ABSTRACT  
Electrosurgery is the most commonly used and misunderstood technology by all surgical and medical disciplines. A lack of basic knowledge or ignorance of principles of electrosurgery and equipment among obstetricians and gynecologists is reported. As a result, thermal injuries during laparoscopic electrosurgery occur, which frequently lead to significant morbidity and mortality and medicolegal actions. Surveys indicate that up to 90% of general surgeons and gynecologists use monopolar radiofrequency (RF) during laparoscopy, 18% have experienced visceral burns, and 13% admitted 1 or more ongoing cases of litigations associated with such burns. This article describes the basics of electrosurgery beginning with the generation of electrons and their physical characteristics and governing laws before their arrival in the operating room where they are fed to an electrosurgical unit (ESU) to boost their frequency with step-up transformers from 60 Hz to $\approx 500\,000\,\text{Hz}$. This RF creates heat, resulting in dissection, desiccation, coagulation, and fulguration of tissues without neuromuscular stimulation, pain, or burn to the patient. The ESU delivers power (wattage = volts $\times$ amps) in monopolar or bipolar (1 vs 2 high-density electrodes) configuration. Because of RF, monopolar electrosurgery compared with other energy sources is associated with unique characteristics, inherent risks, and complications caused by the requirement of a return/dispersive electrode, inadvertent direct and/or capacitive coupling, or insulation failure of instruments. These dangers become particularly important with the popular and frequent use of monopolar electrodes (hook, needle, and scissors) during cholecystectomy; robot-assisted surgeries; and the re-emergence of single-port laparoscopy, which requires close proximity and crossing of multiple intraabdominal instruments outside the surgeon’s field of view. Presently, we identify all these potential risks and complications associated with the use of electrosurgery and provide suggestions and solutions to mitigate/minimize these risks based on good clinical practice and sound biophysical principles. Journal of Minimally Invasive Gynecology (2013) 20, 279–287 © 2013 AAGL. All rights reserved.

Keywords: Bipolar electrosurgery; Electrosurgical generator; Electrosurgical unit; Monopolar electrosurgery; Return/Dispersive electrode

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The application of electrical energy provided by the newly designed Bovie generator as an aid to the removal of intracranial tumors was popularized by Harvey Cushing at Johns Hopkins at the beginning of the last century [1].

Since then, it has been well entrenched as an integral part among all health care providers to treat disease by heating, cutting, coagulating, or ablating tissue. Although it is the most commonly used energy in clinics and operating rooms, it is the least understood by the majority of users because of a lack of basic knowledge or ignorance of principles of electrosurgery and equipment [2,3].

The intent of this article was to allow the reader to travel together with the generated electrons from the nearest power plant and follow them all the way into the operating room, where their mode of delivery is reshaped by electrosurgical units (ESUs); then, they are transferred by a cable to patients...
where they achieve their intended effect, and, finally, they return back to the ESU via another cable. Along the journey, the characteristics, properties, and governing physical laws of these electrons are discussed as well as some of their inherent yet mostly predictable and preventable risks and complications. Finally, we provide suggestions and simple solutions to mitigate/minimize the aforementioned potential risks based on cumulative knowledge, experience, research, and basic biophysical scientific principles. The overall intent is to make the electrons more user friendly and electrosurgery an uneventful, safer, and satisfactory experience for both patients and health care providers.

Generation of Electrical Energy

The source of electrical energy in the operating room originates from surrounding power generation facilities and is delivered to the operating room through many kilometers of wire. It is then modulated by the ESU or generator in order to imbue current with appropriate and specific characteristics to produce the desired effects on tissues without the stimulation of muscles or nerves.

With the exception of solar energy, which takes advantage of the photoelectric effect that was described by Heinrich Hertz in 1887, electricity is generated through the conversion of kinetic energy in the form of a rotating turbine to electrical potential energy. Be it geothermal, tidal, wind, nuclear, coal, or hydroelectric, the prime directive is the mechanical rotation of a magnet, referred to as an alternator, surrounded by multiple coils of wire. The wires are made of atomic particles consisting of a nucleus and a specific number of electrons orbiting the nucleus in several specific orbits. When electrons are pushed or forced to jump from their corresponding atom to their nearest neighbor in 1 direction, a parade or flow of electrons is initiated, which is referred to as electrical current.

