

Understanding the Principles of Electrosurgery for Endoscopic Surgery and Third Space Endoscopy



Andrew A. Li, MD^{a,b}, Margaret J. Zhou, MD^{a,b},
Joo Ha Hwang, MD, PhD^{a,b,*}

KEYWORDS

- Endoscopic surgery • Electrosurgery endoscopy • Submucosal endoscopy
- Electrosurgical generator units

KEY POINTS

- Understanding electrosurgical principles is important in endoscopic surgery to achieve the desired therapeutic effect, optimize patient outcomes, and prevent adverse events.
- Electrosurgical units (ESUs) provide settings with different properties that contribute to current density and tissue effect. Settings are adjusted based the desired tissue effect for different phases of a procedure.
- In addition to ESU settings, other factors, such as device properties, user technique, application time, and patient or tissue characteristics, also impact current density and tissue effect.
- Familiarity with concepts, such as current density, tissue effect, and the duty cycle and crest factor for each waveform, can help with understanding the various cutting and coagulation waveforms available on ESUs and selecting the appropriate setting for the desired therapeutic effect during endoscopic surgery.

INTRODUCTION

Overview of Electrosurgery and Physical Principles

Electrosurgery is the application of high-frequency electrical alternating current to biologic tissue to cut, coagulate, desiccate, and/or fulgurate. The technology of electrosurgery is widely used in many medical and surgical specialties, including gastrointestinal endoscopy. Within gastrointestinal endoscopy, there are a variety of applications including, biliary sphincterotomy, polypectomy, hemostasis, the ablation

^a Division of Gastroenterology and Hepatology, Department of Medicine, Stanford University School of Medicine, Stanford, CA, USA; ^b 430 Broadway, Pavilion C-3rd Floor, GI Suite, Redwood City, CA 94063, USA

* Corresponding author. 300 Pasteur Drive, MC:5244, Palo Alto, CA 94305.

E-mail address: jooaha@stanford.edu

of lesions, and endoscopic surgery. An understanding of the principles of electrosurgery is important to optimize patient outcomes for each of these applications and to prevent adverse events (eg, bleeding, perforation, or inadvertent damage to surrounding tissue). An understanding of several key concepts for electrosurgery is especially important in endoscopic surgery because of the extensive and dynamic use of electrosurgery to achieve the multiple desired tissue effects through different phases of each procedure (eg, marking, mucosal incision, submucosal dissection, hemostasis, and myotomy) while minimizing injury to nearby tissue.

DISCUSSION

Alternating Electrical Current and Tissue Effect

Applying electrical current to biologic tissue has several effects. With the application of direct current, there is an electrolytic effect where electrically charged molecules flow toward the opposite pole. With a rapid alternating current, such as that used in electrosurgical generator units (ESUs), the electrolytic effect is eliminated, and heat is produced through the intracellular oscillation of ionized molecules. This thermal effect is the basis of electrosurgery: high-frequency alternating current is used to directly generate heat within tissue, and the rapidity, amplitude, and depth of the heat generated determines the tissue effect.¹ By manipulating the properties of the rapidly alternating current and its application to the target tissue, different tissue effects are created. For example, with almost instantaneous heating to a high temperature ($>100^{\circ}\text{C}$), water within cells quickly vaporizes and causes the cell membranes to burst, creating a cutting effect.² At lower temperatures (60°C), proteins are denatured, causing shrinking, drying, and devitalization of the tissue, which is used for coagulation or ablation of lesions. The relative balance of these two processes (cutting and coagulation) is referred to as the tissue effect.

A high frequency ($>300\text{ kHz}$) is used in ESUs to avoid neuromuscular effects that are seen at lower frequencies, such as shocking and electrocution. Because this frequency is in the AM radio range, this range of energy is also referred to as radiofrequency. Of note, electrosurgery is distinct from cautery, wherein electrical current is used to heat an element that is in turn used to cauterize tissue through heat conduction. This is different from electrosurgery in that heat rather than electrical current is passed to the tissue. Cautery is rarely used in gastrointestinal endoscopy, but examples include the heater probe.

Monopolar and Bipolar Devices

For circuits to conduct electricity, they must be closed. In electrosurgery, the patient is connected to a circuit containing the ESU through two electrodes, which is in turn grounded. These electrodes may take the form of monopolar devices paired with a return dispersive electrode, or bipolar devices that contain both electrodes (**Fig. 1**).

