Electrosurgical generators

The ASGE Technology Committee provides reviews of existing, new, or emerging endoscopic technologies that have an impact on the practice of GI endoscopy. Evidence-based methodology is used, performing a MEDLINE literature search to identify pertinent clinical studies on the topic and a MAUDE (U.S. Food and Drug Administration Center for Devices and Radiological Health) database search to identify the reported complications of a given technology. Both are supplemented by accessing the "related articles" feature of PubMed and by scrutinizing pertinent references cited by the identified studies. Controlled clinical trials are emphasized, but in many cases, data from randomized, controlled trials are lacking. In such cases, large case series, preliminary clinical studies, and expert opinions are used. Technical data are gathered from traditional and Web-based publications, proprietary publications, and informal communications with pertinent vendors.

Technology Status Evaluation Reports are drafted by 1 or 2 members of the ASGE Technology Committee, reviewed and edited by the Committee as a whole, and approved by the Governing Board of the ASGE. When financial guidance is indicated, the most recent coding data and list prices at the time of publication are provided. For this review, the MEDLINE database was searched through August 2012 for articles related to endoscopy by using the key words electrosurgical generators, electrosurgical generator units, electrosurgery and endoscopy, current and endoscopy, Endocut, argon plasma coagulation, complications and endoscopy, monopolar and endoscopy, bipolar and endoscopy, and a variety of related searches.

Technology Status Evaluation Reports are scientific reviews provided solely for educational and informational purposes. Technology Status Evaluation Reports are not rules and should not be construed as establishing a legal standard of care or as encouraging, advocating, requiring, or discouraging any particular treatment or payment for such treatment.

BACKGROUND

Electrosurgical generator units (ESUs) facilitate therapeutic endoscopy by supplying the high-frequency electrical current required to use many endoscopic accessories. The term electrosurgical energy describes the transformation of alternating electrical current produced by the ESU into thermal energy within tissue. In endoscopy, devices such as polypectomy snares, forceps, and sphincterotomes serve as conduits that deliver electrical energy to the intended therapeutic site. The most currently available ESUs possess sophisticated microprocessors and software enabling them to generate a variety of electrosurgical waveforms that influence the end result of the electrosurgical energy. ESUs possess features that enhance both patient safety and ease of use.

TECHNOLOGY UNDER REVIEW

Basic concepts of electrosurgical generators and electrosurgery

Terminology: current, resistance, voltage. Current (I) is the flow of electrons during a period of time and is measured in amperes. A circuit is the pathway of current. Resistance (R) and impedance represent the impediment to *direct* current (DC) and *alternating* current,[1] respectively, and are measured in ohms. Voltage (V) is the force that pushes a current through a resistance and is measured in volts. Greater voltage is needed to maintain a steady current flowing through a circuit if the resistance within the circuit increases, as is the case when tissue desiccates a current is being applied. This relationship is described in Ohm's law ($V = I \times R$). Power (P), measured in watts, equals current times voltage ($P = V \times I$) and represents the amount of energy transferred in a time interval. The temperature change elicited when current is applied is governed by Joule's law ($Q = I^2 \times R \times t$), where Q is the heat generated by a current of constant intensity (I) flowing through a conductor of electrical resistance (R) for a defined period of time (t).[2,3]

Voltage serves as the driving force that pushes current forward. Higher voltages increase the depth of thermal injury, which can facilitate the desired endoscopic effect (particularly hemostasis), but can also increase the risk of unintended thermal injury to adjacent tissue zones. Inadvertent thermal complications are minimized by attention to endoscopic technique. With some ESU models, when predefined peak voltages and/or tissue impedance levels are detected by the microprocessor, an ESU response can be elicited (eg, terminating power output). This can potentially reduce the risk of inadvertent tissue injury.

