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Pearls, Pitfalls, and Advancement in the Delivery of Electrosurgical Energy During Laparoscopy

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The use of electrical energy for surgical purposes dates back nearly a century. In 1910, William L. Clark, MD, a general surgeon from Philadelphia, was the first to introduce into practice what, in the United States, is now known as electrosurgery. The Germans and the French preceded Clark in the use of electricity in surgery. Electrosurgery consists of the generation and delivery of radio frequency current between an active electrode and a dispersive electrode to increase tissue temperature for the purposes of cutting, fulguration, and desiccation. In contrast with electrocautery, the electric current actually passes through the tissue. Harvey W. Cushing, MD, was the first surgeon to document (1), in depth, the principles of both the art and the biophysics of electrosurgery, with the assistance of William T. Bovie, Ph.D. (2). These early documents detail Cushing's appreciation of and enthusiasm for Bovie's device and the versatility of electrosurgery. During Cushing's years of practice, he changed the course of neurosurgery and other surgeons' views of the potential uses of the technique. With the increased acceptance of laparoscopic access for major surgical procedures, it is clear that the fundamental therapeutic modalities for electrosurgical energy must be understood to enhance the art of delivery in practice. It is equally important to maximize the safe delivery of this most commonly used energy source. This chapter introduces the fundamental therapeutic modalities and discusses the inherent risks of electrosurgical energy during laparoscopy and the methods available that allow the surgeon to deliver electrosurgical energy with the same level of patient safety and confidence as in open laparotomy.

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MONOPOLAR ELECTROSURGERY

Surgeons have used monopolar electrosurgery to cut tissue and control bleeding in open procedures since the 1930s. Today, monopolar electrosurgery is also "the most widely used cutting and coagulation technique in minimally invasive surgery" (3); it minimizes blood loss, provides a dry surgical field, and reduces surgery time. At a 1993 meeting of the American College of Surgeons (ACS), 85.6% of 506 surgeons surveyed said they used monopolar electrosurgery for laparoscopic procedures (3). Other energy sources (such as bipolar electrosurgery, lasers, and the harmonic scalpel) can be applied laparoscopically, but because they have limited clinical efficacy, they are not as popular (4).

A monopolar electrosurgical system consists of a generator, an active electrode, and a return electrode. A complete circuit runs from the generator, via the active electrode to surgeon's target site, through the patient's body, to the return electrode, and finally back to the generator. In recent years, perioperative nurses are the health professionals who have led the way in advocating use of advanced technologies and equipment to improve patient safety during monopolar electrosurgery.

The generator, or electrosurgical unit (ESU), changes the low-frequency current that originates from a normal electrical outlet into the high frequency or radio frequency (RF) current used in electrosurgery. This is to virtually eliminate neuromuscular and muscular stimulation.

Temperature and Tissue

Energy cannot be created nor destroyed, but it can be converted from one form to another. In electrosurgery, electric energy is converted into heat at the active electrode target site for the purposes of vaporizing (cutting) and coagulation. Table 1 shows temperature rise and effect on tissue condition. These data will apply to a later discussion specific to electrosurgical modality and effects on tissue or vessel.

How Electrical Energy Affects Tissue Temperature

The three electrical properties that cause temperature rise are as follows.

Current = I
Voltage = V
Resistance (Impedance − Z) = R

To explain these electrical energy terms, an analogy can be made to a hydraulic energy source. The water tower shown in Figure 1 is a source of work, which is analogous to an electrosurgical tower, and the electrical terms current, voltage, and resistance are demonstrated. Such a model diminishes the mystique of the electrosurgical principles that follow.

Ohms law (I = V/R) shows the relationship between the properties of electrosurgical energy is shown.

Power formula

The energy (in joules) that the surgeon induces in tissue creates an increase in temperature

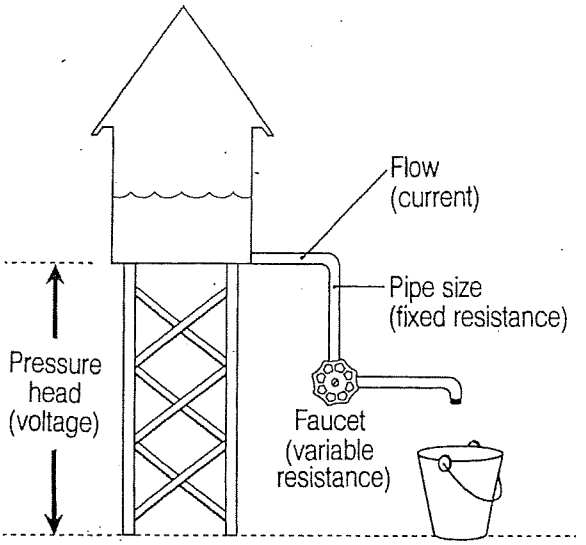

FIG. 1. Voltage is analogous to the pressure head on a column of water. Current (water flow) is dependent on the pressure head and resistance (faucet position) in the system.

that is equal to the wattage multiplied by time, where watts (W) = V × I. The ratio V:I of the electrosurgical waveforms is primarily responsible for the observed effects on the tissue, when time and electrode size are kept equal.

Power density can be shown as follows: power density = (I density)^2 × resistivity. Power density is the relationship between the size of active electrode in contact with tissue and the effect on tissue at a given energy setting. In non-contact modalities (i.e., cutting and fulgurating), this would be equivalent to the sparking area between active electrode and tissue. The exact surface area of the electrode in contact with the tissue is important when calculating power density only when desiccating. During fulguration and cutting, the electrode is not in contact with the tissue.