Most applications of electrosurgery in endoscopic procedures use monopolar devices, wherein one electrode is the device, such as a snare, endoscopic submucosal dissection knife, coagulation graspers, argon plasma probe, and so forth, and the other electrode is a return dispersive electrode. Colloquially, this is sometimes referred to as the “grounding pad,” which is a misnomer, because the ESU is grounded, not the patient. Current flows from the ESU through the path of least resistance between the device and the dispersive electrode back to ESU to complete the electrical circuit. Because the surface area of the pad is orders of magnitude larger than the active device, the current density is extremely low at the pad site. Appropriate pad placement is critical to safely disperse the electrical energy and avoid an increase in skin

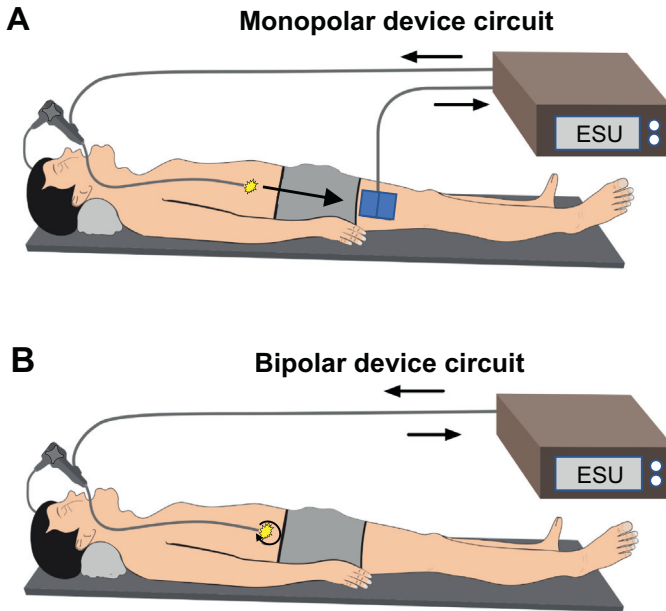


Fig. 1. Overview of electrosurgical generator units (ESU) and circuits. (A) Monopolar device circuits. In monopolar device circuits, current flows from the ESU to the device, which then flows through the target tissue and patient, and returns to the ESU through a return dispersive electrode. (B) Bipolar device circuits. In bipolar device circuits, there is no return dispersive electrode. Instead, current flows within the small area of tissue at the tip of the device, which contains active and return electrodes.

temperature under the pad (see discussion of safety). In contrast to monopolar devices, bipolar devices contain the active and return electrodes in the tip of the instrument. Electrical current flows within the small area of tissue without the need for a return dispersive electrode. An overview of the multiple different monopolar and bipolar devices used in endoscopic surgery is described elsewhere in this issue.

Current Density

The relative balance of cutting, devitalization, coagulation, and desiccation, or tissue effect, is determined by the magnitude of heat generated and the rapidity with which it is achieved. Although ESU manufacturers provide guidance and suggestive settings for common procedures, there are many factors beyond the generator that determine the tissue effect including device properties and operator technique.

The tissue effect is determined by ESU factors (eg, mode, waveform, and power settings), the device, user technique (eg, the surface area of the active electrode in contact with tissue, tension placed on tissue, velocity of the electrode), circuit impedance affected by patient and tissue characteristics (eg, water content, presence of coagulum, fibrosis, or fat content), and time of application. These many factors are summarized as affecting current density, or the intensity or concentration of current in an area of tissue; it is the key variable that determines the tissue effect. It is a measure of current concentration, defined as the current per unit area (Fig. 2).

Current density is important for achieving the desired tissue effect in the immediate vicinity of the active device, but also is important for safety considerations in terms of