In 1831, Michael Faraday experimented with hanging wires over stationary magnets and noted that the wires were moving in circles over the magnets. This “electromagnetic engine,” which was later formulated as electromagnetic induction to move electric trains, trams, cars, and so on, stems from Faraday’s findings that any conductor in motion relative to a magnetic field will generate within it movement of electrons or electric current. As the kinetic energy generated by steam, wind, or water imparts movement of a large magnet within a shell of tightly wound wire with high conductivity (e.g., copper, silver, and so on), the rotation of the magnet causes the movement of electrons within the wire and produces the current used in our daily lives. This is then carried to our homes, commercial centers, industry, and hospitals through several kilometers of wire.

Voltage, Current, and Resistance

The concept of voltage, current, and resistance and their relationship are described in the first article in this special series.

Frequency and Direct and Alternating Currents

Unlike the flow of water, which is driven by gravity only in 1 direction [4], current can be direct (DC) or alternating (AC). In the former, the anode and cathode are fixed, and there is unidirectional travel of electrons (e.g., car battery). In the latter, the anode and cathode are continually interchanged by a mechanically rotating magnet arbitrarily 60 times per second, hence the frequency of 60 Hz. Frequency then refers to the number of cycles or exchanges of polarity between the anode and cathode in a fixed period of time and is measured in hertz (Hz). Essentially, DC can be thought of as AC with a frequency of 0.

Electrosurgical Generators

The generator-active electrode–patient–return electrode relationship can be shown by a simple circuit involving a power source (i.e., the ESU), a body of resistance (the patient), and to and from connecting wires between the 2 (Fig. 1). The ESU modulates the input current from the outlet into that suitable for use on living tissue.

For safe application to the human body, a key characteristic that must be altered is the frequency of the AC. This is based on an important observation on the effects of current on animal muscle noted in 1786 by Luigi Galvani when he showed muscle spasms in frog legs secondary to electrical potentials evoked through galvanization in the metal hooks in his suspension apparatus [5]. If this phenomenon occurs while attempting to electrocoagulate a blood vessel perforating a muscle, it could prove to be very challenging and potentially traumatic to the patient. Furthermore, the standard frequency of 60 Hz also stimulates muscles and nerves, causing unwelcome muscle spasms, contractions, and movement of body parts during surgery. However, the most adverse effect of the 60-Hz frequency is interference with conductivity of heart muscle, resulting in cardiac arrest and death by electrocution, a method used in the past to execute criminals in the so-called electric chair.

Fig. 1
A simplified representation of an ESU circuit.
Radiofrequency and Radiofrequency Currents

The adverse effects of muscle and nerve stimulation were overcome by the use of high-frequency AC. Based on Morton’s observations in 1881 that oscillating current at a frequency of 100 000 Hz could pass through the human body without inducing pain, spasm, or burn, Parisian Jacques d’Arsonval showed in 1891 that AC with a frequency of greater than 10 000 Hz also could elevate tissue temperature without causing burn, muscle contraction, or pain [6]. Subsequently, it was also noted that temperature elevation was proportional to the square of the current density.

Modern-day ESUs use frequency ranges of 200 000 Hz to 5 000 000 Hz because this allows for desired thermal effects without muscle fasciculation or nerve stimulation [7]. Because this frequency is in the range of AM radio waves, the energy used in electrosurgery is also referred to as radio-frequency (RF) or RF currents.

Occasionally, muscle spasm or nerve stimulation is noticed with the application of an active electrode, indicating that the frequency of the current is altered through interaction with surrounding tissues, moisture, gas, and so on. This is referred to as harmonic demodulation of high frequencies to lower frequencies (<100 000 Hz) and possibly the generation of DCs. Currents with frequency <100 000 Hz that stimulate muscle and nerves are referred to as galvanic. Although occasional inconvenience may be unavoidable, the use of this RF range has greatly improved the efficacy of electrosurgery while minimizing traumatic morbidity.