TABLE 1. *Effects of heat on tissue*

	Temperature (° C)					
	34–44	44–50	50–80	80–100	100–200	>200
Visible effect	None	None	Blanching	Shrinkage	Steam "popcorn"	Carbonization
Delayed effect	Edema	Necrosis	Sloughing	Sloughing	Ulceration	Larger crater
Mechanism	Vasodilation Inflammation	Disruption of cell metabolism	Collage denaturation	Desiccation	Vaporization	Combustion of tissue hydrocarbons

The tissue effects of heating are best categorized by the immediate visible effect (surgeon feedback mechanism), the delayed effects, and the mechanism of injury. The delayed manifestation of full-thickness intestinal injury from thermal energy is the major cause of morbidity and mortality after accidental bowel burn.

Therefore, the power density can only be approximated. Also, because the electrode is in motion during cutting and fulguration, the exact energy (in joules) at the surgeon's target site is difficult to calculate accurately.

In general, the larger the electrode's surface area, the lower the power density. The smaller the electrode's surface area, the higher the power density.

Time

The time element is one of the primary components that will determine the depth and degree of tissue necrosis at a given energy setting. Many other components contribute to this discussion, but time is important as will be demonstrated in the following sections.

ELECTROSURGICAL MODES: CUT, FULGURATE, DESICCATE

Cutting, fulguration, and desiccation are the three distinct therapeutic effects to tissue that electrosurgical energy has been reduced to practice. Unfortunately, most ESUs are simply labeled by two modes, "cut" and "coag." This limited selection of terms does not help clarify the present confusion so that the surgeon can optimize the delivery of this energy. In open procedures, the optimal use was overcome often times by vantage point. The surgeon has direct access to the surgical site, therefore, classical devices, such as hemostats and/or suture, could be used in place of electrosurgical energy.

CUT MODE

In the cut mode, a high-current low-voltage (continuous) waveform increases the tissue temperature rapidly (to temperatures >100°C) and produces vaporization or division of tissue with the least effect of lateral thermal spread (hemostasis) to the walls of the incision. Figure 2 shows the cutting waveform with ESU set at 50 W.

During optimal electrosurgical cutting, the active electrode does not make contact with the target tissue. The current is passed through a seam bubble (vaporized tissue) created by the rapid temperature increase between the active electrode tip and the tissue. Therefore, it is important to recognize that electrosurgical cutting is a noncontact means of dissection. The electrode floats through the tissue, and there is very little tactile response transmitted to the surgeon's hand. The dynamics or velocity, as well as the waveform, of the electrode significantly dictate the depth and width of the necrosis in the incision. Very small (<100 μm) lateral thermal necrosis is attainable with fine tip electrodes during electrosurgical dissection or vaporization.

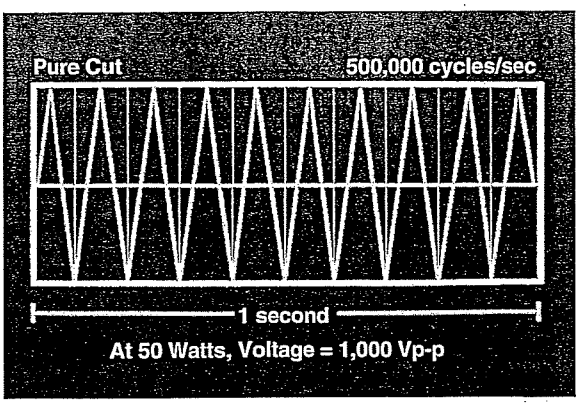

FIG. 2. Pure cutting waveform: continuous flow of current.

The continuous waveform is analogous to the garden valve shown in Figure 1, which has a constant even flow of water. Because of the constant flow of electric current and the lowest possible voltage used in dissection, the width and depth of necrosis to the walls of the incision are minimal. Therefore, the ratio of high current to low voltage within the waveform produces less lateral necrosis when cutting electrosurgically. When the electrode is allowed to remain stationary or is slowed, the maximum temperature attained is increased; therefore, the width of thermal damage to tissue is also increased.

BLEND MODES: 1, 2, 3

The ratio of the cutting waveform can be modified by interrupting the electric current and increasing the voltage (i.e., changing the electric current and the voltage product). In this way, the waveform becomes non-continuous with a train of energy packets consisting of higher voltage and reduced current per time (Fig. 3). Total energy remains the same and the ratio of voltage and current is modified to increase homeostasis

during dissection with electrosurgical current (Fig. 4 shows therapeutic effects of cut and blend modes).

This would be analogous to the garden valve pulsing water. An increased water tower height makes up for the reduction of hydraulic energy, thereby reducing the time that the water is allowed to flow. When the blend modes are also used, the electrode should float through the tissue. The blend waveforms require a longer time to dissect the same incision length as the cutting waveform. This is because of the interrupted delivery of electric current at the same power setting. An increase of time results in an increase of thermal spread from the voltage component of the blend waveforms.

