Monopolar and Bipolar Electrosurgery

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Last Updated:

Wednesday, February 15, 2023

1. INTRODUCTION

Electrosurgery is the application of a high-frequency electric current to biological tissue as a means to cut, coagulate, desiccate, or fulgurate tissue. Unlike electrocautery, during which an electrically heated wire is applied to tissue, with electrosurgery the patient is included in the circuit and current enters the patient's body. The surgeon's goal during the use of electrosurgery is to attain anatomic dissection with hemostasis, while causing the least amount of collateral damage and subsequent scar tissue formation. Physicians using this technique must be knowledgeable about prevention and management of potential complications of electrosurgical procedures.[1]

Keywords: bipolar electrosurgery, monopolar electrosurgery, electricity, cautery, transurethral resection

2. PHYSICS

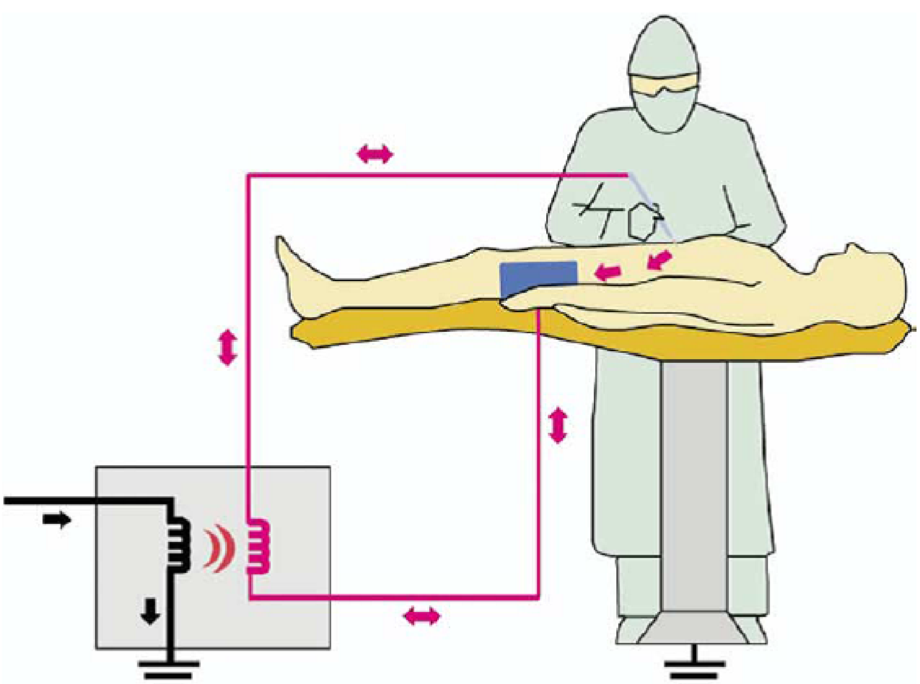


Figure 1: In monopolar electrosurgery, an electrical circuit is formed between the voltage source and the tissue which requires the current to pass through the body. Massarweh NN, Cosgriff N, Slakey DP. Electrosurgery: history, principles, and current and future uses. J Am Coll Surg. 2006;202: 520-530.

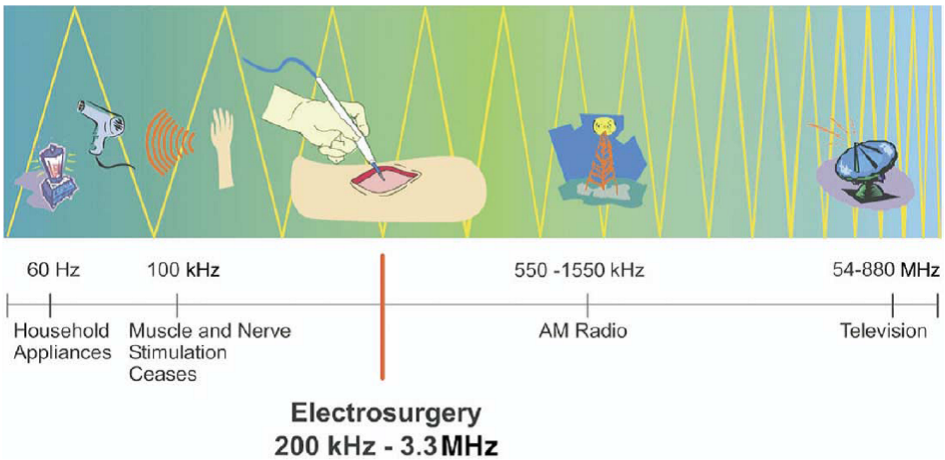


Figure 2: Modern-day electrosurgical units (ESU) use frequency ranges of 200,000 Hz upwards to 5,000,000 Hz, which overlaps with frequencies utilized in radio and television broadcasting, aka radiofrequencies. By exceeding 100 Hz, ESU are able to avoid neuromuscular depolarization. Massarweh NN, Cosgriff N, Slakey DP. Electrosurgery: history, principles, and current and future uses. J Am Coll Surg. 2006;202: 520-530.