In household alternating currents, the polarity switches from positive to negative at a frequency of approximately 60 times per second (60 Hz). Neuromuscular responses and myocardial sensitivity (eg, ventricular arrhythmias) are significant at these frequencies, making them inappropriate for use in electrosurgery. Therefore, ESUs typically operate with higher frequency currents between 300 KHz and 1 MHz. At these high frequencies, neuromuscular and myocardial responses are mostly eliminated.[1,3,4]

Current types: coagulation and cut. Endoscopists often refer to 2 forms of current, coagulation and cut currents, which differ primarily in the rate and magnitude with which they induce a temperature increase within the target tissue. In general, coagulation currents induce a slower increase in temperature within cells (between 70 and 100°C) and cause them to dehydrate and shrink without bursting. The result is tissue desiccation when the active electrode is in direct contact with the tissue (such as that occurring with hemostatic interventions using coaptive bipolar cautery accessories) or tissue fulguration if the electrode is not in direct contact with the tissue (as occurs with argon plasma coagulation). Cut currents, on the other hand, cause more rapid heat increases in the target tissue to temperatures greater than 100°C, causing the cellular water to boil and the cells to rupture, leading to cleavage of the tissue that lies along the electrode. Blended currents are described further in the following.

Several properties of a current's waveform influence its ultimate thermal impact on tissue. *Duty cycle* refers to the percentage of total time that electrical current is actually delivered. This is dependent on the frequency and duration of any pauses that are programmed into the cycle (Fig. 1). Currents that are delivered continuously for the entire activation period (with no pauses) are referred to as having a 100% duty cycle. A 100% duty cycle current with a peak voltage greater than 200 V is often called a pure-cut current, and the cutting effect is promoted by the lack of time for tissue cooling to occur. When interruptions (pauses) are introduced, the target tissue has more opportunity to cool, promoting greater degrees of tissue coagulation rather than cut. A current with a duty cycle of 6% (electricity delivered for only 6% of the total time, off for 94% of the total time) is often referred to as pure-coag current. The term blended current refers to a waveform with duty cycles between 12% and 80%, indicating that there is a blend of the proportion of cells that have burst (cut) and those that have been dessicated (coag).

Another way to quantitatively describe either continuous or modulated waveforms is to use the term crest factor. The crest factor is the ratio of a waveform's peak amplitude to its average amplitude (also known as the peak-to-average power ratio). Currents with low crest factors are typically associated with currents that have more cut than coag effects, whereas those with higher crest factors are associated with greater coag effects. Typical crest factors for different types of electrosurgical current
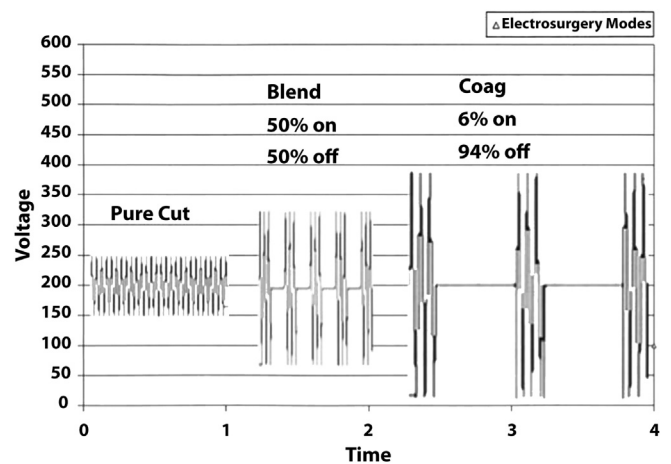

Figure 1. The electrosurgical current modes commonly used in GI endoscopy are represented graphically. Current delivered continuously at 100% duty cycle at more than 200 V is referred to as pure cut. Intermittent current pulsed at a 6% duty cycle is referred to as pure coagulation. Blended current is a mode that uses preset duty cycles ranging from 12% to 80%. To maintain a fixed power setting, lower duty cycles require progressively higher voltage.

waveforms are as follows: less than 2 for pure-cut currents, 2 to 5 for blended cutting currents, and 7 to 8 for pure coagulation currents. The crest factors and duty cycles for select ESUs are shown in Tables 1 and 2.