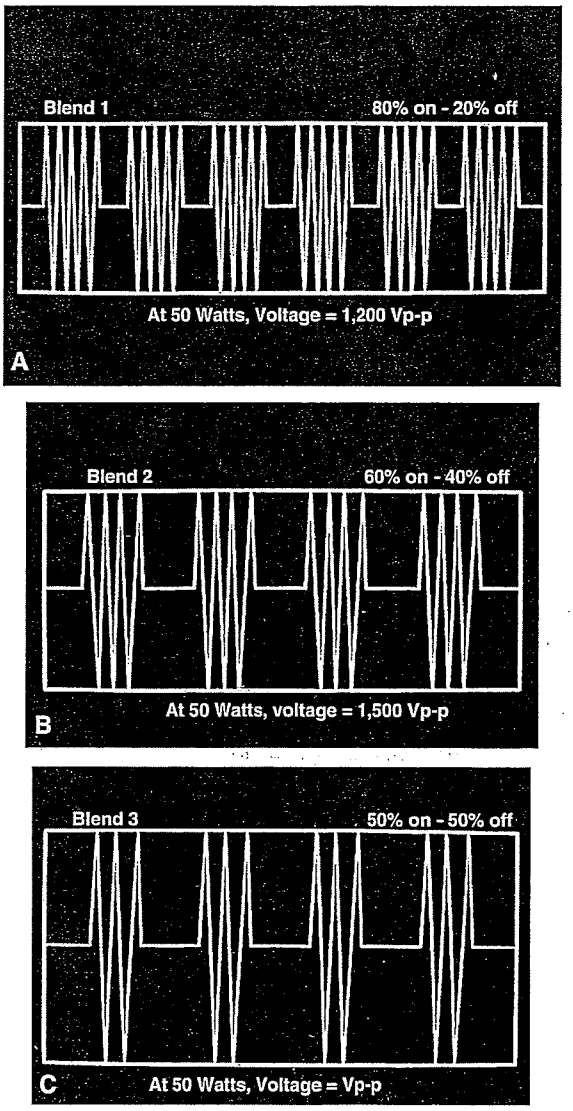

FIG. 3. Blend 1, blend 2, and blend 3. All blend modes have an interrupted or modulated waveform. A train of energy packets consists of higher voltage and reduced current per time.

FIG. 4. Therapeutic effects of pure cut, blend 2, and blend 3, shown left to right.

This increase of thermal spread improves coagulation of small vessels during the dissection. When needed, these blend modes can be a very valuable tool to control excessive bleeding. However, when blend modes are used unnecessarily, the increased width of necrosis may result in a higher level of postoperative infection as a result of the increased amount of tissue necrosis. The greater tissue destruction results in extending the patient's morbidity and may make surgical plains more difficult to recognize. Also, the amount of smoke plume will increase in laparoscopy when using higher blend mode or dissecting with the coag modes. Blend 1 has slightly increased homeostasis, blend 2 moderate, and blend 3 has a marked increase in homeostasis during dissection (Fig. 4).

When dissecting tissue with a cut or blended mode, the ESU should be activated first, before the electrode touches the tissue. Once good tension of the tissue is attained, use a feathering or light stroking action similar to fine touch work when painting with a very fine bristle paintbrush. This technique allows maximum power density when the electrode approaches the tissue just before contact. This helps initialize vaporization or dissection of tissue. In theory and in practice, with optimum technique and control setting, the force required to dissect tissue would be 0*g* of pressure between the electrode and the tissue.

Fulguration Mode

A high-voltage low-current non-continuous waveform (highly damped) is designed to coagulate by means of spraying long electrical sparks to the tissue (Fig. 5 shows coagulation [fulguration] waveform set at 50 W).

The most common use of fulguration is when coagulation is needed in an area that is oozing, such as in a capillary or arteriole bed, where a discrete bleeder cannot be identified. The benefit of fulguration is its ability to stop oozing emanating from a large area in a most efficient manner. Cardiovascular, urology, and general surgeons have relied on fulguration for their most demanding applications (i.e., hepatic resections, bleeding from a bladder tumor resection, and surface bleeding on the heart). In fulguration, a superficial eschar (carbonization of tissue that requires ≥200°C temperature rise) is produced; the depth of necrosis is minimal because the electric current or power density is defocused. Note that the spark (plasma) observed during fulguration is 700°C. The act of drawing the electrode away from the tissue decreases the power density (defocusing the energy or current). A great deal of the energy is dissipated in heating the air between the electrode and the tissue, through which the current must pass. Fulguration and electrosurgical cutting are non-contact modalities. Initiate fulguration in two ways: (a) Ever so slowly approach the tissue until a spark jumps to the tissue, whereby a raining effect of sparks will be maintained until such time the electrode is withdrawn or the tissue is carbonized to the point where the sparks cease. (b) Bounce the electrode off the tissue; this produces a raining effect of sparks to the tissue without taking the effort to approach the tissue slowly until a spark jumps without touching.

Electrosurgical fulguration is the most effective means of arresting capillary bleeding or any oozing type of bleeding. Fulguration is also the most forgiving in protecting against deep tissue necrosis. Before fulgurating, it is key to evacuate blood or saline fluid from the target site. Time and energy are wasted when sparking to a pool of blood or saline. Evacuate or dilute (washing) the field with non-isotonic solutions (such as glycine or sterile distilled water) to pinpoint the target site. Now, the electric current can be applied at the exact site of bleeding, which in turn will enhance efficacy.

The depth of necrosis can range from 1/2 mm to 2 mm, depending on how long the surgeon allows the sparks to flow to the target site. The key is to stop fulguration the moment that bleeding has stopped. The energy setting on the ESU multiplied by time equals total joules delivered. This is important in controlling depth of necrosis by limiting the number of joules delivered at each target site.

Desiccation Mode

Any waveform can be used for desiccation when the electrode comes in contact with the tissue for the first time (Fig. 6). Regardless of the ratio between current and voltage when the electrode comes in contact with the tissue, the magnitude of energy in wattage is of the greatest importance. Desiccation is another form of coagulation. Most surgeons do not make a distinction between fulguration and desiccation and they refer to both as coagulation. Applying electrosurgical current by means of direct contact with the tissue will now result in conversion