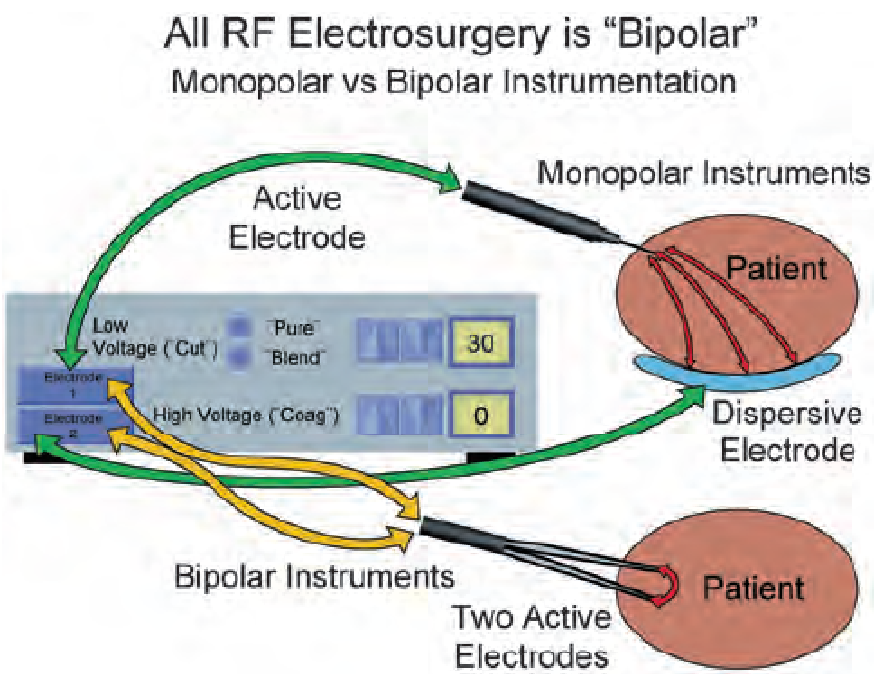


Figure 3: Both "monopolar" and "bipolar" electrosurgery require a closed circuit to allow electrical current to flow through tissue from

an entry (active electrode) to an exit (the return or dispersive electrode). Feldman LS, Fuchshuber P, Jones DB (2012) The SAGES manual on the Fundamental Use of Surgical Energy (FUSE). Springer, New York.

Figure 4: Modern ESU units typically employ a “split pad” for the grounding dispersal electrode. This allows measurement of the impedance in both dispersive electrodes and can thus detect detachment of the pad. If this is detected, such machines will shut off automatically to prevent injury at the dispersal site.

Electricity is a form of electromagnetic energy that flows between atoms. Electrical current (I) is defined as the amount of electricity moving through a conductor over a specific amount of time. Voltage (V) is the force that causes this flow. Resistance (R) (termed impedance with high-frequency AC), is measured in Ohms and represents the property of a conductor that opposes the flow of the current. Electrosurgery requires the presence of a circuit for current to flow and is governed by

Ohm's Law:

***V** (voltage) = **I** (current) x **R** (resistance or impedance)*

- **Current**: the number of electrons flowing per second. This is comparable to the flow of water through a pipe.
- **Voltage**: the unit of force required to drive electron flow against resistance. Similar to water pumped through a pipe or hose under pressure, there is an increased risk of stray current when the voltage is increased.
- **Impedance (or resistance)**: measured in ohms, this is the force against which the electrons work to maintain flow.
- **Power**: the amount of work done, measured in watts. In the water flow analogy, this is similar to horsepower generated by a stream of water turning a water wheel.

The application of a voltage across human tissue results in a simple electrical circuit being formed between the voltage source and the tissue (**Figure 1**). The generated electrical current passes through the tissue, which acts as a resistor within this circuit. This resistance converts the electrical energy of the voltage source into thermal energy which in turn causes heat production. The resistance of a tissue is dependent on its water content. The higher the resistance, the greater the voltage needed for the current to pass. For example, when superficial tissues are cauterized during surgery, they become less electrically conductive, increasing their resistance, and requiring higher amounts of voltage for current to penetrate to the tissues beneath.

Two types of electrical current exist: Direct Current (DC) and Alternating Current (AC). With DC, the electrons flow in only one direction (e.g. simple battery). With AC, the electrons constantly change direction, moving between positive and negative poles as the current flows along a circuit (e.g. electrical wall outlet). The frequency at which AC oscillates between the positive and negative poles is measured in Hertz (Hz), or cycles per second (1 Hz = 1 cycle/sec).

Standard electrical current alternates at a frequency of 60 cycles per second (Hz). Electrosurgical systems used in the operating room cannot function at this frequency, because electrical current would be transmitted through body tissue at 60 cycles and excessive neuromuscular stimulation, and perhaps electrocution, would result. In 1881, Morton found that an oscillating current at a frequency of 100,000 Hz could pass through the human body without inducing pain, spasm, or burn (**Figure 2**). Due to the rapidity of current reversal, ion position change is nil, depolarization does not occur and, therefore, neuromuscular activity ceases.

Because the frequency used for electrosurgery includes that of both radio and television signal transmission (550 kHz - 880 MHz), electrosurgery current is also referred to as radiofrequency current. Modern-day electrosurgical units (ESU) use frequency ranges of 200,000 Hz to 5,000,000 Hz.

Monopolar vs. Bipolar Energy

A closed circuit is necessary so that electrical current can flow through tissue from an entry (active electrode) through tissue to an exit (the return (eg, grounding pad) or dispersive electrode). If the entry electrode is used as the active electrode and the return electrode is inactive, the application is called monopolar electrosurgery. If both electrodes are used as active electrodes, the application is bipolar (**Figure 3**).

In monopolar electrosurgery, the narrow "active electrode" concentrates the current (and therefore the power) at the designated site, elevating the intracellular temperature. The "dispersive electrode" acts as the other pole, "processing" the same amount of current (and power) but dispersing it over the entirety of the large surface area, so much so that the temperature in the underlying skin does not rise, thereby preventing tissue injury (**Figure 3**).

Most (but not all) ESUs sold in the past 20 years are designed to measure the impedance at the level of the dispersive electrode, a function that also requires specialized dispersive electrode design. Usually this is in the form of a "split pad" which, effectively, is two dispersive electrodes in one (**Figure 4**). Differences in the measured impedance in the two dispersive electrodes will generally reflect partial attachment (or detachment) and the machine will not start, or, if already "on," will shut off automatically.

Much like monopolar energy, in bipolar energy a current originates in a generator, passes through an active electrode, and into the tissue of the patient. In contrast to monopolar energy, the patient is **NOT** a component of the circuit in bipolar electrosurgery. The two poles of the circuit are in close proximity to one another. The current passes between these two poles, heating tissue that is located in between (**Figure 5**). A dispersive pad is not needed during bipolar electrosurgery as both the active and return electrode are integrated into the forceps.