Modifying the frequency of AC is complex; however, generating AC with a desired frequency from a DC source is far simpler. Thus, the ESU converts the input of 60 Hz AC into DC and then back to AC with a new higher frequency. This is made possible by a subunit within the generator known as an oscillator. High-frequency AC can now be channeled through the active electrode to heat tissues with little or no neuromuscular stimulation. Tissue effects are a result of the change in temperature at and around the electrode.

Power, Energy, and Power Density

All generators are programmed to deliver power in watts, frequently called “wattage,” and it is defined as the rate at which energy is used and commercially billed to the users. One watt is the product of 1 volt and 1 ampere (W = V × I). However, the effect of the active electrode on tissue is also dependent on the time the electrode is applied to the tissue. Therefore, the product of wattage and time (in seconds) required to affect tissue is referred to as joule energy (J = W × t). When time and electrode size are kept equal, the effect on tissue is primarily dependent on the ratio of voltage and current (V/I). Power density is the relationship between the size of the active electrode in contact with tissue and the effect on tissue at a given power setting (PD = V × I/contact surface area).

Capacitors, Capacitance, and Capacitive Coupling

A capacitor is defined as 2 conductors separated by an insulator. Capacitance is the number of electrons (amount of energy) stored in a capacitor, and capacitive coupling is a condition that occurs when electrical current is transferred from 1 conductor, through intact insulation, into adjacent conductive materials.

Effects of Electrosurgery on Tissues

Electrosurgery uses the conversion of electrical potential energy into thermal energy to cause tissue cutting, coagulation, desiccation, or fulguration. Coagulation (L. coagulatio, to curdle) is the clotting of blood or agglutination of tissue (the formation of coagulum) with no cutting effect by desiccation or fulguration. Desiccation (L. desiccatus, to dry up completely) is the electrosurgical effect of tissue dehydration and protein denaturation caused by direct contact between the active electrode and tissue. Fulguration (L. fulguratio, to flash, to lighten) is the process of arcing, sparking, or jumping of electrons from the active electrode across air or liquid to the target tissue causing superficial coagulation and carbonization.

Spark Gap Electrosurgical Generators

Lightning and Fulguration

In addition to varying the delivery of current by the ESU, further tissue effects can be achieved by the manner in which the electrode is manipulated. Fulguration was the first technique of electrocoagulation identified and applied by Simon Pozzi and refined by Doyen at the beginning of the 20th century [5]. When the electrode is elevated and activated over tissues targeted for coagulation, the electrical potential causes ionization of air/gas in the gap between electrode and tissue, and a spark ensues similar to spark plugs in our cars. Fulguration then can be represented initially by a capacitor wherein the electrode and underlying tissues are conductors, and the 1- to 2-mm air/gas gap acts as an insulator. Subsequently, the air/gas (oxygen/CO₂) is ionized by the high voltage of the interrupted (“coag”) mode, resulting in insulation/dielectric failure of the circuit. At this stage, 30 000 to 40 000 sparks are delivered per second, and the target tissue is superficially desiccated and coagulated by carbonization.

This scenario is not dissimilar to the relationship between a storm cloud, the surface of the Earth, and the interposed atmosphere. Upon reaching maximum capacitance (charge), a spark is discharged across the gap to tissues beneath much like lightning. The voltage associated with lightning is in the range of 100 000 000 V, whereas the voltage of the ESU discharge spikes can be up to 10 000 V peak to peak (p-p) [8,9]. These discharges, arcs, or sparks have been identified to reach temperatures of 700° to 1000°C.
and these generators are referred to as spark gap generators.

The Hyfrecator Electrosurgical Generator

The hyfrecator ESU is frequently used in conscious patients in an office setting. It uses high voltage, but very low current to produce low power, very high RF (1–5 MHz) discharges. The patient becomes a capacitor to Earth ground and a sink of electrons similar to the cloud-lightning-Earth capacity scenario described previously. A ground or return/dispersive electrode is not required. However, the instruction for use suggests mentioning to the patient if he/she feels any pain or burning other than the surgical site to let the surgeon know. The patients unbeknown to the surgeon may have a current concentration to the ground point on the table or chair on which they are positioned. Tissue temperatures exceed 200°C, and the target tissue is destroyed by the process of fulguration and carbonization.