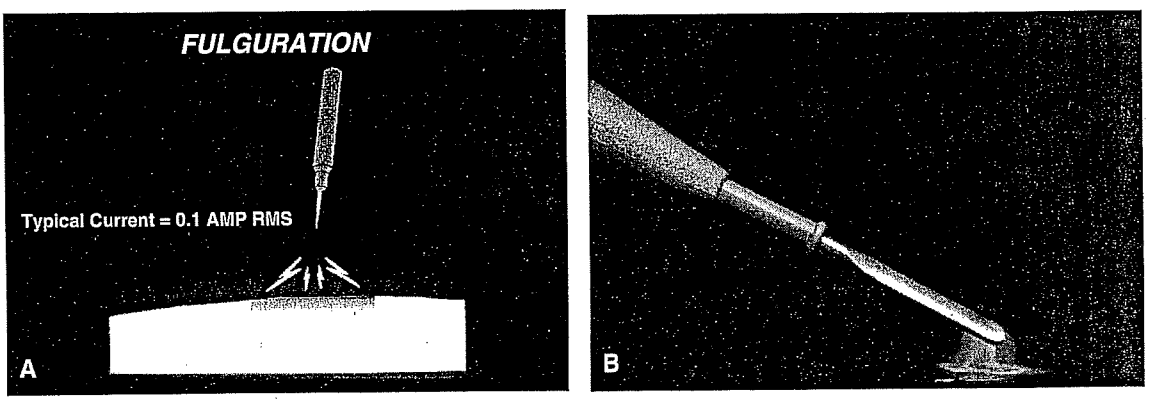

FIG. 5. Fulguration is the non-contact mode for controlling capillary bed bleeding. The spark (plasma) observed is 700°C. Tissue effect results in a superficial ester. Depth of necrosis can be limited.

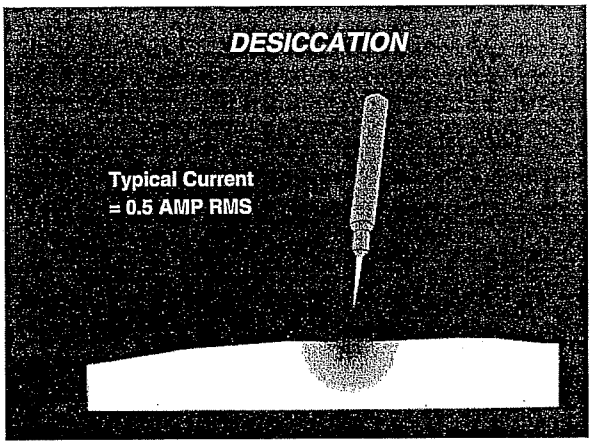

FIG. 6. Desiccation involves contact coagulation or deep ablation of tissue. Desiccation is most commonly used for coaptation of a vessel in conjunction with a hemostat or, during laparoscopy, a grasper or dissector hinged instrument.

of all the energy (set on the ESU) into heat within the tissue (desiccation temperature range, 80°C–100°C). By contrast, during cutting and fulgurating, a significant amount of the electrical energy is dissipated into heating the atmosphere (air or CO_2) between the electrode and the tissue.

Therefore, with contact coagulation or desiccation, the increased energy delivered into the tissue results in deep necrosis. The necrosis is as deep as it is wide, as observed on the surface, where the electrode makes contact (Fig. 6).

The most common application of desiccation is when a discrete bleeder is encountered and a hemostat or a grasper-dissector in laparoscopy is introduced to occlude the vessel first by mechanical pressure, then by application of electrosurgical energy to the hemostat or grasper. In this way, the electric current must pass through the hemostat or grasper into the tissue that is grasped by the jaws and back to the electrosurgical unit via the return electrode. Coaptation of vessels with electrosurgical current produces a collagen chain reaction, resulting in a fibrous bounding of the dehydrated denatured cells of the endothelium (5). Because the electrode is in good electrical contact with the tissue, the voltage-current ratio is not nearly as important as in cutting and fulgurating. However, in practical application, the cut or blend waveforms are superior for this application compared with the fulguration waveform when desiccation is desired. The primary reason is the fulguration waveform will tend to spark through the coagulated tissue, resulting in voids in the bonding to the end of the vessel. Also, when sparks occur at the electrode in contact or near contact with the tissue, the metal in the electrode will heat up rapidly and cause the tissue to adhere to the electrode. This is turn may cause the eschar tissue to stick to the jaws of the instrument and be drawn off the target site. Reoccurring bleeding will result each time the eschar is pulled off in this manner.

In bipolar desiccation, the waveform plays a far more important role. Today, for the most part, the manufacturers' have incorporated a continuous low-voltage, high-current waveform in the bipolar output to maximize the effect on desiccation. When performing desiccation, patience is the key to good results. Typically the power density is much lower in desiccation than in fulguration. The physical size of the active electrodes is therefore larger. The larger electrode or contact area to tissue will require longer activation times to attain the desired therapeutic effect. Introducing higher energy to speed up the desiccation process will likely be counterproductive (i.e., exacerbating the sticking problem). Higher energy levels will increase the temperature of the tissue adjacent to the electrode, potentially forcing the electric current to spark through the necrosis and resulting in fulguration rather than desiccation. Fulguration or sparking immediately stops the deep heating process and starts to carbonize the surface of the tissue only. Therefore, when sparking is observed during desiccation, stop, reduce the power, or pulse the current by keying the ESU on and off to over come this natural tendency of the electrosurgical energy. Sparking is not needed or wanted when desiccating. It causes tissue sticking and creates uneven necrosis and may compromise the intent to coapt the vessel. To assist the surgeon during desiccation, an ammeter may be used to help determine endpoint coagulation/desiccation. This helps confirm the visual effect seen by the surgeon. The ammeter (model EM2+; Encision, Boulder, CO, U.S.A.) shows current flow with both visual and audible indicators, and when the electrolytic fluid in the tissue is dehydrated, the meter will show no flow of electric current. Total or complete desiccation occurs after dehydration has taken place.