3. MECHANISM OF DELIVERY

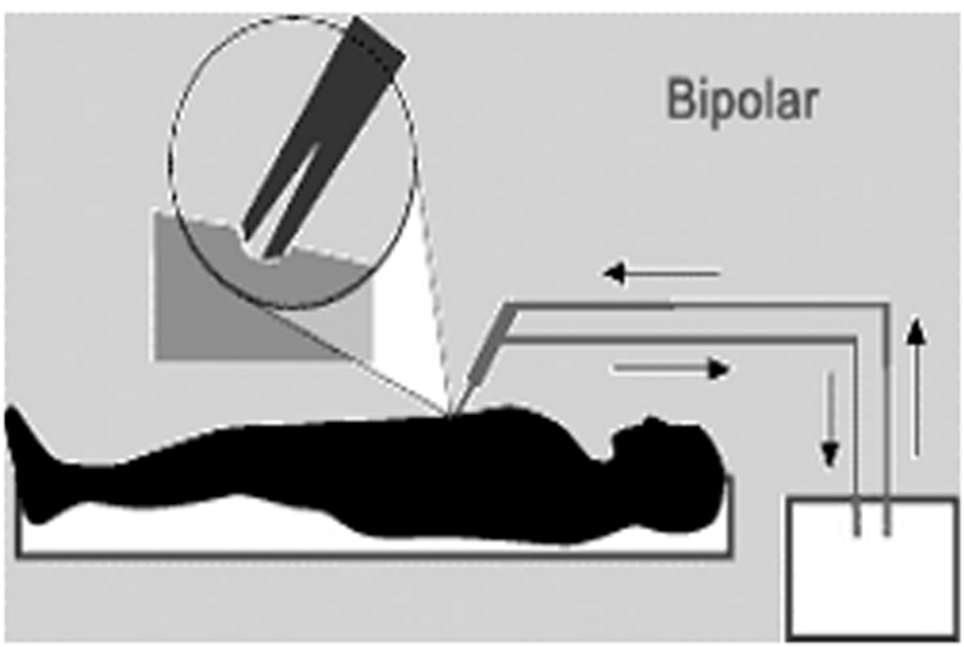


Figure 5: The bipolar circuit in electrosurgery, from Alkatout, 2012.

As the dispersal of electric current occurs through the application instrument itself, “bipolar” ESU applications do not require a dispersive pad. In addition, the path of the current through the patient is limited only to the tissue between the electrodes.

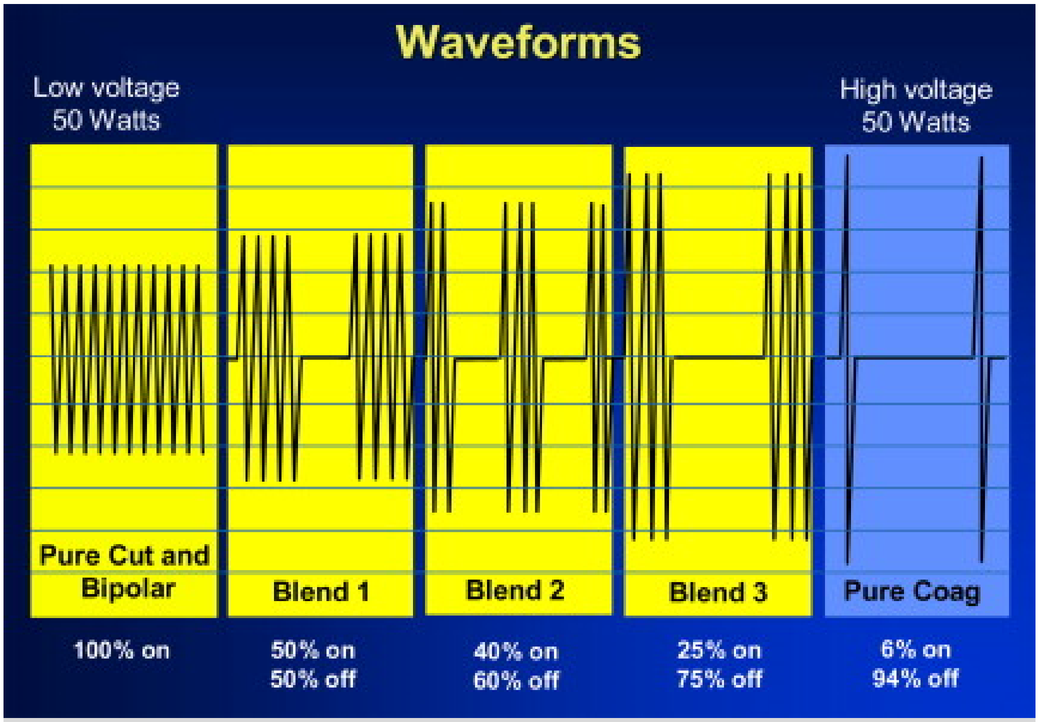


Figure 6: Voltage and duty cycle varies between mode settings employed by ESU such that pure cutting has the lowest voltage and pure coagulation has the highest voltage. By modifying the duty cycle, the blended modes offer intermediate voltages. (http://www.sciencedirect.com/science/article/pii/S1556793107000162)