Current density and power density

Many variables that are not directly related to the ESU can affect the electric circuit and the desired tissue effect.[1,4,5] The most important of these is the *current density,* which essentially determines the intensity of the effect achieved during electrosurgery. Current density is defined as the amount of current flowing through a cross-sectional area of tissue or [(current/area)^2]. Current density can be increased by either increasing the intensity of the current delivered into the same cross section of tissue or by decreasing the cross-sectional area of tissue to which a current is being delivered (eg, snare a smaller portion of tissue, selecting a smaller diameter snare wire). The heat generated in the tissue is directly proportional to the power dissipated by the tissue. Applying current to a small area of a polyp stalk causes disproportionately high heat generation compared with the same current applied to a larger area of the same polyp stalk. Similarly, to generate the amount of heat required to transect a polyp with a larger diameter stalk, greater current intensity is required.

Tissue effect

The type of tissue effect (eg, cutting, coagulation) is dependent on many factors, such as voltage, power, tissue resistance, current density, and electrosurgical waveform properties. The primary user-adjustable variable of essentially all ESUs until recent years was *power output*. The

endoscopist would select a desired power setting and the ESU would deliver that power output, regardless of the surrounding tissue properties. During electrosurgery (eg, during polypectomy), tissue resistance is initially low and current flows easily into the tissue. However, progressive tissue desiccation increases the resistance (impedance) to current flow. The generator attempts to maintain constant power output, but as tissue changes occur, there can be significant fluctuations in voltage. In recent years, advances have led to ESU circuitry capable of monitoring for changes in voltage that occur during the delivery of electrosurgical energy. These ESUs are capable of keeping voltage constant while power fluctuates to the lowest effective output, based on impedance within the circuit. This facilitates reproducible and consistent target tissue effects during electrosurgery.

Electrosurgical waveform properties also influence the type of tissue effect. In general, *initiation* of an incision can be problematic for an ESU, particularly if the active electrode is firmly pressed against the target tissue, because this scenario causes low current density and low tissue impedance. ESUs therefore need to supply higher power output to initiate a cut, but this power output is often not needed to maintain the incision.[4] Specialized proprietary output modes have been developed to facilitate controlled tissue cutting during various applications. For example, ENDO CUT (ERBE USA, Marietta, Ga), is a mode which rapidly modifies the current in response to changes in the tissue impedance and fractionates the electrosurgical output to facilitate controlled cutting of tissue.[4] ENDO CUT is based on a staged process, including an initial incision phase followed by phases of cutting current interspersed with phases of coagulation current (described in Figure 2). The ConMed Beamer ESU (ConMed Corp, Utica, NY) offers an Endo-Mode, marketed as a dynamic process controlled cutting mode with pulsed or fractionated currents that provide controlled cutting with varying, adjustable degrees of coagulation. The Beamer also offers 5 preset settings for various applications (eg, PolypCut, PapillaCut). Genii's gi4000 (Genii Inc, St. Paul, Minn) offers 2 controlled (fractionated) cutting modes with 2 degrees of coagulation (pulse blend cut, pulse cut). Both modes use advanced tissue sensing to deliver the chosen power selection over a broad range of impedances. Some Covidien ESUs incorporate Valleylab Instant Response (Boulder, Colo), which attempts to facilitate controlled cutting by delivering a selected power output very quickly when tissue impedance is low (at the onset of the cut), then maintaining constant power output despite changes in impedance that occur throughout the cut.[4] The names of the modes offered by ESUs may be proprietary or nonproprietary, such as ENDO CUT and DRY CUT (ERBE), blend cut, fulgurate (Valleylab, a division of Covidien), forced coag, spray coag, and soft coag, but they are not standardized.

Monopolar and bipolar circuitry

Electrosurgical generators complete electrical circuits by using either monopolar or bipolar devices. The difference between the 2 relates to the location of the active and the neutral electrodes. In endoscopy, the active electrode is a through-the-scope endoscopic accessory, such as a polypectomy snare and thermal ablation device. In a monopolar circuit, current passes from the active electrode into the target tissue, then courses through the patient in the least resistant direct path to a neutral electrode, then back to the ESU. Neutral electrodes are sometimes referred to as return electrodes and inaccurately as grounding pads. Older ground referenced ESUs, which required the current to pass into the ground rather than back to the ESU, are now obsolete. Examples of endoscopic interventions delivered using monopolar circuitry include snare polypectomy, sphincterotomy, hot forceps biopsies, argon plasma coagulation (APC), and endoscopic submucosal dissection by using needle-knives and similar accessories.