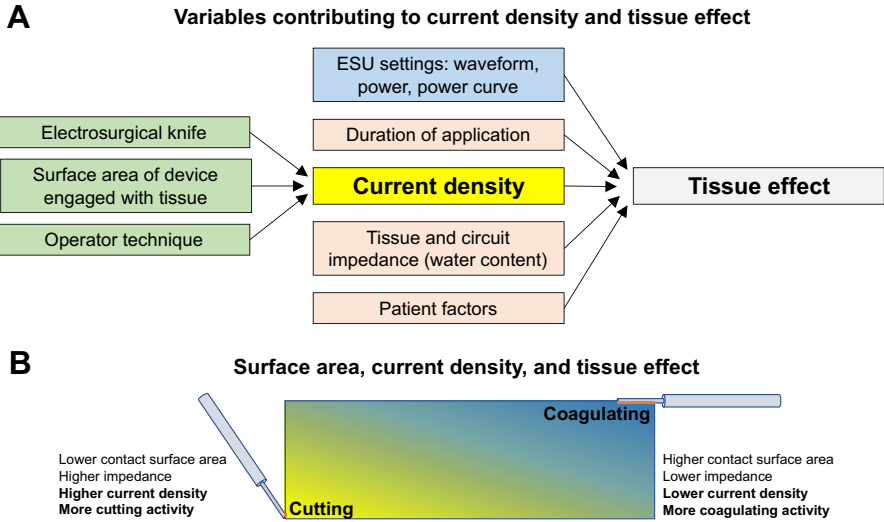


Fig. 2. Illustration of the factors that contribute to current density and tissue effect. (A) Current density is the principal factor in determining tissue effect. Many variables contribute to current density, including device selection, surface area of device used, technique, and electrosurgical generator unit settings. (B) Surface area, current density, and tissue effect. Illustrative example of how surface area affects current density, and thus tissue effect, even when the same device is used. If only the tip is in contact with tissue, there is higher current density and more of a cutting effect compared with if a broader area of the device is in contact with the target tissue resulting in lower current density and more of a coagulative effect.

minimizing thermal injury to nearby tissue. Mathematically, the temperature in tissue rises as a square of the current density, such that a current that almost instantaneously vaporizes water in a 1-mm² area, thereby cutting tissue, does not generate an appreciable effect on a 1-cm² area.³

Current density is affected by ESU settings (discussed later), but also the properties of the active device and user technique. For example, if a higher current density is desired to achieve more of a cutting effect rather than coagulation, options include changing the waveform to one with a higher duty cycle or lower crest factor (discussed in the next section) or using a smaller surface area to contact the tissue either through selection of a device with a thinner electrode or manipulating the device such that a smaller area is in contact with tissue (see Fig. 2B). This higher current density more rapidly heats the cells in contact with the active electrode to beyond 100°C, vaporizing the cells and cutting tissue with less heating of the immediately surrounding tissue leading to less coagulation effect. Conversely, if a lower current density is used, either through ESU settings, or a larger surface area of the active electrode contacting tissue (eg, with coagulation forceps), then tissue is heated slowly such that water is more gradually evaporated allowing for desiccation, coagulation, and fulguration of the tissue (see Fig. 2B). Moreover, beyond current density, user technique, such as tension on tissue, also alters the tissue effect.

Understanding Cut and Coagulation Settings

The rapidity and degree to which tissue is heated by electrical current determines the tissue effect, or the relative balance of cutting, coagulation, and desiccation of tissue.

Current density over time is the major factor in determining the tissue effect as discussed in the previous section.

The electrosurgical generator is an important aspect of the many factors that affect current density and tissue effect. Each ESU manufacturer has different settings, but the concepts that govern them are the same. Here, we provide a framework to better understand these different waveforms and settings, and their potential applications. There are sparse evidence-based data for the optimal waveform choice, so this is left to the physician's preference and experience based on the desired tissue effect.

Before discussing the continuum of cutting and coagulation currents, two key concepts for understanding the qualitative nature of waveforms warrant discussion. These are duty cycle and crest factor, which can provide a framework to understand several key properties of these waveforms (Fig. 3).

Duty cycle refers to the percentage of time that the energy is being actively delivered in each waveform. With a 100% duty cycle, the waveform is on for the full duration of time, whereas with a 6% duty cycle, the waveform is modulated such that energy is being delivered only 6% of the time and is off 94% of the time. These time intervals are modulated on the order of milliseconds. As discussed later, in general, higher percentage duty cycle waveforms produce more cutting and less coagulation tissue effect and lower percentage duty cycle waveforms produce more coagulation and less cutting for a given voltage. This is caused by the rapidity with which tissue is heated, wherein high duty cycle rapidly heats tissue compared with a low duty cycle waveform, wherein there is time between pulses of energy for heat to gradually rise and dissipate into nearby tissue, creating more gradual heating with a wider area of effect.

Crest factor is a term that refers to the peak voltage relative to the average voltage of a waveform (defined as peak voltage over the root-mean-squared average voltage). Higher voltage spikes can force current through desiccated tissue with high impedance adjacent to the active electrode, resulting in deeper tissue effect.

Fig. 4 lists cutting, coagulation, and blended currents for common waveforms with their associated duty cycle and crest factors.

