pad should be placed on the patient's right.

There is a misconception that current can be delivered only through the tip of the instrument's electrode; this is not the case. The surgeon's attention will generally be focused on the tip of the electrode, where it is expected all the current will be delivered. In fact, current may be delivered anywhere from the tip of the electrode to the hands of the operator. Although it is not common for current to pass from a point other than the tip, it does occur. Wu and coauthors[23] cited the main reasons for instrumentation failure as the following: direct application, insulation failure, direct coupling, or capacitative coupling. When an electrosurgical instrument is placed on the surgical field, it can be inadvertently activated either by a hand or another instrument. When this occurs, current will be delivered, possibly causing injury. The electrosurgical electrode is almost entirely surrounded by insulation (minus at the tip, where current delivery is intended). Any visible or unseen defect in the insulation can lead to most, if not all, current being delivered through the defect to unintended sites. Although reused instruments have higher rates of insulation breakdown with time, disposable instruments can also have defective insulation. Surgeons routinely use the "coag" mode, which is comparatively high in voltage relative to the "cut" mode. The higher voltage can spark through compromised insulation or even disrupt and arc

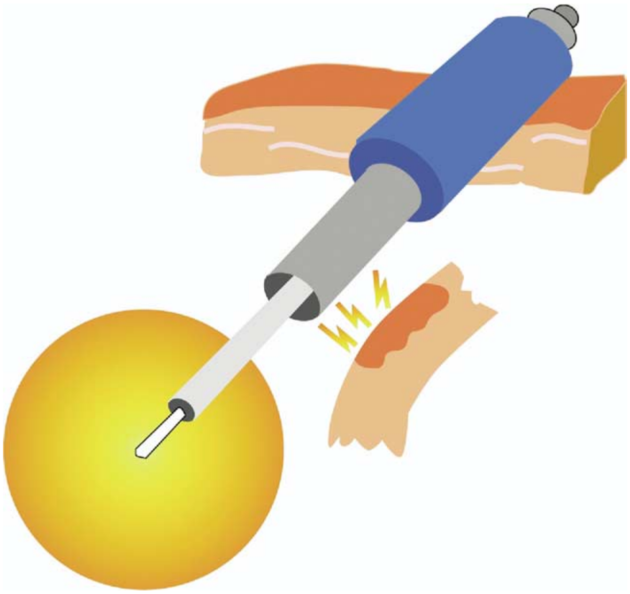

Figure 9. Reduction of capacitive coupling injury risk by dispersing energy over larger surface area.

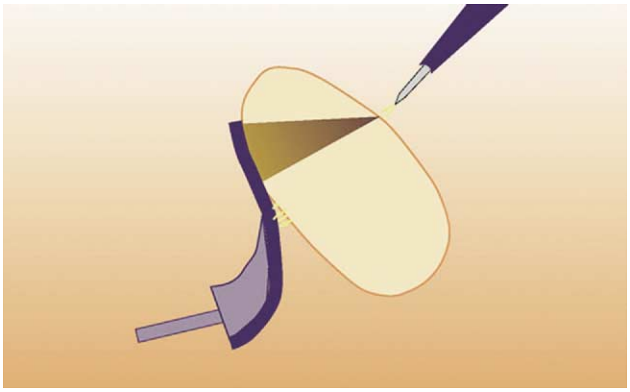

Figure 10. Off-site burn caused by poorly adherent grounding pad.

through weak insulation, creating the potential for an alternate current path. Use of the "cut" mode while holding the active electrode in direct contact with the tissue can achieve the desired hemostatic effect while reducing the potential for insulation failure. This is particularly desirable in laparoscopic procedures, during which the potential for out-of-visual-field injuries is increased.

Coupling occurs when the tip of the electrode comes in contact with a metal instrument while current is being delivered. This is generally an easily avoidable complication because it often happens at a site in plain view, but the potential for injury in laparoscopic surgery is high because the newly energized metal instrument might be in contact with the patient outside of the field of view.

A capacitor can result whenever a nonconductor is placed between two conductors in an electrical circuit. During laparoscopic procedures, an inadvertent capacitor can be created when the electrode insulation is surrounded by the conducting electrode and a conducting cannula. A capacitor creates an electric field that can induce current flow in the cannula. Capacitative coupling of the active electrode to a conductive cannula can generate a great deal of electrical energy, particularly when the electrode is activated before making contact with the target tissue. This energy can result in patient injury whenever the cannula makes contact with tissue, especially in the situation of a hybrid trocar system in which the cannula is conductive and the anchor is nonconductive. Although capacitive coupling cannot be avoided, the potential for injury can be eliminated by using all conductive trocars, which allow the energy to dissipate over a larger surface area on the patient's skin rather than at an area of high current density along the cannula (Fig. 9).

Off-site burns are another possible complication. This type of injury is a result of improper grounding. When an adhesive grounding pad is completely adherent to the patient's skin, it provides a sufficient dispersive area for current density flowing from the patient back to the generator. Conversely, if the grounding pad is not completely adherent, the interface is compromised and current density may become too high at one point of the skin/pad interface, resulting in a burn (Fig. 10). Alternatively, if the patient is not properly grounded, the current may seek other grounding points such as electrocardiogram leads, causing burns at remote sites.

Electrosurgical injuries may also affect the surgeon. Surgical gloves are misperceived as offering insulation from radiofrequency current when, in fact, they do not. There are three ways in which current can penetrate gloves: hydration, in which the wet glove becomes conductive; capacitative coupling, as described previously; and breakdown of the glove.[24]

Proper use and safety

Although electrosurgical instruments are commonly used, they are powerful and potentially dangerous, and most surgeons and residents do not receive any formal training in their proper use.