In bipolar circuits, the device contains both the active and neutral electrodes in close proximity. Applied current passes from the active electrodes into the target tissue, then immediately returns to the neutral electrodes on the same device, and then back to the ESU. Because bipolar circuits are completed locally, no separate return electrode (grounding pad) is required. Endoscopic interventions using bipolar circuits have been used for tissue coagulation, such as contact thermal hemostasis with bipolar probes and radiofrequency ablation of Barrett's esophagus.

Tables 1 and 2 show waveform properties of representative monopolar and bipolar modes available for several ESUs commonly used in GI endoscopy. Similar information for other ESU brands and models can be obtained by contacting the specific manufacturer (Web sites and mailing addresses provided in Table 3).

Typical settings for various hemostatic interventions using contact bipolar devices are shown in Table 5.

Argon plasma coagulation

APC is a noncontact method of delivering monopolar electrosurgical energy to target tissue and requires an APC-capable electrosurgical generator to be performed. Unlike conventional delivery of electrosurgical energy, in which electrical arcs are created through direct contact between an active electrode and target tissue, APC uses the conductive properties of gas *plasma* to deliver the energy from the active electrode to the tissue. Argon plasma is created by ionizing argon gas with voltage derived from the generator. Argon gas flows down a specialized through-the-scope catheter into the GI tract lumen. The catheter contains an active electrode (eg, a tungsten wire) that is connected to the ESU and delivers a monopolar electrical current to the cloud of argon gas, converting the inert argon to ionized argon gas, which is called argon *plasma*. The argon plasma delivers the

TABLE 1. Monopolar output characteristics for select electrosurgery generator units

		Argon capable			
		ConMed	**ERBE**	**ERBE**	**Genii**
		600 Beamer Mate Beamer Plus	**ICC200/APC 300**	**VIO300D/APC 2**	**gi4000**
kHz range		357-833	330	350	350-500
Argon, kHz		833	1000	350	460-500
Duty cycle, %	Crest factor				
100	1.4		SoftCoag (<190 Vp) Autocut and ENDO CUT*	SoftCoag (<190 Vp) Autocut, ENDO CUT I, Q*	Pure cut, pulse cut,* soft coag (284 Vp)
	1.5	Pure cut (4 pulse cuts, crest factor N/A)†			
70	1.7				
	1.8	Blend cut			
	2.1				
50					Blend cut, pulse Blend cut* (crest factor 2.7)
	2.5	Super blend			
37.5	3.9				
30	2.7				
	3	Pure coag (640 Vp)		Dry cut effect 1-4	
	3.2			Dry cut effect 5-6	
	3.7	Hot Bx coag			
	3.8			Dry cut effect 7-8	
25					
12					Blend coag (crest factor 6.3)
8	5				
	5				
	5.4			Swift coag	
	5.5				
	6			Forced coag	
	6.6	Argon			
6	7				Coag
6					
4			Forced coag		
	7				
	7.4		Argon, (crest factor N/A)†	Spray coag,	Argon
	8				
	8.5				

ESUs, Electrosurgical generator units; *Vp*, peak voltage; *Coag*, coagulation; *Bx*, biopsy; *N/A*, not available.

This table compares duty cycles or crest factors to aid endoscopists in quantifying different ESU modes. Each ESU will have additional unique waveform properties that contribute to the tissue effect. Refer to the operator's manual for each ESU or contact the manufacturer for further information.

Peak voltages are maximum at rated load and are indicated in parentheses where particularly relevant.

Data published or provided by the manufacturers: ConMed Corp, Utica, NY; EndoStat distributed by Boston Scientific Inc, Natick, Mass; ERBE USA Inc, Marietta, Ga; Meditron/Nexcore, Waldwick, NJ; Valleylab, a division of Covidien, Boulder, Colo; Genii Inc, St. Paul, Minn. Several ESU models included in the table are no longer commercially available in the United States (eg, Covidien's Valleylab Force EZ-C and Force 2; Boston Scientific's Endostat I) but are included for reference purposes.

*Duty cycle/crest factor for pulse modes refers only to on phase.

†If duty cycle or crest factor is not available, output position is estimated. Crest factors are at stated loads and power.