INHERENT RISKS

Since the inception of monopolar electrosurgery and before laparoscopic surgical access, there have been three potential sites for patient burns due to the presence of electrosurgical current—one intended, two unintended. The intended site is at the active electrode, where the unit is used to cut, fulgurate, or desiccate the tissue in surgery. Due to its design, the active electrode has a high-power density to heat tissue rapidly. This active electrode, when not tended (i.e., laying on the sterile drape), can burn through the drape and burn the patient severely in a very short period of time. Most manufacturer instructions strongly recommend that the active electrode be stored in an insulated holster or tray when not in use.

There are two unintended sites, and the first is a consequence of division in the electric current. Current division to alternate ground points to the patient can only occur on ground referenced ESUs. Secondly, it can occur due to a fault condition at the site of the patient return electrode (i.e., partial detachment or manufacturing defect) that forces the electric current to return to the ESU via a high-current density. The patient may be burned because of this fault. The patient return electrode (ground plate) has a surface area of approximately 20 in^2 or larger when properly applied. Therefore, very little temperature rise occurs at this site in normal conditions. Both of these potential burn sites have been avoided because of improved design within the newer ESUs developed in the last three decades. These safety circuits or features are available on most units. The two major advancements in overcoming these risks are described in the following sections.

Isolated Electrosurgical Outputs

Isolated ESUs were introduced in the early 1970s. The primary purpose was to prevent alternate ground site burns due to division of electric current. Today, the number of alternate site burns resulting from current division is essentially zero because of the introduction of isolated ESUs. Today, very few hospitals used ground reference ESUs. Therefore, it is wise to identify the type of output of the ESU that is in service at your hospital.

Contact Quality Monitors

Contact quality monitoring or return electrode monitoring (REM) circuits were introduced in the early 1980s (6). The primary purpose was to prevent burns at the patient return electrode site. The contact quality monitor incorporates a dual-section patient return electrode and a dynamic monitoring circuit for the purpose of evaluating the total impedance of the patient return electrode during surgery. Therefore, during the surgery, if the patient return electrode becomes compromised, the contact quality circuit detects and inhibits the electrosurgical generator's output as a result of the dual section patient return electrode and monitoring circuit combination. This advancement in ESU or pad design has essentially eliminated the unintended patient burns that appear at the site of the patient return electrode.

These two technological advancements have truly reduced the potential for patient burns while performing classic open electrosurgical procedures. These features are now found on ESUs produced by major manufacturers, such as ConMed-Aspen (Utica, NY, U.S.A.), Erbe (Tübingen, Germany), Pegasus/Ethicon (Cincinnati, OH, U.S.A.), and Valleylab/Tyco (Boulder, CO, U.S.A.).

Laparoscopic Issues: Stray Electrosurgical Burns

Despite the use of REM and isolated generators, monopolar electrosurgery applied laparoscopically involves the risk of serious injury to the patient. Stray electrosurgical currents, also called stray energy, can leak from the active electrode and burn a patient's internal organs and structures. (The active electrode introduces electrosurgical current into the patient's body at the surgical site. The electrode can be a blade, ball, loop, needle, or an articulating insert that fits into a modular handle, with a hand control or foot switch that activates the electrical current.)

Unintended or stray electrosurgical burns can result in significant morbidity and mortality. Recent surveys hint at the magnitude of the problem:

> Of the aforementioned ACS survey respondents, 18% reported that an internal electro-

surgical burn occurred in a patient while the surgeon was performing a laparoscopy (3).

- A Physician Insurers Association of America (PIAA) study of 31 medical malpractice insurers reported a total 615 claims for 13 different laparoscopic procedures during a 1-year period. Among cholecystectomies, a lacerated, transected, or punctured common bile duct was the most common injury reported. Bowel perforation was the second most common injury. In all other procedures, bowel perforation was the most common injury reported (7–9).
- A survey conducted at a 1995 meeting of the Society of Laparoendoscopic Surgeons (SLS) revealed that 13% of attending members had one or more laparoscopic electrosurgical malpractice cases currently in litigation (10).

There is a general lack of awareness concerning the problem of stray electrosurgical burns as well as an understanding of recent technological advancements developed to address or prevent them from occurring. Burns caused by stray energy are less understood than other surgical injuries, because of difficulties in detection and diagnosis. Stray electrosurgical burns typically go unnoticed during a procedure. Furthermore, presentation is usually delayed, and initial symptoms may appear unremarkable. Finally, infection can compromise a burn site, making it difficult to determine the original cause of injury. Complications resulting from electrosurgical injuries can be treated even when the exact cause has undetermined.

STRAY ENERGY

Stray electrosurgical burns are caused by stray energy. Stray energy can be the result of instrument insulation failure, capacitive coupling, and direct coupling (Fig. 7A,B).

Insulation Failure

Insulation failure is a breakdown in the insulating material along the shaft of the active electrode (Fig. 7A shows conventional instrument). Damage to the insulation of the active electrode provides an alternate pathway for the electric current to leave the electrode (Fig. 7B shows insulation failure). These burns are instantaneous because of the high-power density and the spark's (plasma) minimum temperature of 700C.