The “Bovie” Electrosurgical Generator

A further application of electrosurgery was described in 1914 by William Clark. He coined tissue desiccation as a means of tissue destruction not by carbonization, as described in the former technique of fulguration, but rather tissue dehydration [5,6].

William T. Bovie, a botanist and plant physiologist at Harvard, was the first to develop an ESU providing both continuous and interrupted waveforms to cut or desiccate tissue (Fig. 2). He also added a pistol grip activation handle with interchangeable electrodes [5]. This was a feature of the original Bovie unit in 1926, facilitating cellular dehydration through a relatively slow elevation of temperature to greater than 90°C. At these temperatures, intracellular water is vaporized and cells explode causing dissection of tissue (cut) or cells are dehydrated and protein is denatured (50°C–80°C) resulting in a coagulum and hemostasis [11]. The use of Joule heating to provide coagulation is the most commonly practiced technique in electrosurgery today. Reportedly, Bovie never financially profited from his invention although his generators were popularized and adopted by many surgeons including the father of modern neurosurgery Harvey Cushing.

The Ground Pad

To complete the circuit from the ESU to the patient and back to the ESU, the Bovie generators required a return or pad plate electrode, which was referenced to the ground. Because this was truly a ground electrode, all return electrodes used today are frequently, but erroneously, referred to as ground pads, ground electrodes, or simply grounds. Furthermore, all modern generators are frequently referred to as “Bovies,” and the process of electrocoagulation of vessels has been verbalized to “bovieing.”

Modern Electrosurgical Generators

Isolated Electrosurgical Units

In 1968, the use of isolated systems was introduced in which the therapeutic current is isolated from the power current by a transformer (Fig. 2). Under this configuration, the therapeutic current must return to the ESU itself to complete the circuit. The therapeutic current does not cross pathways with the power current, and it does not recognize the ground because it is not referenced to it. These isolated systems virtually eliminate current division/diversion and alternate site ground point burns. However, under high-voltage conditions, stray currents may be generated by capacitive coupling, which seek the ground, just like lightning, and cause burns to intermediate tissues as will be discussed later. Thus, by removing the ground as a reference for the current, the isolated ESUs virtually eliminated all the hazards inherent in the grounded systems, such as current diversion and alternate site burns.

Adaptive Electrosurgical Generators

To minimize capacitive coupling, advanced feedback systems, also referred to as instant response technology that automatically adjusts the computer-controlled output, are now available on many ESUs [12]. These devices measure tissue impedance/resistance at the active electrode–target tissue contact site and provide instant response to changes producing a consistent tissue effect. In addition, they control maximum output voltage, thereby reducing capacitive coupling and video interference and minimizing sparking. However, the ability to reduce capacitive coupling is dependent on some variables outside the control of the ESU. One such important variable may be insulation deficiency of the active electrode, which is not recognized by the ESU, resulting in
Return or Dispersive Electrodes

**Split Return or Dispersive Electrodes**

As stated earlier, current starts flowing from the ESU to the patient through the so-called active electrode disperses through the patient tissue around the neighborhood where surgery is performed, and it must be collected and return back to the ESU through a second attachment to the patient to complete the circuit.

**Capacitively Coupled Return Electrodes**

Capacitive-coupled return electrodes are large reusable gel pads on which the patient lies. As there is no direct contact with the inner conductive material these electrodes transfer current similarly to the cloud-lightning-Earth concept described earlier. They are designed to be large enough to maximize contact with the body and thus minimize current density.