Adapted from Morris et al.[4]

TABLE 1.	Continued				

Nonargon capable					
Boston Scientific	Boston Scientific	Olympus	Valleylab	Valleylab	Valleylab
EndoStat	EndoStat III	ESG 100	Force EZ-C	Force 2	Force FX
550-750	460	330-380	240-470	510	240-470
	Cut, control cut*	SoftCoag (<200 Vp) Cut 1, 2, 3, pulse slow, fast*			
			Pure cut (2000 Vp), dessicate low 2 (660 Vp) low 3 (1100 Vp)		Low cut (1350 Vp), pure cut (2300 Vp)
Cut	Blend				
			Blend	Cut	
Blend				Blend 1 (crest factor 3.4)	
					Blend
				Blend 2	
	Coag				
				Blend 3, low-volt coag	
Coag					
		Forced 1, 2 (crest factor N/A)†	Desiccate low 1 (3500 Vp)		Desiccate
		Fulgurate high 1 (6200 Vp)			
					Fulgurate low
		Fulgurate high 2			Fulgurate high
					Spray
				Coag	

TABLE 2. Bipolar output characteristics for select ESUs

Max Vp	Crest Factor	ConMed Beamer Mate	ERBE ICC200	ERBE VIO300D	Genii gi4000	BSC EndoStat I/II/III	Olympus ESG 100	Valleylab Force EZ-C	Valleylab Force 2	Valleylab Force FX
95	1.4				Bipolar					
140	1.6	BiCap								
170	1.5									
190	1.4		Bipolar	Soft bipolar						
200	1.4						Bipolar coag			
250	1.4					Bipolar				
300	1.5							Standard		
320	1.5									Standard
450	1.5									Precise
560	4.4			Forced bipolar						
600	2								Bipolar	
610	1.6									
650	1.4					Bipolar cut 1, 2, 3				
740	1.4			Bipolar cut						
800	1.7	Bipolar cut II								

ESUs, Electrosurgical generator units, *Max Vp*, maximum peak voltage.

Voltage outputs greater than 250 Vp with bipolar hemostasis probes may be suboptimal.

Data published or provided by the manufacturers: ConMed Corp, Utica, NY; EndoStat distributed by Boston Scientific Inc, Natick, Mass; ERBE USA Inc, Marietta, Ga; Meditron/Nexcore, Waldwick, NJ; ValleyLab, a division of Covidien, Boulder, Colo; Genii Inc., St. Paul, Minn.

Vp is listed at rated loads, which vary. Several ESU models included in the table are no longer commercially available in the United States (eg, Covidien's Valleylab Force EZ-C and Force 2; Boston Scientific, Inc. Endostat I) but are included for reference purposes.

Adapted from Morris et al.[4]

current to the target tissue. Factors influencing the tissue effect include the *duration* of APC application to a specific target area, the *power setting* or selected wattage, and the distance between the APC probe and the target tissue. Some APC-capable generators offer different effect settings, which can also influence power output. APC has many clinical applications, including hemostasis, tissue ablation, and tumor debulking.

Since the last published ASGE Technology Evaluation Report on APC,[6] newer generations of APC-capable ESUs have become commercially available (Table 1). Some models (ERBE VIO/APC2 and ConMed Beamer) possess amplified power profiles, referred to as high-power APC). These produce comparable tissue effects by using lower power settings compared with older models. The high-power APC units are also capable of greater absolute power outputs than their predecessors. Because of their amplified power profiles, manufacturer-recommended default settings tend to be lower than those of nonamplified APC generators. If the required power setting for a particular GI application is not certain, it is advisable to start at the lower manufacturer suggested levels and gradually increase power (wattage) until the desired tissue effect is achieved.

All available argon-capable ESUs have the ability to deliver a *continuous* stream of ionized argon plasma for the duration of activation (the time that the pedal is depressed). Some generators offer alternative modes of delivering argon plasma. The modes are differentiated by vendor-specific names. For example, the ERBE VIO300D/APC unit provides forced, pulsed, and precise modes. The ConMed Beamer Plus offers steady and pulsed modes. These are intended to minimize excessive thermal injury to a single point of contact with the target tissue.