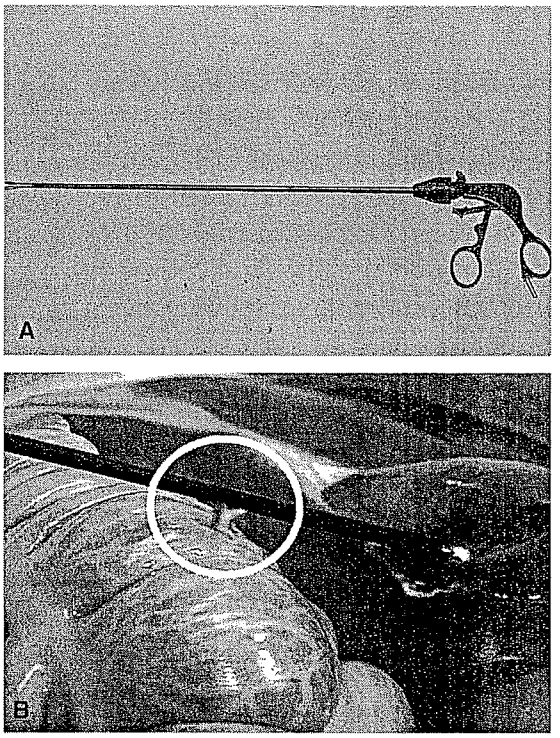

FIG. 7. A: Conventional laparoscopic instrument is the most unforgiving electrosurgical device developed because of the high-power density that occurs as a result of a crack in the insulation. There is no guarantee that the surgeon will be supplied with an instrument free of insulation defects or that defect will not develop during the procedure. **B:** Insulation failure during laparoscopy. Most often, this insulation failure is out of the view of the laparoscope. Therefore it is out of the surgeon's control.

As an aside, most surgeons have experienced a high-power density injury as a result of "buzzing" a hemostat during an open surgical procedure and received an instantaneous burn to their hand at a point in the latex glove, where a small hole was created unintentionally. A question to consider: did you ever think of keying it a second time to confirm you have a hole in your glove? This is an important point, because when this happens during laparoscopy, the insult to tissue is instantaneous and unbeknownst to the surgeon. Several activations at this one site may create a severe injury (Fig. 8). This injury to the patient will typically go unnoticed at the time of surgery and then it will show at 3 to 7 days after the operation.

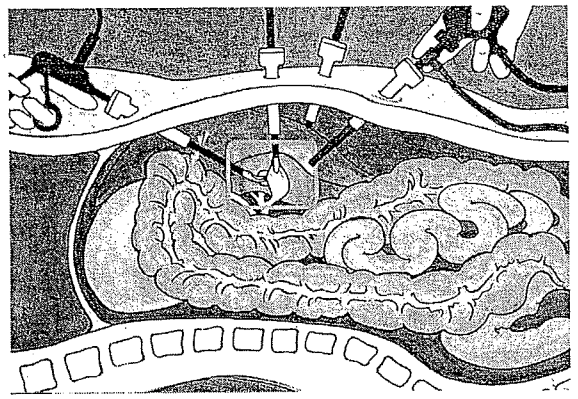

FIG. 8. Cross sectional view of peritoneal cavity. Outline represents the view of the laparoscope. Note the burn to tissue occurring out of the view of the laparoscope and therefore the surgeon view as well.

Electric current can flow through the insulation defect and burn the patient's abdominal viscera. Even a small defect can leak substantial energy, causing unintended tissue burns. In fact, the smaller the defect, the greater the hazard. A tiny insulation defect (virtually imperceptible to the naked eye) permits a much higher current density, and therefore, a more concentrated current travels to nearby tissue. This results in a more serious burn.

Defects can occur both before and during a procedure. Before a procedure, defects occur as a result of handling or high temperatures during the cleaning and sterilization process (sometimes reaching 270°F). During a procedure, defects occur because of the stress of high-voltage electric currents passing through the instrument, or when the insulation comes in contact with the sharp edges of another instrument (e.g., trocar cannula). Insulation defects occur in both reusable and disposable electrodes (11). In fact, the insulating effectiveness of some disposable electrodes is less than that of most new reusable electrodes.

Also, most hospitals do not have policies or formal inspection and testing protocols (within the perioperative staff or biomedical engineering departments) to serialize and perform routine audits on the insulation of an electrosurgical laparoscopic device. There is no guarantee that the surgeon will be handed an instrument free of insulation defects. It is virtually impossible to rely on visual inspection of these instruments at the beginning of each procedure to protect the patient from the risk of insulation failure.

Most insulation failures occur in zone 2 (Fig. 9) at the shaft of the electrode. Zone 2 measures approximately 20 cm (8 in). In both reusable and disposable electrodes, manufacturing defects may be in zone 2, which is outside the surgeon's field of view (outside the view of the laparoscope) and outside the trocar cannula. Insulation failure in zone 2 is not noticed easily.

Capacitive Coupling

Capacitive coupling is the transfer of electromagnetic current to adjacent conductive material (e.g., patient tissue, trocar cannula). Capacitive coupling can instantaneously transfer significant amounts of stray electrosurgical energy to non-target tissue through intact insulation, causing serious internal burns.

Capacitive coupling occurs in the presence of a capacitor. A capacitor is formed when two conductors surround an insulator (Fig. 10). These are four situations in which a capacitor forms, causing potentially dangerous capacitively coupled current:

- The insulated shaft of an active electrode is placed against non-target organ or tissue.
- An active electrode is placed inside a metal suction irrigator.
- An active electrode is inserted through an operative laparoscope.
- An active electrode is placed through a metal trocar cannula.

No matter how the capacitor is formed, it is important to understand that capacitively coupled current is always present and cannot be eliminated. Any electrosurgical current will induce stray currents on other nearby conductors, even through intact insulation.

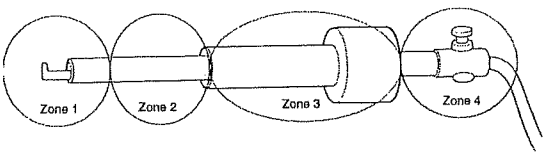

FIG. 9. Zone 1 is the surgeon's view. Zones 2 and 3 in the insulated portion of the laparoscopic instrument are out of the laparoscope's view. Zone 4 is the handle. Some handles are metal with a coating of insulation and may burn the surgeon or patient in the event of an insulation failure.