**Dispersive Electrodes and Implanted Electronic Devices**

Implanted electronic devices (IEDs) are battery-powered units implanted within a patient’s body to treat a physiologic deficiency or replace a sensory function. Common examples include cardiac pacemakers, ventricular assist devices, and neurologic stimulators such as vagal nerve and spinal cord stimulators. Because of RF used in electrosurgery, electromagnetic interference may interrupt, obstruct, or degrade the effective performance of an IED. Therefore, in the presence of an IED, an effort should be made to consult the IED manufacturer to determine if the device will be affected by the use of electrosurgery and, if so, what the recommendations are. They may also suggest this IED is checked postoperatively to be sure that it is functioning as initially intended.

Alternatively, surgeons should avoid the use of monopolar electrosurgery and use alternatives such as bipolar electrosurgery, ultrasonic energy, or laser energy. If monopolar energy is necessary, the dispersive electrode should be applied as far as possible from the IED and avoid the use of capacitively coupled return electrodes [13].

Electrosurgery and Body Piercing

Body piercings are commonplace in our society and have been a part of human culture for thousands of years. The general recommendation is that piercings be removed before surgery regardless of the use of electrosurgery. This is to prevent the potential morbidity of skin damage or piercing loss when patients are transported or positioned intraoperatively, aspiration and tissue trauma during endotracheal intubation, and infection and hindrances to the operator when within the surgical field (i.e., the umbilicus or labia) [14–16].

It has also been a longstanding belief that if metal body piercings are left in place during electrosurgery this may result in alternate site burns. This complication may have been more prevalent with the use of ground-referenced ESUs (the predecessors to modern-day isolated generators). Unlike the latter, ground-referenced generators transmitted current through the active electrode to the Earth via the site of interest and the patient. This was much more hazardous with respect to alternate site burns because any conductor in contact with ground (i.e., the operating table touching the operating room floor drain) and in proximity to the patient could cause inadvertent concentration of current in an unexpected area of the body and result in a burn [17]. With modern-day ESUs, this phenomenon has been abolished.

Because metal is a far superior conductor than tissue, it is possible that current density can be increased around metal body piercings if located between the active and dispersive electrodes. Alternate site burns can occur as well if insulation failure, in proximity to metal body piercings, results in arcing. Furthermore, if a metal piercing were sufficiently close to but not communicating with an active monopolar electrode, then capacitive coupling may result.

No case reports involving body piercings–related alternate site burns have been published to date. Because metal body piercings can only concentrate energy if en route from an active to a dispersive electrode, an elegant means of eliminating this risk when piercings cannot be removed is to reduce the distance between these electrodes or use bipolar electrosurgery.

Tissue Effects from Electrosurgery

As stated earlier, all modern ESUs are programmed to deliver power in watts in the so-called monopolar or bipolar configuration. To deliver the requested wattage, the ESU must adjust the voltage and current in a given time. By adjusting the voltage and active time of the electrode that energy is applied to target tissues, effects vary. In the monopolar configuration, the adjustment of these electrosurgical waveforms provides various settings on the ESU (Fig. 3).

In the “pure cut” mode, current is continuously delivered 100% of the time. Because current is plentiful, the requirement for voltage is low in accordance with \( V = W / I \). Therefore, this mode is better referred to as the high-current/low-voltage waveform rather than the cut mode.

This continuous, low-voltage, high-current output rapidly elevates the temperature of tissues and can exceed 100°C [11]. This causes explosive vaporization of intracellular fluid and then ionization of the gas/moisture released. The superheated ionized gas forms plasma surrounding the electrode and further conducts current to nearby tissues to propagate this effect as the electrode is carried through target tissues. This produces a clean incision with minimal hemostasis and a collateral thermal damage zone of 100 to 400 microns.
This mode produces the least charring tissue destruction and collateral thermal injury [9]. In the interrupted mode, current is delivered only 6% of the activated time. Therefore, the generator must compensate by increasing the voltage to deliver the preset wattage in accordance with \( W = V \times I \). Coag current then is better described as an interrupted or low-current/high-voltage waveform because it uses current at a significantly higher voltage (4000–10 000 V p-p) [19]. This is necessary to generate the heat required to render tissues hemostatic. However, because current is delivered in a pulsatile (interrupted) manner, in this mode a greater voltage is necessary to achieve tissue destruction [11]. Because of the lower current density, the rate of temperature change is significantly less. This results in the denaturation of proteins and the formation of a coagulum as well as greater thermal spread. In the bipolar mode, current is also continuously delivered 100% of the activated time. Therefore, the bipolar configuration waveform is also of low voltage/high current to accomplish the desired clinical effect (<1000 V p-p).