Ultimately, choice of mode is often based on endoscopist preference and experience as there are no large studies of outcomes data from comparative human studies.
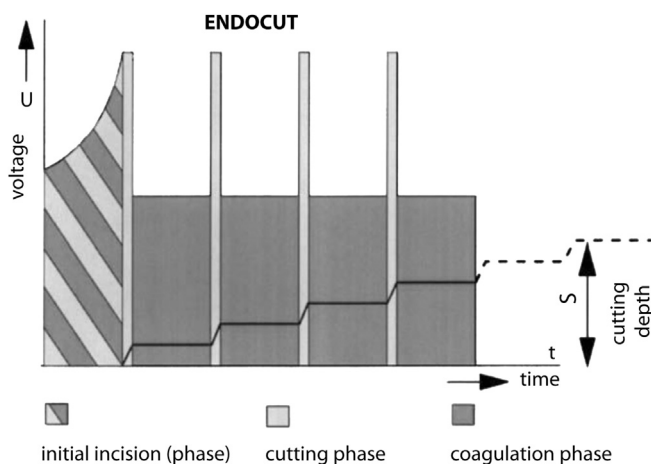
Figure 2. The ERBE Endocut current mode depicted graphically. After an initial incision phase, the generator delivers bursts of cutting current that are interspersed by coagulation current. The endoscopist can vary the cut *DURATION* (duration of cutting bursts), the cut interval (length of time between bursts of cutting current), and the effect (to vary the intensity of the coagulation bursts). Two ENDO CUT modes exist (ENDO CUT I for sphincterotomy and ENDO CUT Q for snare polypectomy). (Image courtesy of ERBE, Marietta, Ga.)

EASE OF USE

There is no industry standardization of user-interface or the method of representing the power output, and there may be significant differences in microprocessor-controlled algorithms used to deliver various forms of electrosurgical energy (eg, duty cycles, peak voltages, crest factors).

Modern ESUs have unique, brand/model specific user interfaces and displays that enable the clinician to easily toggle between different modes and make adjustments in select mode-specific variables. Some ESUs display power output using specific units of power (watts), whereas others use arbitrary numerical representations of power output (eg, 0-10).

Electrosurgical generators typically are activated by depressing a foot pedal. Some units have an integrated water pump, also activated by a foot pedal, to facilitate endoscopic visualization. ESU pedals may have toggle buttons that can be depressed by the endoscopist's foot to make changes in the electrosurgery mode or settings to enhance the endoscopist's ease of use.

INDICATIONS AND EFFICACY

Colonic polypectomy

There are little uniformity and no standardization regarding ESU settings used for polypectomy. Suggested generator settings for various ESUs and procedures are listed in Tables 5-7.

Modern ESUs have microprocessor-controlled feedback mechanisms that can vary generator output when changes in tissue resistance (eg, from desiccation of the stalk) occur,[7] potentially reducing the risk of stalling (ie, snare entrapment) during resection of a large volume of captured tissue or a thick stalk, although this theoretical advantage has not been well studied in humans. Multiple factors influence outcome after "hot" polypectomy, including operator technique, type of current waveform, and accessories used. For example, the physical diameter of the snare wire influences the current density deposited at the point of contact with tissue, which in turn influences tissue transection. Assuming comparable power settings and comparable polyp characteristics, a thin snare wire yields significantly higher current density than a thick snare wire, allowing faster electrosurgical transection. The wire thickness of commonly used snares ranges from 0.3 to 1.0 mm.[1] The physical diameter of the opened snare itself does not influence current density.

There are relatively few comparative studies assessing outcomes associated with the use of various types of electrosurgical waveforms (eg, pure cut, blended current,) during polypectomy. Animal data suggest that depth of injury in the porcine colon is greater with coagulation current (compared with blended and pure-cut current) and with hot biopsy forceps (compared with hot snare).[8] However, pure coagulation currents (15-70 W) have been used to successfully and safely remove large colon polyps.[9,10] A retrospective analysis of blended versus pure coagulation current reported no significant differences in the overall complication rates between the 2 groups, although timing of postpolypectomy bleeding was significantly influenced by the type of current used.[11] All major hemorrhages occurred immediately or within 12 hours when blended current was used, whereas delayed bleeding (2-8 days) was more commonly seen with pure coagulation current; the difference was statistically significant. Some studies have compared outcomes after procedures using pure-cut, blended, and commonly used proprietary currents such as ENDO CUT (ERBE, Fig. 2). A large, multicenter, prospective study including 9336 polypectomies identified use of pure-cut waveforms rather than blended or ENDO CUT currents (odds ratio 6.95; 95% CI, 4.42-10.94) and inadvertent cold snare polypectomy (odds ratio 7.15; 95% CI, 3.13-16.36) as 2 of 9 risk factors associated with *immediate* postpolypectomy bleeding.[12]