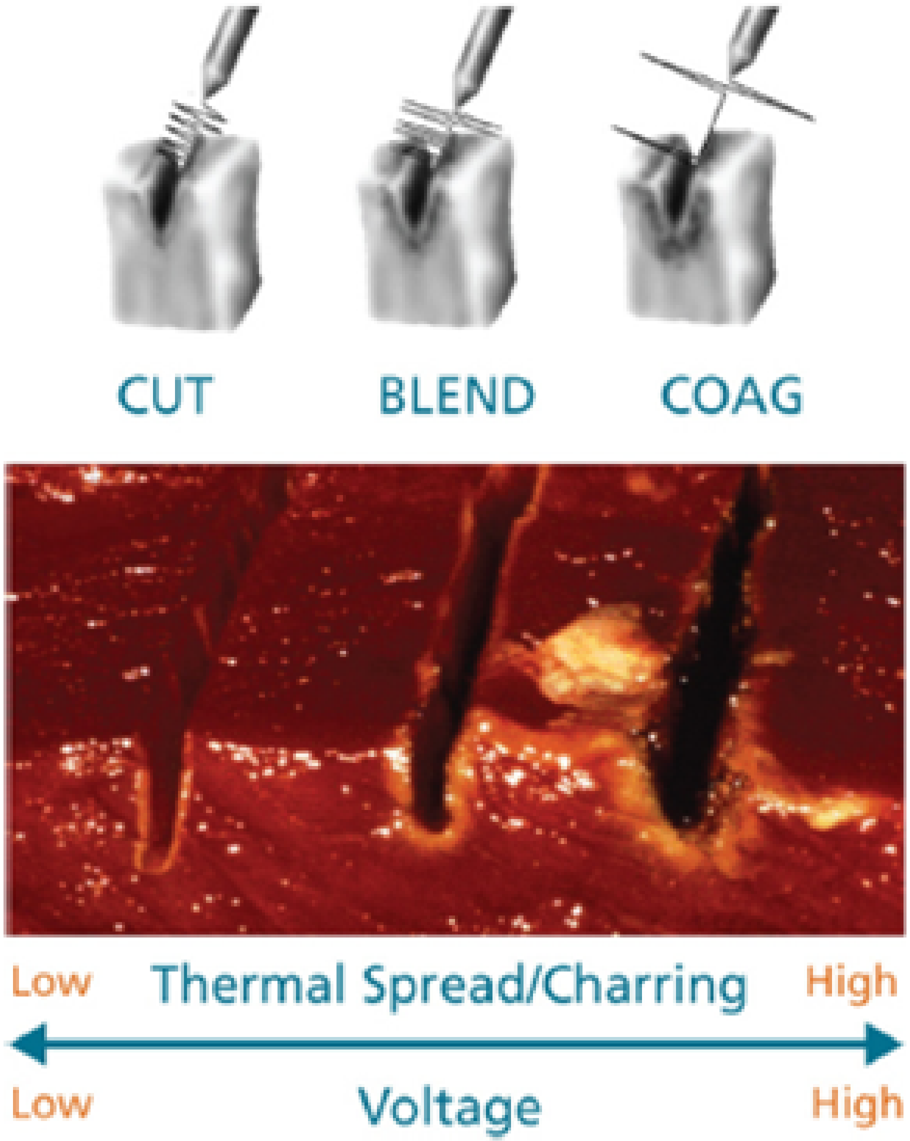


Figure 7: An example of the spectrum of thermal spread and surrounding tissue effect between pure cutting modes, blended modes, and pure coagulation modes

Electrosurgery is the application of electricity, the flow of electrons from one pole to another. This is in contrast to electrocautery, in which heat is transferred from a source that is heated by an electrical current. Two important principles of electrophysics are:

1. Electricity always seeks ground.
2. Electricity always seeks the path of least resistance.

In electrosurgery, several types of current are utilized for different tissue effects:

- Cutting current (yellow) is continuous, unmodulated, and undampened and is characterized by the least voltage.
- Coagulation current (blue) is interrupted, modulated, and dampened and utilizes the highest voltage.

- Blended current is a modification of the "duty cycle" - the current is passed through tissue for a variable percentage of time thus offering intermediate voltage levels between cutting and coagulation settings.

The relationship of these generator settings and the voltage and current parameters delivered is shown in **Figure 6**.

While monopolar electrosurgery may utilize any of these electrical delivery profiles, bipolar electrosurgery usually uses the pure cut waveform. Typically, the power output of a bipolar device is one-third to one-tenth of monopolar devices because the two poles of the bipolar device are in close proximity. The cutting waveform is used in order to deliver a lower voltage. This lower voltage helps to provide hemostasis without excessive charring of tissue (**Figure 7**).

The transformation of electrical energy to heat follows Joule's Law, which can be expressed by the following equation:

$$\text{Energy} = (\text{current}/\text{cross-sectional area})^2 \times \text{Resistance} \times \text{Time}$$

Therefore, the following variables have impact on the tissue effect produced during electrosurgery:

a. **Current**:
The higher the electrical current, the more heat is produced at the tip of the active electrode. With modern ESUs, different tissue effects are seen when using different current settings and intensity (as will be discussed later).
b. **Size of the "Active electrode"**:
The heat generated is inversely proportional to the surface area of the electrode; thus, the smaller the electrode, the more localized and intense the heat energy produced. For practical purposes, there is a 16-fold increase in thermal change with reduction of radius by half (in a circular active electrode).
c. **Type of Tissue**:
Tissues vary widely in resistance. Tissue electrical resistance mostly depends on the degree of vascularity and water content. For example, bone and fat present a higher electrical resistance than skin and muscle. When electrosurgery is applied, progressive tissue desiccation increases tissue resistance, which reduces current intensity. Eschar is relatively high in resistance to current and keeping electrodes clean and free of eschar will enhance performance by maintaining lower resistance within the surgical circuit.
d. **Time**:
At any given setting, the longer the generator is activated, the more heat is produced. And the greater the heat, the farther it will travel to adjacent tissue (thermal spread).

Bipolar energy is delivered to tissue in a closed circuit, with the two poles of the electric circuit in close proximity to one another. A simple example of this is the use of a surgical forceps during an open surgical procedure. Tissue is grasped between the two tines of the forceps, and current is delivered via the electrocautery device. The tissue between the two tines is heated and various tissue effects may occur depending on the voltage delivered, duration of current application, and characteristics of the forceps (i.e. size of the forceps tines).

The advantages of bipolar electrosurgery compared to monopolar electrosurgery are the ability to occlude and seal blood vessels, limit the amount of thermal spread to adjacent tissue, decreased smoke production, and the ability to apply the current in saline or nonelectrolyte solutions. In addition, there is less concern regarding implanted devices such as pacemakers.

Different materials are used to coat the bipolar device tips in order to decrease charring and tissue adherence. These include titanium, nickel, gold, and silver.

4. SAFETY: RECOMMENDATIONS FOR USE OF ELECTROSURGERY

When using electrosurgical or ultrasonic techniques, one must have knowledge of electrophysiological functioning and effects.