The following are some suggestions to avoid injury to

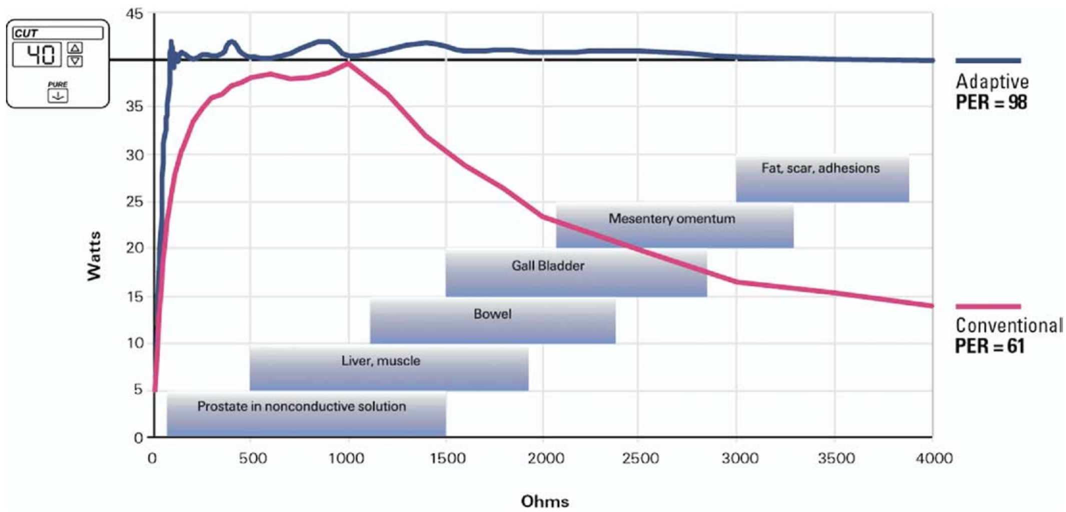

Figure 11. The difference between an "adaptive" generator and one that does not sense the impedance and adjust accordingly. PER = {1 − [(desired power output) − (delivered power output)]/(desired power output)} * 100.

the patient and to the surgeon and operating team. First, the simplest means of avoiding injury is to always use the lowest possible generator setting that will achieve the desired surgical effect and to never exceed the power settings recommended by the manufacturer. When higher than necessary voltages are used, the chances of arcing and capacitative coupling are increased.

Frequent cleaning of the electrode tip is recommended. As eschar builds up on the tip, impedance increases and can cause arcing, sparking or ignition and flaming of the eschar. When cleaning the electrode, the eschar should be wiped away using a sponge rather than the common scratch pad, because these pads will scratch grooves into the electrode tip, increasing eschar build-up.

It is important to remember that surgical gloves do not insulate against the radiofrequency current delivered by the Bovie. This is why burns to surgeons can and do occur. When using hemostats or a forceps to deliver current to a bleeding vessel from a monopolar electrode ("buzzing the hemostat"), the surgeon should not touch the patient with his free hand. By holding the forceps and then touching the patient with a separate part of the body, a new circuit is created and offers an alternate pathway for current to travel. (Instead of through the forceps to the patient, the current in this example travels through the forceps, through the surgeon's arm and body, and then into the patient.) The potential for a burn can be further mitigated by firmly grasping the forceps, providing greater surface should a secondary current path occur. In addition, use of the lower-voltage "cut" mode will also decrease the risk of a burn while "buzzing the hemostat." Avoiding open circuits and leaving space between the electrode and the surgical instrument when delivering current though a forceps can also increase metal-to-metal arcing and the chances of burn.

As mentioned earlier, insulation can be defective at any point on these instruments. Current can leak through small defects in the cord connecting the electrode to the generator. When more than one cord is placed on the surgical field, it is recommended that these cords not be bundled together and that they not be wrapped around metal instruments affixed to the patient, because current can unintentionally pass at any of these points and burn the patient. When the electrode is not being used, it should be placed in an insulated holster rather than on the surgical field. This will help to avoid accidental discharge of the instrument and consequent burns to the patient or surgeon.

Future directions

Electrosurgery is a continuously evolving field, with active research into new applications. Today's electrosurgical generators use closed-loop control loops to adjust the voltage and current to keep the output power constant as the active monopolar electrode moves through tissues of varying impedance. These "adaptive" generators are a significant improvement over those used in traditional electrosurgery (Fig. 11).

Because the ability to incorporate more sophisticated computer chip technology into electrosurgical generators has grown, the potential for increasing clinical applications has evolved at a dramatic rate. Radiofrequency energy is now being used extensively for ablative therapy in a number of target tissues. From cardiac arrhythmias to hepatocellular carcinoma, electrosurgical radiofrequency energy is finding new applications.[25]

Building on experience with vessel sealing and protein fusion, the future may see successful sealing of lung parenchyma and anastamosis of bowel and blood vessels performed using optimized delivery of electrosurgical energy.[26,27] This technology may similarly allow for fusion of skin grafts without the need for foreign bodies.

In the not-too-distant future, herniorrhaphy may be accomplished by fusing alloderm or similar tissue to the margins of the defect, eliminating the need for and complications of prosthetics.

In conclusion, mastery of electrosurgery remains a fundamental skill in the repertoire of the accomplished surgeon. Central to the development of this skill is a complete understanding of the biophysical aspects of the interaction of electrosurgical energy and tissue. Continued research into the area of tissue interaction shows promise in the potential development of novel applications of electrosurgery. In addition to improved electrosurgical cutting and hemostasis, tissue fusion and ablation have seen increasing application in the surgical setting. A more thorough understanding of the technology is essential to the safe and effective application for improved patient outcomes.

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