As current flows through the tissues, air, or vapor that surrounds the active electrode, the resistance of these media causes the generation of heat through the process of Joule heating (i.e., the rate of temperature change is directly proportional to the resistivity of the substance and the square of the concentration of electrical current or current density). This relationship of heat factor was described by Pearce [20] as proportional to the square of the current delivered times the duration of the current applied. This relationship is approximated by the following: heat factor = \( I^2 \times t \).

As stated earlier, in addition to these 2 extreme modalities, the pulsatile release of current can be varied between 6% and 100%, interrupted and continuous, respectively, to produce the “mix” or “blend” settings found on many modern-day ESUs (Fig. 3). The blended currents in between are arbitrarily chosen, and one could construct an unlimited number of such combinations. By convention, in blend 1, 2, and 3 modes, current is delivered 80%, 60%, and 50% of the time, respectively. This middle ground setting provides good dissection with varying degrees of coagulation. The active time of current delivery or duty cycle is manufacturer specific. The ratio of “on” to “off” duration is referred to as the duty cycle.

**ESU Settings**

The requirements of power settings of the ESU may vary in accordance with the needs and experience of the surgeon as well as tissue characteristics. For example, a monopolar hook may provide an adequate effect at 80 to 90 W of continuous current for peritoneal incisions, dissecting gallbladder, or cutting bowel wall. On the other hand, 50 W of interrupted current may be all that is required to control small bleeders or cutting through fat. For resectoscopic surgery, a power setting of 100 W (± 20 W) in both interrupted and continuous waveforms provides an adequate effect in ablating or resecting tissue.

**Monopolar Electrosurgery**

There is no such a thing as monopolar electrosurgery. However, all modern ESUs are designed to provide power in the so-called “monopolar” and bipolar configuration. The nomenclature regarding monopolar and bipolar configuration of the electrosurgical circuit, although misleading, stems from our forefathers’ logical notion that monopolar had “one” site where the therapeutic effect was desirable and bipolar had “two.” Monopolar implies that there is only a single pole or electrode in the ESU-electrode-patient circuit when in fact there must always be 2: 1 high-power density pole (i.e., the active electrode) and a second low-power density pole (i.e., the dispersive [“return”] electrode at a remote site). A more appropriate rationale to support the designation “monopolar” is that the active electrode in monopolar electrosurgery contains only 1 of the poles in the circuit. In this construct, the patient is the other electrode. An example of this is the hyfrecator described earlier.

In the bipolar configuration, both electrodes are high-density power and are situated across from each other. In the monopolar configuration, electrons travel from the generator through a wire to the tip of the active electrode where the current density it greatest and thus where maximal Joule heating can occur. From the point of contact between the active electrode and the patient’s tissue, electrons disperse throughout the patient’s body. The pattern of dispersion is not uniform and is a function of electrostatic repulsion between electrons and varying tissue resistivities [18]. Finally, the electrons must return to the ESU through the dispersive electrode to close the circuit for the desired clinical effect (Fig. 4).

Because body compositions vary across individuals, a generalized model to predict the flow of current would
be inaccurate. The displaced charge must travel to a location relatively deplete of electrons to achieve a net neutral charge and a state of lowest entropy. Electrons will always take the path of least resistance to achieve this goal. Because temperature change is a function of the square of current density and this is significantly reduced as electrons disperse, the change in tissue temperatures elsewhere are miniscule. Furthermore, because of the high-frequency nature of the AC used, there is no excitation of nervous or muscle tissues en route. Ideally, electrons will return to the ESU by means of the return/dispersive electrode pad. However, if there is a source of ground (a conductor with sufficient contact with the Earth) in contact with the patient, electrons may preferentially travel to this site, and if current density is sufficiently elevated at any point along this alternate path, a burn may occur. This issue has been addressed in modern ESUs through circuitry that does not reference ground and actively monitor the condition of the return electrode circuit as described earlier.