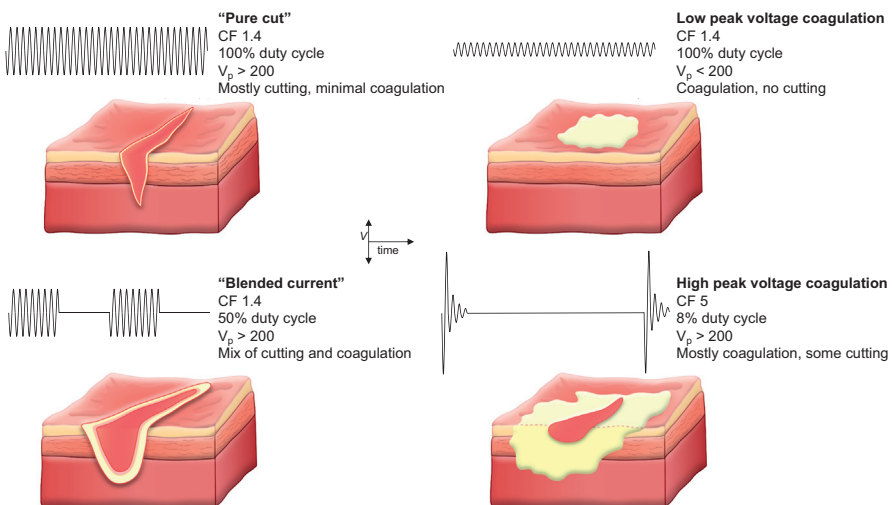


Fig. 3. Different waveforms produce different tissue effects based on crest factor, duty cycle, and voltage. CF, crest factor.

CUT	COAG	Crest Factor	Duty Cycle	Peak Volts
High Cut		1.4	100%	>200
Endo Cut		1.4	100% (cutting cycle)	>200
Dry Cut		2.7-3.8	30%	>200
	Swift Coag	5.4	8%	>>200
	PreciseSect	4.0 (dynamic)		>>200
	Forced Coag	6.0	8%	>>200
	Spray Coag	7.4	4%	>>>200
	Soft Coag	1.4	100%	<200

Fig. 4. Crest factor and duty cycle for common Erbe ESU waveforms.

Understanding cutting settings

A cutting current divides tissue by nearly instantaneously heating water within cells to greater than 100°C to create steam that bursts these cells’ membranes. This is achieved by creating high current density along the leading edge of the electrode, typically though the use of a continuous (100% duty cycle, crest factor of ~1.4–1.6) high-frequency (>300 kHz) sine wave with a peak voltage greater than 200 Vp. This intensity of current is sufficient to create microelectric sparks between the active electrode and the target tissue that vaporizes cells and creates a microsteam layer, propagating the cutting effect.⁴

Although the term “pure cut” is sometimes used to refer to these waveforms, there is a layer of cells along the margin of the cut path that are heated less rapidly and not to the point of vaporization, but rather to the point of coagulation. The depth of this coagulated tissue is related to the peak voltage and surface area of the active electrode of the device. A higher peak voltage or a broader active electrode leads to a thicker margin of coagulation, whereas a lower peak voltage or thinner active electrode leads to a thinner margin of coagulation.

Most cutting waveforms are based on this 100% duty cycle setting. Some ESU manufacturers have created settings that introduce either pauses with no current (Olympus [Center Valley, PA], Genii [St. Paul, MN], and ConMed Pulse Cut [Utica, NY]) or alternating with a coagulating waveform (Erbe EndoCut I and Q [Marietta, GA]).

Blended cutting waveforms produce a tissue effect of cutting activity but with a greater depth of thermal injury and coagulation along the path of the electrode. This is achieved through modulation of the current with a lower duty cycle, typically ranging from 30% to 70%, and higher crest factor in the 1.8 to 3.8 range, as compared with a “pure” cutting current, which is 100% duty cycle and crest factor of about 1.4. The higher peak voltage (reflected by higher crest factor) and slower delivery of energy (reflected by lower duty cycle) allows current and heat generation to be delivered more deeply and slowly, respectively. Examples of this include Dry Cut (Erbe) or Blend Cut (Genii).

Understanding coagulation settings

Coagulation of tissue is achieved through the comparatively slow heating of tissue in close contact with the active electrode. Modern ESUs have various coagulation modes. With low duty cycle waveforms, the gradual heating of tissue is achieved by pulsing short bursts of energy with longer pauses between them. This results in the period delivery of current to create bubbling of cellular water content (wave on) and then steam release with cooling (wave off) repeated with each duty cycle, thereby desiccating and shrinking the cells, creating a coagulation effect.^{5,6} However, these

do have some electrosurgical cutting activity because of the voltage spikes, with peak voltages typically greater than 200 Vp, which are sufficient to create microsparks that cause cutting. Because of this, the conventional wisdom is that these waveforms are usually less suitable for precoagulation of large vessels, such as arteries, because they can be cut by the sparking before the vessel's edges are fully desiccated and coagulated. However, for small vessels and capillaries, it is often suitable because they are small enough in diameter to be sufficiently desiccated and coagulated before being cut by the sparking. Examples of these coagulation waveforms include Forced Coag, Spray Coag, and Swift Coag (Erbe Vio 3).