To reduce the risk of electrosurgical complications, the following precautions are recommended:

- When both mono- and bipolar instruments are used, pedals and connections should be checked for accuracy before activating the electrosurgical units.
- Instrument electrodes should be kept smooth and clean from char, to avoid disruption of current transfer.
- To prevent capacitive coupling, an isolated position of metal trocars from the abdominal wall should be avoided. Use all-metal or all-plastic cannula systems; the use of metal-plastic hybrids is discouraged.
- An instrument should be activated only when its electrode is fully visible and in contact with the target tissue. Do not activate in an open circuit.
- Preferably use brief intermittent activation versus prolonged activation.
- Use the lowest possible power setting and low-voltage waveform for the desired effect.
- Prior to each minimally invasive surgical procedure, monopolar instruments should be tested for insulation failure with a porosity detector at the central sterilization department.
- With monopolar electrosurgery, the dispersive pad should be applied to well-perfused, dry skin over a large muscle away from bony prominences and conductive prostheses. When disinfecting the skin, be cautious that there are no fluid leaks under the dispersive pad. The larger the surface area of contact between the dispersive pad and the patient, the lower the current density, heat generated, and the lower the risk of thermal burns.
- In patients with conductive prosthesis, it is strongly recommended to place the prosthesis out of the direct path of the electrical circuit.
- For procedures in patients with a cardiac implantable electronic device (CIED), the use of bipolar over monopolar electrosurgery is preferred. Where necessary CIED can be temporarily deactivated to prevent accidental discharge intra-operatively (**see below**).

- Alertness for electrothermal injury is needed when a patient presents with mild symptoms such as slight abdominal discomfort or slight temperature increase.
- Lateral spread of thermal injury must be considered and the surgeon must be aware of nearby structures and maintain an appropriate margin of tissue to avoid inadvertent injury.
- The application of monopolar current to the forceps to create a bipolar current can injure the surgeon holding the forceps especially if gloves are torn or wet. Avoid contact with the patient (i.e. grounding the surgeon) during application of the current.

5. DEVICES

Monopolar Devices

Active electrodes of the ESUs can be activated by means of a hand held device or using a foot pedal (**Figure 8**). The active electrode can have many designs (**Figure 9**), but those with a point, hook, narrow tip, or bladed edge are generally used to concentrate current and power, for the purpose of tissue vaporization and cutting. When the active electrode has a slightly larger surface area, such as the side of a blade, when it is shaped like a ball, or is in the form of a grasper, the same output used for cutting will result only in local coagulation, and, consequently, can be used for the purpose of hemostasis.

Figure 8: http://www.d4surgicals.com/Electrosurgical-Generator and http://www.soundveterinary.com.au/osc/product_info.php?products_id=1269

Figure 9: Variety of active electrode designs for use in surgery.

Bipolar Devices

The most simple and least expensive bipolar device is a forceps with direct application of current. The current passes down the instrument, heats the tissue between the two tines and returns via the second tine of the device. Commercially available devices available for open surgery are shown in **Figure 10**.

Figure 10: Standard bipolar forceps, from spectrumsurgical.com

Figure 11: Kleppinger forceps, from superiorsurgical.com

Figure 12: Histologic findings after vessel sealing using a combination of mechanical pressure and bipolar current, from Massarweh 2006.

Early utilization of bipolar devices in laparoscopic surgery decreased potential for local tissue injury as compared to monopolar devices.

Kleppinger Forceps (**Figure 11**): The classic example of a laparoscopic bipolar device is the Kleppinger forceps.

Within the last ten years, a number of new devices have been introduced for use during open, laparoscopic, and robotic surgery. These include basic bipolar technology devices as well as more sophisticated devices with feedback mechanisms and combination with other energy technology.

Newer bipolar devices employ generators that sense tissue impedance and can regulate power output accordingly. The vessel sealing devices use mechanical pressure combined with electrical current and heat generation to result in vessel wall fusion (**Figure 12**).

Plasmakinetic Forceps (Gyrus ACMI, Olympus Corporation, Southborough, MA): This device delivers pulsed energy with continuous feedback control utilizing a conventional tissue grasping mechanism. It is available for open, laparoscopic, and robotic surgical procedures. The basis of the technology is the passage of current within moisture of the tissue during cut and coagulation cycles, resulting in a more hemostatic division of tissue. A variety of instrument tips are available based on the specific application of this technology. One example of the technology was designed for use with the daVinci robotic platform (Intuitive Surgical, Sunnyvale, CA, USA. (**Figure 13**).

Figure 13: PK dissecting forceps utilized for the da Vinci robotic platform, from: http://www.intuitivesurgical.com/products/instruments

Figure 14: Laparoscopic LigaSure^{TM} Device

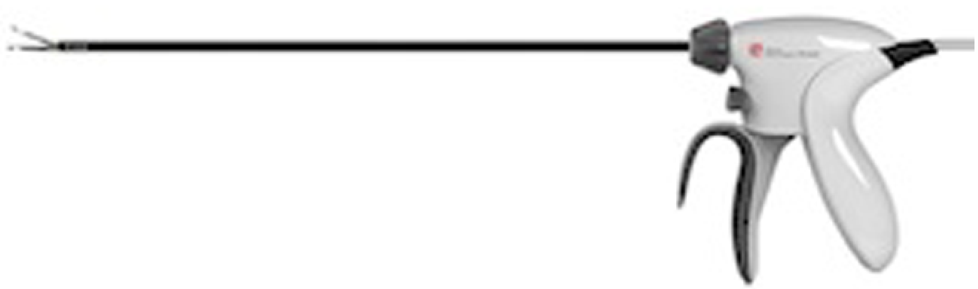


Figure 15: ENSEAL^{TM} Tissue sealer

Figure 16: Da Vinci® Vessel Sealer Extend

LigaSure™ (Covidien, Mansfield, MA) (**Figure 14**): The LigaSure™ device combines mechanical pressure with the continuous tissue impedance feedback that is offered by the plasmakinetic device. By responding to changes in the tissue impedance, less total energy is delivered to the tissue when compared to traditional bipolar devices. During the delivery of thermal energy and mechanical compression, the blood vessel walls are opposed, and collagen and elastin in the walls are denatured to create a hemostatic seal. The proprietary generator measures voltage and current and adjusts these two parameters accordingly based on tissue impedance. A cool cycle is also used to improve the safety of the device. Real-time thermography suggests that thermal spread is reduced compared to traditional monopolar and bipolar devices. The LigaSure ™ device is FDA-approved for sealing vessels up to 7 mm in diameter. Division of the tissue is a separate step after vessel sealing. Multiple hand pieces and jaw designs are available for use during open, and laparoscopic surgery. A proprietary generator is required for use of the device.