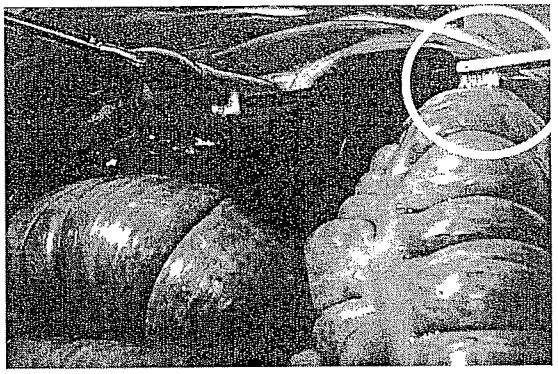

FIG. 10. Transfer of electrosurgical current through intact insulation as a result of capacitive coupling.

Capacitive coupling that occurs in zone 3 is not easily apparent. Zone 3 is within the trocar cannula and measures approximately 10 cm (4 in).

Direct Coupling

Direct coupling occurs when the active electrode accidentally touches another metal instrument or object within the surgical field (Fig. 11), thereby transferring energy and possibly burning the tissue with which that instrument or object comes in contact. Direct coupling can be avoided, because it is within the surgeon's control. The surgical team should be alerted to the dangers of direct coupling.

Zone 1 measures approximately 4 cm (1.5 in) and is the distal end of the electrode, where direct coupling usually occurs. Zone 1 is the intended point of delivery of the electrosurgical energy and is within the surgeon's view.

Zone 4 is the electrode handle itself. Injuries in Zone 4 are usually in the form of a burn to the surgeon or nurse holding the instrument. It is possible that unexpected shock to the surgeon may lead to patient injury. Patient skin burns are also a possibility if the handle touches the patient's skin.

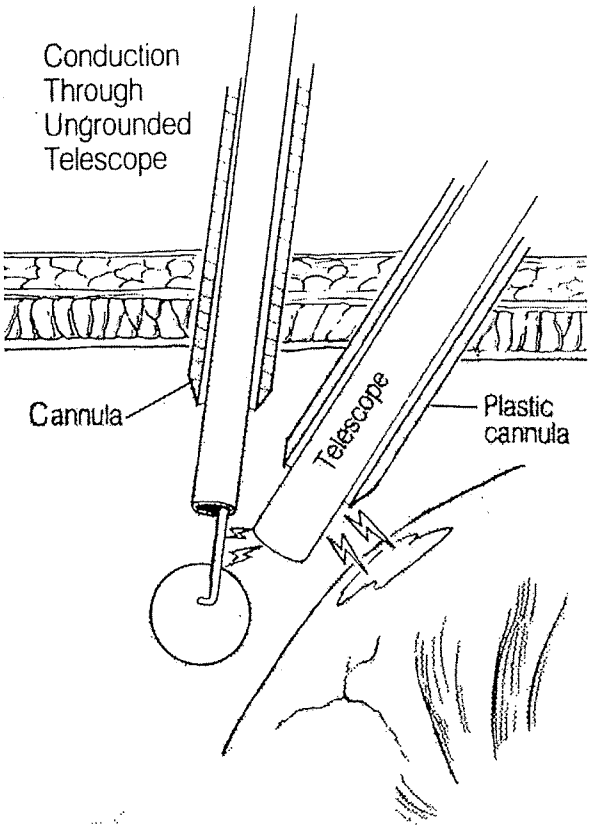

FIG. 11. Direct coupling occurs during accidental contact of the active electrode to an adjacent conductive device.

DIFFICULTIES IN DETECTION AND DIAGNOSIS OF STRAY ELECTROSURGICAL BURNS

Limited Field Of View

During laparoscopy, stray electrosurgical burns can occur outside of the surgeon's small, keyhole field of view. The shaft of the active electrode measures 35 cm (14 in). However, during laparoscopy, the surgeon only sees a magnified view of zone 1, a 4-cm (1.5-in) field (4). Thus, 90% of the active electrode, including the electrode shaft and the trocar cannula, are beyond the surgeon's view at any one time. Because stray energy can leak from anywhere along the shaft, serious burns to non-target tissue can occur unbeknownst to the surgeon.

The PIAA study found that internal injuries went unrecognized at the time of surgery in 73% percent of laparoscopic cholecystectomies (243 of 331 cases). Internal injuries that resulted in mortality went unrecognized in 77% of laparoscopic cholecystectomies (27 of 35 cases) (7).

Delayed Presentation

Once internal burns occur, they are difficult to catch and diagnose. It may be several days before the patient returns to the physician with a complaint. Initial symptoms may mimic normal postoperative symptoms of laparoscopy, including abdominal pain, feeling "off," etc. (12).

The results of a stray electrosurgical burn can be catastrophic (13). When a burn causes bowel perforation, the intestinal contents can leak into the peritoneal cavity, causing bacterial contamination (i.e., fecal peritonitis), a condition requiring immediate, aggressive treatment. Despite modern antibiotics, "the mortality rate from fecal peritonitis is reported to be as high as 25%." (4).

Patients who survive electrosurgical burns can experience serious and long-lasting physical, emotional, and financial complications. For example, necrosis of gastrointestinal tissue at a burn site can necessitate surgical resection of a length of bowel and a temporary or permanent colostomy. Treatment is expensive and convalescence may take many months. Internal electrosurgical burns suffered during laparoscopic surgery also mean high medicolegal costs for surgeons and the institutions in which these procedures are performed (9).