With low power (<200 Vp) pure sinusoidal waveforms (eg, Soft Coag, TouchSoft), a similar effect is achieved through the slower and gradual heating of the tissue. Although this is a 100% duty cycle waveform, the peak voltage is too low to generate the microsparks necessary for rapid vaporization and cutting tissue effect, in contrast to the low duty cycle high peak voltage waveforms described previously. The minimal cutting activity makes it a current more suitable for the coagulation of larger vessels, such as arteries. However, a limitation of this waveform is that because of the lower voltage, energy cannot be delivered as deeply when the tissue resistance is high after a coagulum has formed. Therefore, use of a device with a larger electrode surface area, such as hemostatic forceps (coagulation graspers), is needed to decrease current density and resistance to allow for sufficient coagulation, in addition to the coaptive properties of the forceps that decrease blood flow during coagulation reducing the heat sink effect of blood flow.

Most coagulation waveforms on modern ESU generators are variations of the low duty cycle, high peak voltage waveforms with high crest factors. Beyond the most common waveform with a 6% duty cycle (as in forced coagulation or pure coagulation), waveforms with a slightly higher duty cycle and lower crest factor offer more cutting activity and less thermal spread. Examples of these include Blend Coag or Swift Coag.^{7,8}

Finally, a low duty cycle waveform with very high voltage waveform is used to induce arcing in a noncontact fashion. Very high voltages are required to ionize the mixed air between the electrode and tissue and therefore have high crest factors (>7–8) and may be named Spray Coagulation or fulgurate. Notably, this is a similar principle used in argon plasma coagulation (APC), but because of argon's more stable plasma, lower voltages can be used in APC as compared with mixed air. Although this setting has very high voltages, if the electrode is not in contact with the tissue, the current density at the level of the tissue is low as the current passes from the electrode, through air or CO₂ to a much larger surface area of target tissue; therefore, the current density is decreased and the current effectively coagulates vessels without deep penetration. However, if the electrode is in contact with the tissue, the very high voltage delivered directly to the tissue can result in very high current density resulting in deep penetration of current and resulting tissue effect. This setting should be used with caution. Also, this setting should be used with devices that are rated for high-voltage waveforms.

Practical Considerations

Cutting and coagulation waveforms exist on a continuum of the relative balance of cutting and coagulation activity, a large degree of which is captured with understanding the duty cycle and crest factor for each waveform.

In endoscopic surgery, considerations for which waveform to use depend on the desired tissue effect (eg, cutting, coagulation, or blend of both), tissue site and risk of thermal injury to adjacent tissue, the device used, user technique, and the many other factors that affect current density. Power settings are also affected by these considerations. In general, when the aim is to cut tissue, high current density is desired. If

coagulation of vessels is the aim, a lower current density should be delivered to avoid prematurely cutting a vessel before it has been fully coagulated. For larger vessels, especially arteries, the use of coagulation graspers delivers lower current density (because of the large surface area of the electrode) and also coapts the vessel during the delivery of energy, decreasing blood flow and preventing a heat sink effect. Suggested settings for common applications in endoscopic surgery are listed in [Table 1](#), but these must be individualized and potentially adjusted during the procedure to achieve the desired tissue effect and minimize risk of damaging nearby structures, bleeding, and perforation.

Safety

General safety features of electrosurgical generator units

ESU-related complications are rare; however, it is important to understand the potential risks. Historically, the most commonly reported patient injury with ESUs has been a skin injury at the site of the dispersive electrode, although to our knowledge this has not been reported with endoscopic procedures.^{8,9} Other possible complications include burns from capacitive coupling (ie, a burn resulting from current transfer from the active electrode to a second conductive structure), interaction with implantable devices, or colonic gas explosion.^{8–11}