Advantages of Monopolar Electrosurgery

Advantages to this configuration include the ability to use continuous and “mix/blend” current to dissect with ease while providing some hemostasis, fulguration in the interrupted mode can produce adequate hemostasis by carbonizing tissues with high capillary or small vessel density, and coaptive coagulation of grasped tissue can be achieved where desiccation occurs and proteins denature resulting in a “collagen weld” [21,22].

Disadvantages of Monopolar Electrosurgery

Monopolar electrosurgery requires considerable knowledge, understanding, and vigilance of the operator to avoid the hazards of unintentional thermal injury by means of accidental visceral contact with active or heated electrodes; direct or capacitive coupling; insulation defects in instruments or connecting wires; damaged, faulty, or improper placement of the return electrode; and combustion of volatile substances [23,24].

Clinical Implications of Monopolar Electrosurgery

Laparoscopic Tubal Electrocoagulation

A review of monopolar sterilization of 3500 patients yielded 10 cases of electrical bowel injury. The incidence of approximately 3 per 1000 was deemed to result from direct coupling. In these cases, it is believed that current traveled to the nearby bowel by way of either grasping forceps (direct contact with bowel visualized by the surgeon in 5 cases) or via the fallopian tube [25]. It is important to recognize that tissues targeted for dissection or coagulation can act as secondary conductors and convey energy to unintended termini. However, because the majority of these cases were performed through a single port using an operative laparoscope, the mechanism of capacitive coupling as a cause of the bowel burns appears more plausible.

Laparoscopic Cholecystectomy

In March 2010, a newsletter from the Canadian Medical Protective Association reported on 131 litigated and concluded cholecystectomy cases from 2003 to 2007. Among these, there were 22 laparoscopic cholecystectomies associated with intestinal complications, 20 of which were caused by direct trauma (10 duodenal [3 died], 9 jejunoileal [3 died], and 1 transverse colon). The exact mechanism of injury was often difficult to determine because there was frequently a significant inflammatory response by the time the site of the intestinal damage was visually examined. Surgical experts were critical of the technique, the use of cautery, and the delay in diagnosis. Of the intestinal injuries, 52% were settled in favor of the patients. This percentage is higher than the overall Canadian Medical Protective Association experience with legal action [26]. From the location of bowel injuries (duodenum, jejunoileal, transverse colon) and the delay in diagnosis, it is more than likely that some of the bowel injuries were caused by capacitive coupling and/or insulation failure associated with monopolar electrosurgery and the hook electrode used frequently during laparoscopic cholecystectomy.

Single-Port Endoscopy

The inherent dangers of monopolar electrosurgery may become particularly important with the reemergence of single-port laparoscopy, which requires close proximity and
crossing of multiple intraabdominal instruments. Indeed, simulation in a dry laboratory using livers from pigs and sheep and the bowels and livers of anesthetized animals (1 dog and 1 sheep) during single-port laparoscopy and the use of monopolar RF indicated that the proximity and crossing of multiple instruments generated sufficient capacitive and/or direct coupled currents, which caused visceral burns [10].

Robotic Assisted Laparoscopic Electrosurgery:

The risk of bowel burns may be particularly amplified with the use of some of the new popular technologies such as robotics (da Vinci; Intuitive Surgical, Sunnyvale, CA). As a rule, the da Vinci robot uses both monopolar and bipolar energy to affect tissue. Indeed, we have witnessed arcing of energy with burns to bladder and kidney in our own operating room during robotic urologic procedures. Furthermore, we analyzed all incidents from the Manufacturer and User Facility Device Experience database, which is administered by the US Food and Drug Administration, in the context of robotic surgery between January 2001 and June 2011 to identify those related to the use of electrosurgery.