ENSEAL™ Tissue Sealer (Ethicon EndoSurgery Inc.) (**Figure 15**): This device is similar to the LigaSure™, utilizing mechanical pressure and electrical energy in combination to create a hemostatic vessel seal. When compared to the LigaSure™, a greater degree of pressure is applied at the tips of the ENSEAL™ combination to create a hemostatic vessel seal. When compared to the LigaSure™ device. The temperature along the tissue seal is limited to 100 degrees C. In addition, this device utilizes a proprietary electrode with conductive particles in the temperature-sensitive material, which detects tissue impedance and changes energy output over nanometer-sized areas of the tissue. Sealing and division of the tissue occur simultaneously with this device. This device can be used during open and laparoscopic surgery. Similar to the other devices, a proprietary generator is required for use.

Thunderbeat™ (Olympus Medical): This device combines ultrasonic and bipolar vessel sealing technology. When compared to the LigaSure™, it may offer faster dissection speed with similar vessel sealing capability. The device reaches temperatures similar to those seen with the harmonic scalpel and thus care must be taken when utilizing this instrument. Multiple hand pieces and jaw designs are available for use during open and laparoscopic surgery. Similar to the other devices, a proprietary generator is required for use.

Da Vinci Vessel Sealer Extend (Figure 16): This device is utilized on the Da Vinci surgical robot and controlled by the surgeon. It is similar to a Ligasure™, utilizing mechanical pressure and electrical energy in combination to create a hemostatic vessel seal. It has wristed motion and in addition to being able to be used to grasp and dissect, it is approved for sealing and cutting vessels up to 7mm in diameter, or tissue bundles that fit in the jaws.

Bipolar transurethral resection: Bipolar technology can be applied to transurethral resection of the prostate (TURP) and bladder tumors (TURBT) using bipolar resectoscope 'loops'. An advantage of bipolar TURP and TURBT is that saline is used as the irrigation fluid. Irrigation with saline decreases the risk of dilutional hyponatremia which is associated with the use of water, glycine, or sorbitol as the irrigant. The technique of bipolar TURP and TURBT is similar to that used with monopolar technology, thus making it an accessible procedure for most urologists.

6. CLINICAL USE/PROCEDURES

- Open procedures:
    - Monopolar electrosurgical energy is the most commonly used energy source during all open surgical procedures.
    - Bipolar electrosurgical energy is useful when collateral tissue damage must be minimized such as in reconstructive urology.
- Endoscopic procedures:
    - Transurethral resection procedures (TUR) including prostate, bladder and urethra. Use of monopolar energy for these procedures precludes the use of isotonic saline as irrigation, since saline in a conductive media will ground the active monopolar electrode, rendering it ineffective. As a result monopolar TUR procedures require the use of hypotonic irrigation fluid, which can lead to hyponatremia and TUR syndrome. In contrast, bipolar energy can be used in conjunction with isotonic saline irrigation, without any loss of current or efficacy.

    - Hemostatic fulguration using bugbee electrode.
- Laparoscopic / Robotic procedures:
    - Monopolar electrosurgical energy is the most commonly used energy source during all minimally invasive surgical procedures.
    - Bipolar electrosurgical energy is used when cautery of tissue is needed.

7. COMPLICATIONS

Exact incidence rates of electrosurgery-related complications are unknown. The estimated incidence is 2 to 5 per 1,000 procedures. Electrical and thermal burns to patient are usually predictable and preventable. Electrosurgically induced thermal injury may occur because of one of the following mechanisms:

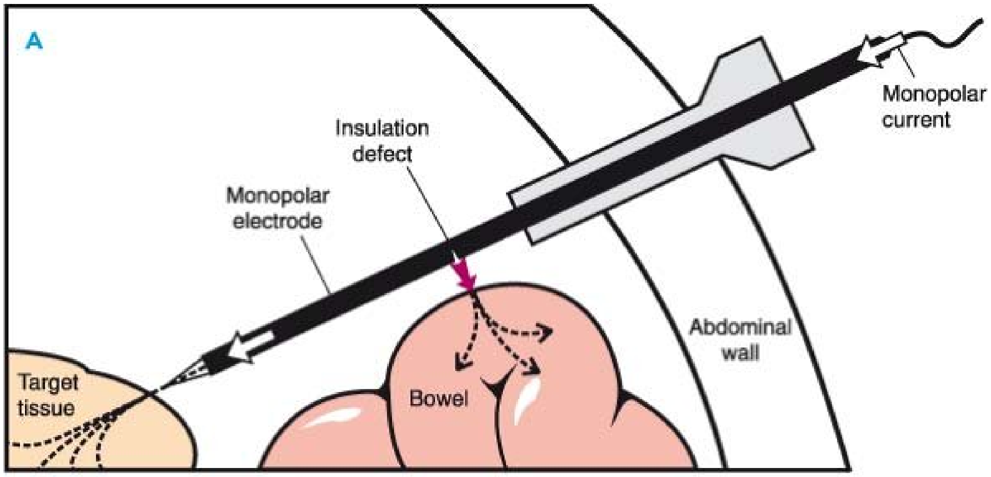
Complications can include:

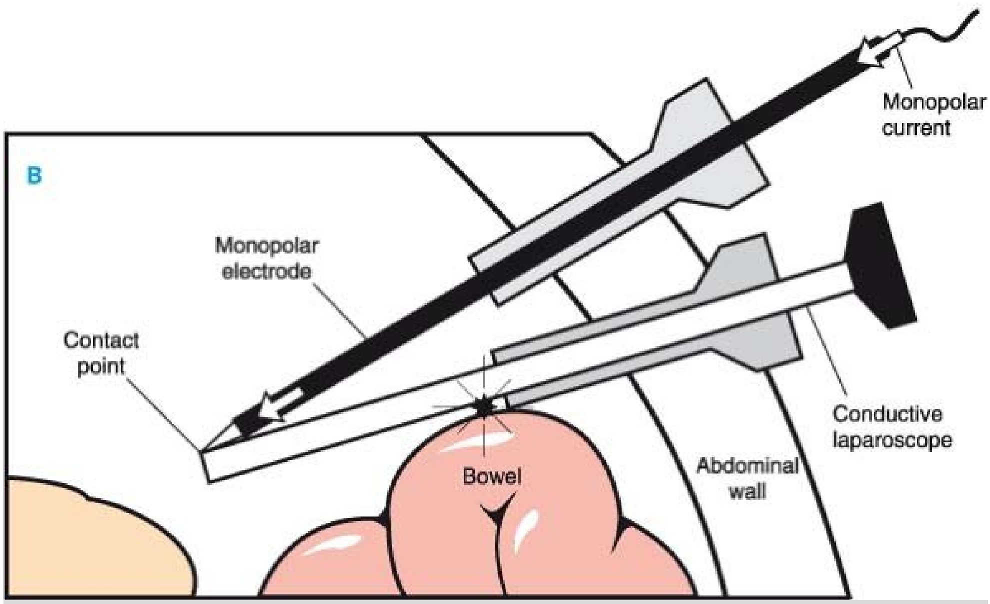
1. Direct coupling: Direct coupling may occur when the active electrosurgical instrument makes an unintended contact with another instrument (e.g. laparoscope) that is in direct contact with unintended tissue (e.g. bowel) (**Figure 17**). This may happen out of the field of view of the surgeon.
2. Residual heat injury when the device has not been allowed to cool before coming into contact with tissue
3. Insulation failure: Insulation breakdown may allow current to escape along the shaft of the instrument (**Figure 17**), thereby harming tissues that are otherwise outside the field of view of the laparoscope (**Figure 18**). Insulation breakdown along the shaft of the instrument may be a result of repeated use, re-sterilization, or mechanical damage to the instrument during repeated insertion through a trocar.
4. Capacitative Coupling: In monopolar mode, capacitive coupling injury occurs when the surrounding charge is not allowed to conduct back to and disperse via the abdominal wall. This condition may develop when a metal cannula is anchored to the skin with a nonconductive plastic grip (e.g., Hybrid cannula), which should never be done. As a result, the electrical field, which builds up around the activated electrosurgical instrument, cannot be conducted to the abdominal wall because the plastic retainer acts as an insulator. Therefore, bowel or any other nearby conductor can become the target of a relatively high-power density discharge (**Figure 19**).
5. Shearing injury of tissue from aggressive manipulation with the jaws of the device closed
6. Injury to nearby tissue during resection of the prostate or bladder tumor
7. Undesired tissue effect (example: charring)
8. Poor quality of contact between the dispersive pad and the patient's skin compromises a safe return of the current to the generator. When the dispersive pad is (partially) detached through bony prominences, adipose, excessive hair, scar tissue, presence of fluid or lotions, or dryness of the pad, the current exiting the body can have a high density. This may produce heat and unintended burns at the site of the dispersive pad. The use of a return electrode monitoring system averts these burns. This system inactivates the electrosurgical unit if the resistance

between the patient's body and the dispersive pad is too high (**Figure 20**).

Complications of electrosurgery can be avoided by applying basic principles of safety:

1. The surgeon should always be aware of the location of the device whether open or laparoscopic surgery is being performed. The electrocautery handpiece should be replaced into its insulated holder to avoid inadvertent activation. This is critically important during laparoscopic or robotic surgery, when the device can be moved out of the field of vision with the assumption that it is not contacting tissue.
2. Avoid activation of the energy source until either in close proximity to the target tissue or in contact with the target tissue (depending on the desired clinical effect and device)
3. The tips of the device should be allowed to cool before placing them in contact with tissue
4. The lowest power settings necessary to achieve the desired result should be employed
5. The surgeon and operative team should be familiar with each device and the manufacturer's recommendations. The tips of bipolar devices should be cleaned according to the manufacturers' recommendations. This will avoid the need for higher power delivery to achieve the desired tissue effect and will decrease tissue charring.