Best practices when using ESUs include inspection of the ESU and power settings before activation, disconnecting the device from the active cord when not in use, placing the generator in “standby” mode if the procedure has not commenced, avoiding accidental activation of the electrode, handling tools by the plastic insulated areas, and never attempting to connect or disconnect accessories while current is flowing.^{8,9,12} Most modern ESUs include a system that monitors contact quality between the patient and the dispersive pad when used with a split (ie, dual, or sensing) dispersive pad. This can trigger an alert if there is a change in contact (decreased surface contact, increased resistance to current) that could lead to heat dispersion on the patient’s skin and a possible burn at the area of contact. This technology significantly reduces the risk of skin injury under the pad. It is thus highly recommended to use these safety features and a split pad.⁹ In addition, it is important to always be aware of active electrodes to ensure the safety of patients and staff. A monopolar tool connected to a generator that is “on” is considered an active electrode and can potentially cause an electrosurgical injury if it is unintentionally activated.

Placement of dispersive electrodes

Dispersive electrode/pad placement is an important aspect of electrosurgery. When using a monopolar device, a dispersive electrode (grounding pad) is required to complete the electrical circuit. The current flows from the ESU to the treatment site via the device, through the patient’s tissue to the dispersive electrode on the skin, and completes the circuit by flowing back to the generator.

It is crucial to train staff on best practices for the placement and management of dispersive pads. Proper pad placement includes placing pads as close as possible to the treatment site to allow for the shortest monopolar circuit, ensuring pad placement over areas with good blood supply, and avoiding placement over skin irregularities (scars, broken skin, excessive hair, or tattoos) or implants, because these can interfere with smooth current dispersion. Avoiding having vulnerable structures (eg, an implantable device) be placed between the active and dispersive electrode is also recommended. Ensuring the best possible contact between the skin and the entire dispersive pad is essential, and this is accomplished by using only fresh disposable pads with adherent gel, checking expiration dates of pads, and avoiding placing

Table 1
Suggested Erbe generator settings^a for common applications in endoscopic surgery

Technique	Output Name	Power (W)	Cut Duration	Cut Interval	Effect	General Approach
Mucosal marking	Soft Coag	60–80			5	Coagulation setting.
	Forced Coag	10			1	Low power to avoid piercing through the muscularis mucosae.
	Spray Coag	10			1	Often performed with the knife tip retracted.
Mucosal incision	EndCut I	—	2–3	2–3	2–3	Cut setting.
	Dry Cut	60–80			2–5	Increase effect and/or cut interval if the tissue is more vascular.
Submucosal dissection	Forced Coag	30–50			2–3	Any cut or coagulation setting (other than Soft Coag) works for submucosal dissection.
	Precise Sect (Erbe VIO3)	40–60			—	Decreased surface area in contact with tissue increases current density and provides more dissection/cutting capability.
	Swift Coag	40–50			2–5	Coagulation of submucosal vessels requires lower current density to coagulate the vessel while cutting through the vessel. If the vessel is large or pulsating, use coagulation graspers to coagulate the vessel before cutting across the vessel.
	Spray Coag	40–50			1–2	
	Dry Cut	30–40			3–5	
	EndoCut I	—	2–3	2–3	2–3	
Myotomy	EndoCut I	—	2	2–3	2–3	EndoCut I with low effect or “tapping” of the pedal is effective for muscle with minimal vessels.
	Dry Cut	60–80			3–4	EndoCut I with higher effect (effect 3–4) or Dry Cut 80 W if the muscle is vascular.
Hemostasis	Soft Coag	60–80			5	Coagulation setting.
	Spray Coag	10			1	Low current density.
	Forced Coag	10			1	Coagrasper works best with Soft Coag resulting in low current density because of large surface area. Use for any arterial vessels. If using knife, increased surface area in contact with the vessel decreases current density and provides more coagulation capability.

^a The Erbe VIO 300D and VIO3 have different power and effect settings. The suggestions are based on the power setting for the VIO3. The effect setting only applies to the VIO 300D.

pads over irregular skin surfaces.^{9,12,13} These steps are important to allow for even dispersal of energy and to avoid a possible burn at the pad site. For endoscopic procedures, recommended areas for pad placement are on the flank or upper thigh, taking into consideration the aforementioned best practices for individual patients.⁹

Bowel preparation and explosion risk

There have been case reports of colonic gas explosion, characterized as rapid increase of temperature and pressure caused by sudden energy release leading to volume expansion of naturally occurring gases, such as hydrogen and methane that exist in the colon.¹⁴ These cases have involved APC in the rectum or sigmoid, typically after enema preparation.¹⁵ Prior studies have found that levels of hydrogen and methane may be lower after full bowel preparation for colonoscopy, such as with polyethylene glycol, compared with enema preparation for sigmoidoscopy.¹⁶ Thus it has been posited that full bowel preparation may decrease the risk of colonic gas explosion. If electrosurgery must be performed on an unprepared colon, exchanging the colonic gas for carbon dioxide with repeated insufflation and suction may reduce the risk.