The type of current used for polypectomy has the potential to affect the quality of histological interpretation. GI pathologists blinded to the polypectomy technique evaluated 148 polypectomy specimens (78 blended current, 70 ENDO CUT current) and concluded that polyps resected with ENDO CUT had better overall quality, primarily because of improved ability to evaluate the margin of the specimen (75.7% vs 60.3%, $P = .046$).[13] Additional prospective studies are needed to confirm these findings.

In the absence of robust, evidence-based data, the optimal electrosurgical current or ESU settings for polypectomy cannot be provided. It may be prudent to avoid the

TABLE 3. Select ESU manufacturers

Company	Address	Web site
Boston Scientific	One Boston Scientific Place, Natick, MA 01760	www.bsci.com
Bovie Company	7100 30th Ave N., St. Petersburg, FL 33710	www.boviemedical.com
ConMed	525 French Rd., Utica, NY 13502	www.conmed.com
ERBE	2225 Northwest Parkway, Suite 105, Marietta, GA 30067	www.erbe-usa.com
Genii	2145 Woodlane Dr., Suite 101-W, St. Paul, MN 55125	www.genii-gi.com
Olympus	3500 Corporate Parkway, Center Valley, PA 18034	www.olympusamerica.com
Valleylab, a division of Covidien	5920 Longbow Dr., Boulder, CO 80301	www.valleylab.com

ESU, Electrosurgical generator unit.

TABLE 4. List prices (US$) for select electrosurgical generator units and components included in list price (as of August 2012)

Company	List price*(US$)	Items included
Argon-capable units		
ConMed Beamer Argon Module (Mate/Plus)	21,000	Includes ESU. Beamer cart ($6000), footswitch ($1700), CB200 argon module for the Beamer ESU ($21,000), and the CB200-A01 connecting cable ($800) purchased separately
ERBE ICC 200/APC300	Price varies based on configuration; contact company	
ERBE VIO 300D/APC2	Price varies based on configuration; contact company	
Genii GI 4000	22,000	All-inclusive (foot pedal, ESU, argon control unit, regulators, pump)
Nonargon-capable units		
Boston Scientific Endostat III	14,250	List price includes foot switch, power cord, water bottle, spare pump tubing, spare fuse
Olympus ESG 100	14,000	List price includes foot switch and active cord
Valleylab Force FX-C	16,598	List price includes generator only

ESU, Electrosurgical generator unit.
*Actual purchase prices may vary.

use of pure-cut currents because of the increased risk of immediate bleeding.

Endoscopic sphincterotomy

The ideal ESU setting would enable efficient incision of the papilla while minimizing the complications of pancreatitis and bleeding. Blended current or other proprietary modes offering combined cutting and coagulation characteristics are most commonly used. Four randomized trials compared the use of pure-cut and blended current during endoscopic sphincterotomy (ES); 2 of the studies included an arm in which pure-cut current was used to initiate the cut, and blended current was used to finish.[14-17] With regard to bleeding, two of these studies[15,16] showed increased rates of minor immediate bleeding with pure-cut current and one showed no difference in bleeding.[17] For pancreatitis complications, two studies[14,17] showed less pancreatitis with pure-cut compared to blended current, and two showed no change in pancreatitis rates.[15,16]

Several studies compared ENDO CUT with other current waveforms for ES, including pure-cut and blended current modes.[18-24] Overall, these studies, which included 2 randomized trials, suggested that there was a lower rate of uncontrolled "zipper" cuts with ENDO CUT mode but no difference in the rates of perforation, pancreatitis, or clinically significant hemorrhage. A meta-analysis of 4