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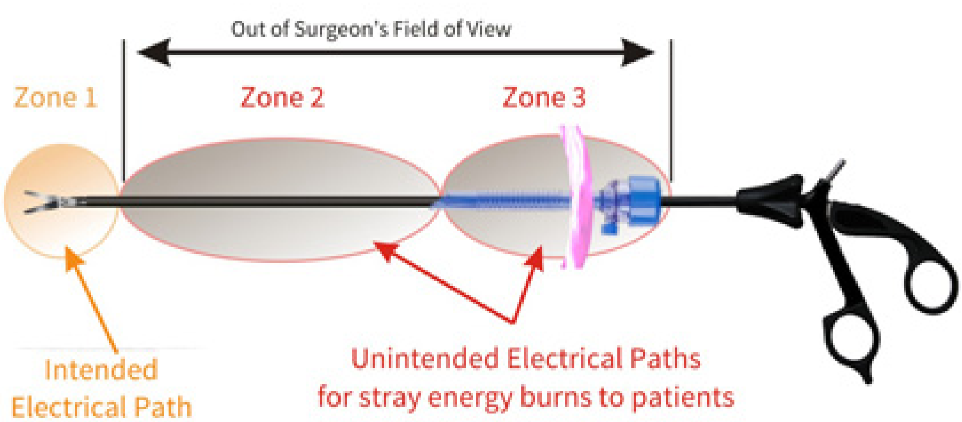
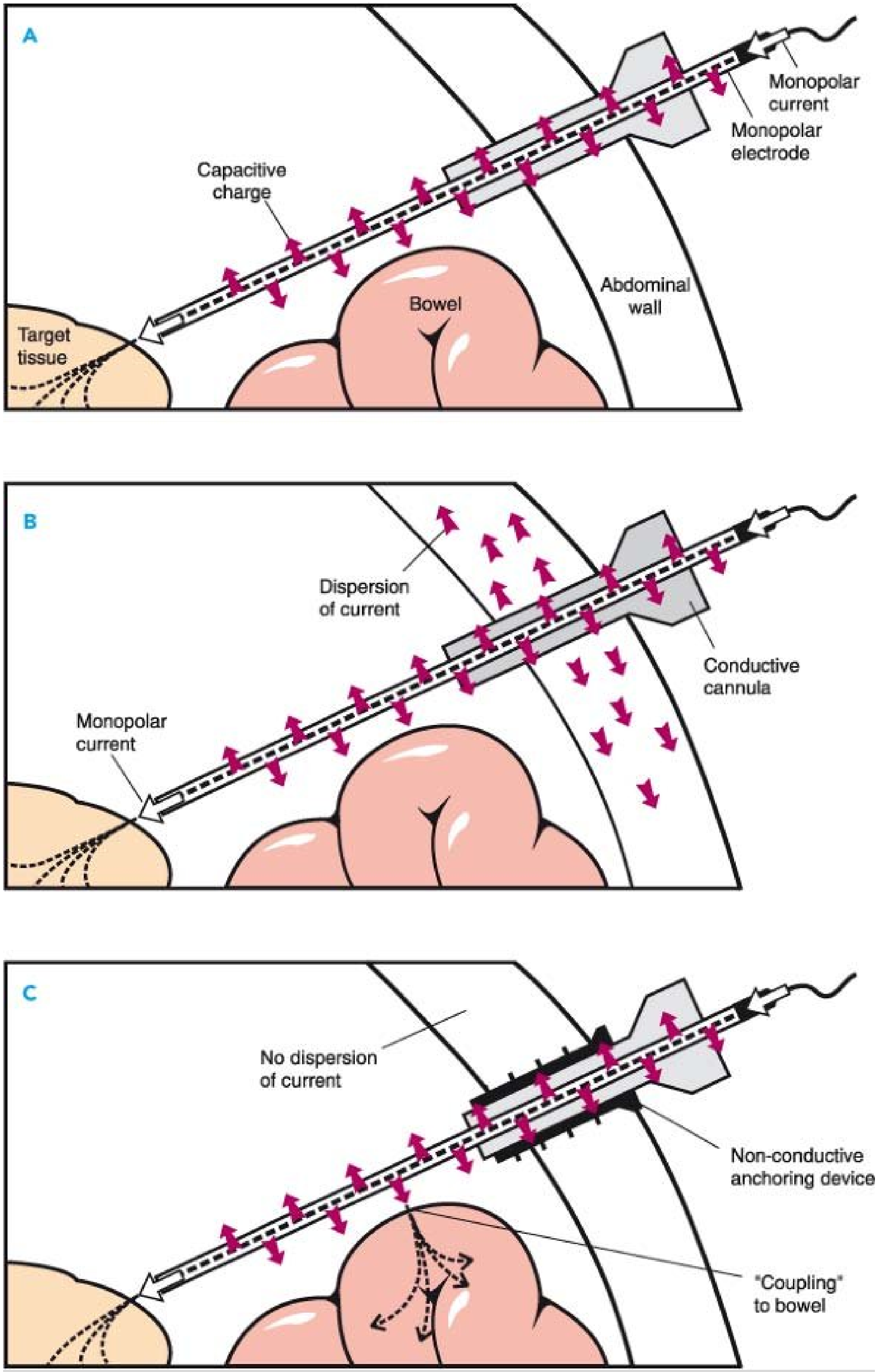


Figure 18: http://encision.com/aem-technology/why-aem/



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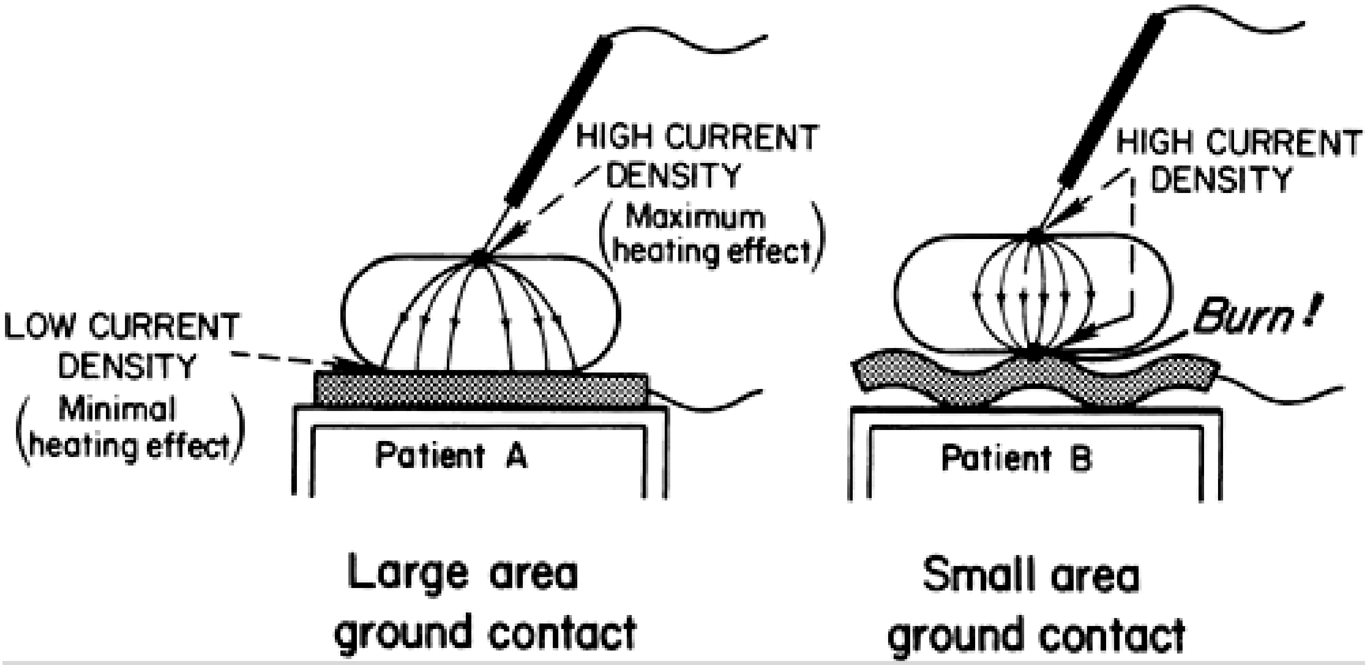

Figure 20:
http://web.squ.edu.om/med-Lib/MED_CD/E_CDs/anesthesia/site/content/v06/060143r00.HTM

Videos

Core Curriculum Monopolar and Bipolar Energy 2021 Powerpoint

Presentations

Monopolar and Bipolar Electrosurgery Presentation 1

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