Electrosurgery with Implanted Devices

Implanted cardiac devices, including cardiac pacemakers and implantable cardioverter defibrillators, sense and react to electrical signals from the heart. Thus, they are subject also to sensing noncardiac electrical signals. Patients with these devices can undergo electrosurgery, but it is important to take adequate safety measures. The risk of device interference is variable depending on the type of interfering signal and the type and design of the device. Before the procedure, it is essential to obtain information about the device, indication for the device, the patient's underlying cardiac rhythm, and whether the patient is device dependent. All patients should undergo continuous cardiac rhythm monitoring throughout the procedure.^{17,18}

Possible adverse effects of electrical interference from electrosurgery include inappropriate device programming because of signal misinterpretation by the device, inhibition of signal output, negative effects on battery life, or delivery of inappropriate shocks to the patient in the case of implantable cardioverter defibrillators.^{18–20} Consultation with a cardiologist should be considered before a procedure in which electrosurgery is anticipated. Endoscopy units should have equipment for resuscitation, cardioversion, and defibrillation readily available, and all staff should be trained in protocols for managing patients with implantable devices. Consensus statements regarding management of patients with cardiac devices have been released by multiple societies including the American Society of Gastrointestinal Endoscopy and the Heart Rhythm Society/American Society of Anesthesiologists.^{18,21}

Other implanted devices include implantable neurostimulators that deliver electrical stimulation to target nerve tissue for various conditions. These include gastric electrical stimulators for gastroparesis; deep brain stimulators for Parkinson disease; or other devices that can target areas including the spinal cord, cochlea, and bladder.¹⁷ Most have an external control module that allows setting adjustment, including controlling the on/off status and electrical output.^{22,23} Possible risks can include inhibition of neurostimulator device output or electrode heating. These risks may be able to be reduced by turning off the device before the procedure.

SUMMARY

An understanding of the basic principles of electrosurgery is important in endoscopic surgery to achieve the desired tissue effect through each portion of the procedure. Modern ESUs provide a variety of waveforms with different properties that contribute

to current density over time and in turn, the tissue effect. Moreover, current density is also affected by factors beyond the ESU, including the device properties, user technique, and patient factors. A working knowledge of these principles is therefore essential in reducing risks and achieving the therapeutic effect.

CLINICS CARE POINTS

- Understanding electrosurgical principles used with electrosurgical units (ESUs) is important in endoscopic surgery to achieve the desired therapeutic effect, optimize procedural outcomes, and minimize adverse events.
- ESUs provide various settings with properties that contribute to current density and tissue effect. The tissue effect, or balance of cutting and coagulation, is determined by the magnitude and rapidity of heat generation by the electrical current.
- A working knowledge of concepts, such as current density and tissue effect, and knowledge of the duty cycle and crest factor for each waveform, can help with understanding the various cutting and coagulation settings available on ESUs.
- Current density is impacted by the duty cycle (percentage of time with active energy delivery), crest factor (measure of peak voltage), and surface area in contact with tissue. In general, cutting is best achieved with higher current density, whereas coagulation is best achieved with lower current density.
- In general, higher percentage duty cycle, lower crest factor, and decreased surface area contribute to a higher current density and greater cutting ability. However, these effects can vary depending on the clinical situation. ESU settings must be individualized and potentially adjusted to achieve the desired tissue effect at different phases in the procedure and minimize thermal injury to adjacent tissue.
- Although understanding properties of ESU settings is imperative, other factors, such as device properties, user technique, application time, and patient or tissue characteristics, are equally important in achieving the optimal therapeutic effect in endoscopic surgery.
- ESU-related complications are rare. However, it is important for the endoscopy team to understand best practices when using ESUs, such as optimal dispersive pad placement. When performing endoscopic surgery in patients with implanted devices, especially cardiac devices, it is essential to obtain information about the device and indication for the device.

DISCLOSURE

A. Li: No relevant disclosures. M.J. Zhou: No relevant disclosures. J.H. Hwang: Consultant for Olympus, Medtronic, Boston Scientific, Micro-Tech, and Lumendi.