PREVENTING STRAY ELECTROSURGICAL BURNS WITH ACTIVE ELECTRODE MONITORING DURING LAPAROSCOPY

Active electrode monitoring (AEM) is a technology designed to protect the patient against stray energy due to instrument insulation failure and capacitive coupling (Encision, Inc., Boulder, CO, U.S.A.; formerly Electroscope, Inc). Use of AEM is the only way to eliminate the risk of stray electrosurgical burns due to insulation failure and capacitive coupling. The AEM system consists of 5-mm coaxial conductive shielded instruments and a monitor that continually checks for insulation failure and excessive capacitive coupling.

The 5-mm shielded, monitored instruments are modular, with reusable or disposable scissors, dissectors, and grasper jaw inserts, or fixed-tip electrodes in a variety of styles (including hooks, spatulas, and needles).

A protective shield built into the instruments provides a neutral return path for capacitively coupled energy and a safe path for any stray current in the event of insulation failure (Fig. 12).

The monitor continually searches for primary (internal) instrument insulation failure and excessive capacitive coupling during monopolar

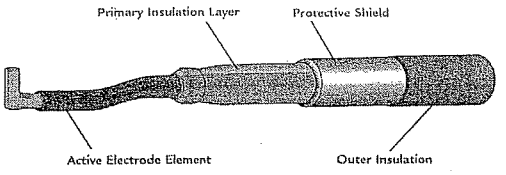

FIG. 12. Cut away of the shaft of an active electrode monitoring (AEM) instrument. (Reprinted with permission from ElectroScope.)

electrosurgical procedures. If the monitor detects a dangerous level of stray energy, it signals the electrosurgical generator to deactivate before patient injury can occur. With AEM, the patient is safe from stray electrosurgical burns caused by insulation failure or capacitive coupling during laparoscopy (Fig. 13A,B).

An article published in *Health Devices* concludes that, after extensive laboratory testing, electrode shielding safely diverts stray electrosurgical energy originating from the shielded portion of the active electrode shaft. This is true even in high-power settings and simulated fulguration (10): "It is the most effective means currently available of minimizing the potential for patient injuries due to active electrode insulation defects or capacitance." Additionally, it is easy to use. AEM requires no change in the surgeon's technique and very little additional training for the surgical staff. It is fail-safe and cost-effective.

Presently, the only way to eliminate internal burns due to stray electrosurgical energy is to use AEM to detect and manage instrument insulation failure and capacitive coupling. However, the surgeon should not rely on just one single mechanism, including AEM, to protect against every risk. Risk managers should make their biomedical engineering staff and nursing staff aware of the dangers of monopolar electrosurgery during laparoscopy.

HISTORICAL PRECEDENTS: ADVANCEMENTS IN THE "STANDARD OF CARE" IN ELECTROSURGERY

There have been several benchmarks in the standard of care.

- Isolated generators (1970s) eliminated the patient's risk of invisible ground point burns.

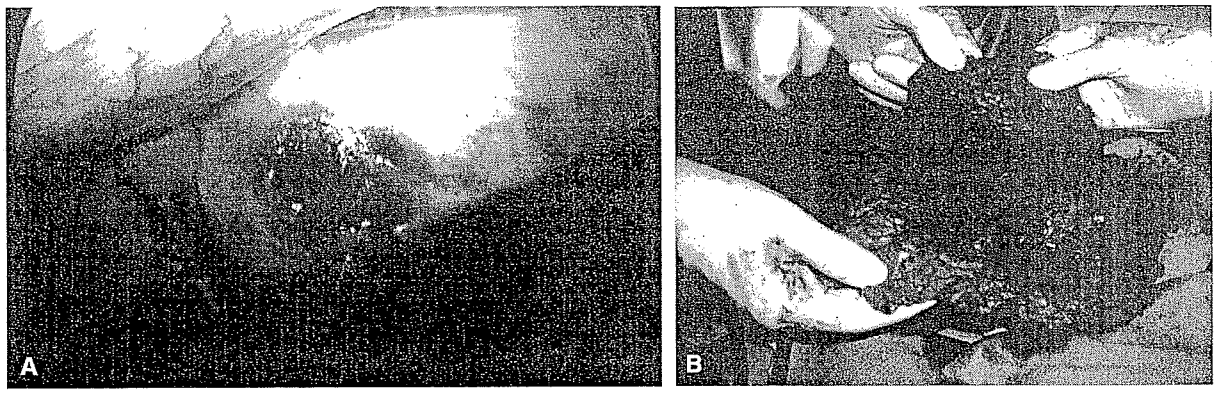

FIG. 13. These are two examples of stray energy burns as a result of insulation failure or capacitive coupling. Active electrode monitoring (AEM) used during laparoscopy keeps the patient safe from stray electrosurgical burns.

- Return electrode monitoring (REM) (1980s) eliminated the patient's risk of invisible patient plate burns.
- Active electrode monitoring (AEM) (2000) addresses or eliminates the new class of risk to the patient of insulation failure and capacitive coupling intra-abdominal burns during laparoscopic surgical procedures.

This "new class" of electrosurgical risk to the patient for the first time involves both mortality and morbidity. Skin burn is usually a morbidity issue only.

CONCLUSION

The use of monopolar electrosurgical energy has been the gold standard for the past 50 years (11). It has the most diverse capabilities (fulguration, precise vaporization, coaptation of large vessels) compared with other energy sources. Medical economics has also benefited from this device. The technological advancements in performance and safety (10,12) have made this device one of the most useful tools in a surgeon's armamentarium.

Adaptation of AEM for stray energy as a result of insulation failure or capacitive coupling has taken the guesswork out of these two matters. The assurance that 100% of the electric current will now be delivered at the target site should enhance the surgeon's confidence in the delivery of this energy. Unintended laparoscopic burns are now a preventable tragedy with AEM technology.

As with any surgical tool or energy source, education and skill are required. This introduction to the biophysics of electric energy on tissue and the safety consideration is a start to further understanding this powerful surgical tool to help advance electrosurgery.

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