Of the 605 cases identified, 24 (3.9%) were related to potential or actual electrosurgical injury, 9 of which (37.5%) required additional surgical intervention. There were 6 bowel injuries, of which only 1 was recognized and managed intraoperatively. The remainder required laparotomy between 5 and 8 days after the initial robotic procedure. Additionally, there were 3 skin burns [27].

Furthermore, the da Vinci instruments are reusable with a limited number of uses. One study reported on 81 robotic and 299 laparoscopic instruments visually inspected and electrically tested. Insulation failures were detected in 72.8% and 35.1% of robotic and laparoscopic instruments, respectively. Most of the robotic insulation failures were located in the intraabdominal portion of the instrument, whereas the laparoscopic insulation failures were extraperitoneal [28].

Our group previously conducted an in vitro study that provided both a qualitative and quantitative assessment of stray current in laparoscopic instruments used for robotic surgery [29]. By using an electrosurgical generator at pure cut and coagulation waveforms, a total of 37 robotic instruments at the end of their programmed life were assessed. The magnitude of stray currents was measured by an electrosurgical analyzer. This showed energy leakage from all tested instruments. The magnitude was noted to be higher during coagulation (i.e., high-voltage) waveforms.

Bipolar Electrosurgery

Bipolar electrosurgery was devised and applied in gynecologic surgery in 1973 by Canadian gynecologist Dr. Jacques-Emile Rioux. In fact, he constructed the first laparoscopic bipolar forceps using a coat hanger and broom handle. A nylon version of the prototype was used to perform the first laparoscopic bipolar sterilization on March 12, 1973, and histologically showed significantly less collateral thermal damage when compared with the monopolar technique [30]. Many variations of Rioux’s design have been used for bipolar electrosurgery, of which the most popular was coengineered by Dr. Richard Kleppinger [31].

Forceps and clamp configurations are the 2 principle bipolar devices. In both cases, the circuit is as such that electrons travel from the ESU to the distal aspect of 1 tine (or active electrode), through grasped tissues, to the sister tine (or return electrode), and back to the generator. In bipolar electrosurgery, electrons do not dissipate throughout the patient’s body because the active and return electrode are in close proximity to each other and only those tissues that are interposed are included in the circuit. Thus, only said tissues and those immediately surrounding are affected by the heat generated (Fig. 5).

As shown in Figure 3 and stated earlier, in the bipolar configuration, current is delivered 100% of the time just as in the continuous mode of the monopolar configuration. Therefore, the bipolar setting is also a high-current/low-voltage waveform. The principle of Joule heating applies equally to this modality; the simple difference is the location of the return electrode. Because these devices have similarly sized electrodes, the current density is approximately equivalent at both the active and return electrodes. This produces similar Joule heating and temperature changes at each tine of the instrument and, thus, desiccates target tissues from both sides, simultaneously allowing for lower power settings on
the generator. Desiccation is superior to their monopolar counterparts and yields less collateral thermal damage [21].

**Advantages of Bipolar Electrosurgery**

In addition to superior desiccation and the lower voltage requirement, the close configuration of the active and return electrode in bipolar instruments virtually eliminates the threats of alternate site burns as well as direct and capacitive coupling [21]. Because the corona discharge travels in opposite directions along the 2 cables, it cancels itself out, and capacitive coupling does not occur. Furthermore, a return/dispersive electrode is not required, and the risk of dispersive electrode burns is also eliminated. In addition, during resectoscopic surgery, the use of bipolar technology requires a conductive irrigant solution such as saline, thus eliminating the potential risk of hyponatremia. However, a common pitfall among users who rely on the safety of bipolar devices is prolonged activation of the electrode. This may generate significant heat, which is absorbed by the metal electrode head and can cause injury to other tissues upon contact.

**Disadvantages of Bipolar Electrosurgery**

Bipolar electrodes cannot cut tissue. Although a continuous (“cut”) waveform is applied to bipolar instruments, cutting is inefficient because the amount of tissue involved is minimal, and vaporization is inefficient and cumbersome [21]. In lieu of this shortcoming, advanced bipolar devices incorporate a mechanical cutting blade at the electrode site allowing for virtually bloodless dissection after excellent tissue desiccation.

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