REFERENCES

1. Tucker RD. Principles of electrosurgery. In: Sivak MV, editor. *Gastroenterologic Endosc.* 2000. p. 125–35.
2. Honig WM. The mechanism of cutting in electrosurgery. *IEEE Trans Biomed Eng* 1975;1:58–62.
3. Barlow DE. Endoscopic applications of electrosurgery: a review of basic principles. *Gastrointest Endosc* 1982;28(2):73–6.
4. Munro MG. Fundamentals of electrosurgery part I: principles of radiofrequency energy for surgery. In: Feldman L, Fuchshuber P, Jones DB, editors. *The SAGES manual on the fundamental use of surgical energy (FUSE)*. New York: Springer; 2012. p. 15–59.

5. Morris ML. Electrosurgery in the gastroenterology suite: principles, practice, and safety. *Gastroenterol Nurs* 2006;29(2):126–32.
6. Morris ML, Hwang JH. Electrosurgery in therapeutic endoscopy. In: Chandrasekhara V, Elmunzer BJ, Khashab MA, et al, editors. *Clinical gastrointestinal endoscopy*. 3rd Edition. Philadelphia: Elsevier; 2019. p. 69–80.e62.
7. Singh N, Harrison M, Rex DK. A survey of colonoscopic polypectomy practices among clinical gastroenterologists. *Gastrointest Endosc* 2004;60(3):414–8.
8. Tokar JL, Barth BA, Banerjee S, et al. Electrosurgical generators. *Gastrointest Endosc* 2013;78(2):197–208.
9. Morris ML. Electrosurgery in the gastroenterology suite: principles, practice, and safety. *Gastroenterol Nurs* 2006;29(2):126–32, quiz 132–124.
10. Tucker R. Commentary on clinical applications of argon plasma coagulation in endoscopy. *Gastroenterol Nurs* 2007;30(2):129–30, author reply 130.
11. Spruce L, Braswell ML. Implementing AORN recommended practices for electrosurgery. *AORN J* 2012;95(3):373–84, quiz 385–377.
12. Rey JF, Beilenhoff U, Neumann CS, et al, (ESGE) ESoGE. European Society of Gastrointestinal Endoscopy (ESGE) guideline: the use of electrosurgical units. *Endoscopy* 2010;42(9):764–72.
13. Wright VC. Contemporary electrosurgery: physics for physicians. *J Fam Pract* 1994;39(2):119–22.
14. Ladas SD, Karamanolis G, Ben-Soussan E. Colonic gas explosion during therapeutic colonoscopy with electrocautery. *World J Gastroenterol* 2007;13(40):5295–8.
15. Manner H, Plum N, Pech O, et al. Colon explosion during argon plasma coagulation. *Gastrointest Endosc* 2008;67(7):1123–7.
16. Monahan DW, Peluso FE, Goldner F. Combustible colonic gas levels during flexible sigmoidoscopy and colonoscopy. *Gastrointest Endosc* 1992;38(1):40–3.
17. Parekh PJ, Buerlein RC, Shams R, et al. An update on the management of implanted cardiac devices during electrosurgical procedures. *Gastrointest Endosc* 2013;78(6):836–41.
18. Dawes JC, Mahabir RC, Hillier K, et al. Electrosurgery in patients with pacemakers/implanted cardioverter defibrillators. *Ann Plast Surg* 2006;57(1):33–6.
19. Schulman PM, Treggiari MM, Yanez ND, et al. Electromagnetic interference with protocolized electrosurgery dispersive electrode positioning in patients with implantable cardioverter defibrillators. *Anesthesiology* 2019;130(4):530–40.
20. Fiek M, Dorwarth U, Durchlaub I, et al. Application of radiofrequency energy in surgical and interventional procedures: are there interactions with ICDs? *Pacing Clin Electrophysiol* 2004;27(3):293–8.
21. Crossley GH, Poole JE, Rozner MA, et al. The Heart Rhythm Society (HRS)/American Society of Anesthesiologists (ASA) Expert Consensus Statement on the perioperative management of patients with implantable defibrillators, pacemakers and arrhythmia monitors: facilities and patient management this document was developed as a joint project with the American Society of Anesthesiologists (ASA), and in collaboration with the American Heart Association (AHA), and the Society of Thoracic Surgeons (STS). *Heart Rhythm* 2011;8(7):1114–54.
22. Medtronic Inc. Digestive & Gastrointestinal Products: Information for Healthcare Professionals. Available at: www.medtronic.com/physician/gastroenterology.html. Accessed 31 March 2022.
23. Medtronic Inc. Neurological Products: Information for Healthcare Professionals. Available at: www.medtronic.com/physician/gastroenterology.html. Accessed 31 March 2022.