TABLE 5. Typical settings for contact bipolar hemostasis of nonvariceal GI bleeding lesions

Parameters	Upper GI lesions					Lower GI lesions		
	Peptic ulcer	Dielafoy	Mallory-Weiss tear	Watermelon stomach (GAVE)	Diverticular bleeding	Postpolypectomy bleeding	Vascular ectasia	Focal ulcer
Power, W	15-20	15-20	15	15	15	15	15	15
Contact duration, s	10	10	3-5	3-4	3-4	3-4	3-4	3-4

GAVE, Gastric antral vascular ectasia.
Adapted from Morris et al.[4]

TABLE 6. Typical ESU power settings for various endoscopic devices during routine endoscopic interventions

Device/intervention	Power setting, W*
Hot biopsy forceps	15-25
Snare polypectomy	15-40
Sphincterotomy	30-60

ESU, Electrosurgical generator unit.
*Power requirements may vary based on the ESU output mode being used.

randomized trials comparing pure-cut with mixed currents (eg, ENDO CUT or blended currents) for biliary sphincterotomy showed a higher rate of mild postsphincterotomy bleeding in the pure-current versus the mixed-current group (37.3% vs 12.2%; 95% CI, 12.3%-37.9%), but no differences in pancreatitis or major bleeding. Collectively, these studies suggest that there are no differences in major complications with the use of pure-cut versus mixed currents for ES, but there is a higher rate of minor bleeding with pure-cut currents.

Outcomes studies for ES using proprietary current waveforms offered by other companies are not available.

Miscellaneous procedures

ESUs are used in a broad range of procedures with a variety of accessories. Details regarding particular applications and devices have been published elsewhere, including use of hot biopsy forceps,[25] bipolar and multipolar accessories,[26] polypectomy devices,[27] endoscopic hemostatic devices,[28] mucosal ablation devices,[29] APC,[6] endoscopic management of variceal and nonvariceal upper and lower GI bleeding,[30-32] EMR, and endoscopic submucosal dissection.[33,34] Typical power settings for commonly performed procedures (hemostasis, polypectomy, sphincterotomy, APC) are given in Tables 5 and 6. There are limited data comparing technical success or clinical outcomes achieved by using different ESU models during these procedures.

Dedicated electrical generators that are manufactured for specific applications, such as Heat Probe (Olympus America Corp, Melville, NY) and radiofrequency ablation (Covidien–GI Solutions, Mansfield, MA, formerly BÂRRX Medical, Inc.) have been described previously and are not addressed in the text or tables of this article in detail.[35-38]

SAFETY

ESU malfunction may result in failure to generate any current, current in the specified mode, and/or current at the desired power output. Complications directly related to ESUs are rare and are more often related to faulty connections and operator error than to malfunction of the generator itself. A search of the MAUDE database (August 11, 2012) for adverse events or warnings pertaining to ESUs indicated that the majority of events were operator or accessory related.

Potential complications include burns at the neutral electrode pad site, fetal stimulation, capacitive coupling discharges (burn), interaction with implantable cardiac devices, interactions with other noncardiac implantable electrosurgical stimulators (deep brain stimulators, gastric stimulators, medication delivery pumps), and bowel explosion.

Capacitive coupling refers to transfer of a portion of the electrical current from the active electrode to a second electrically conductive structure through insulation. It can result in a discharge that inadvertently delivers current to an undesired location (to the endoscopist or the patient, for example). These are uncommon with current endoscopic technologies and techniques.[39] Direct electrical connections (shorts) between the active electrode and a second conductor (such as can occur between a sphincterotome cutting wire and a guidewire with damaged coating insulation) can lead to severe complications (bile duct perforation). These are fortunately quite rare and can be prevented by avoiding the use of guidewires that are damaged or not approved for the applied use and by avoiding inadvertent placement of guidewires in direct contact with the active electrode.

TABLE 7.   Manufacturer's recommended initial/default power settings for select ESU models, based on location within the GI tract

ESU model	Location in GI tract					
	Right side of the colon	Colon	Rectum	Esophagus	Stomach	Duodenum/ small intestine
ERBE ICC200/APC300	Forced mode, 40 W	Forced mode, 40 W	Forced mode, 60 W	Force mode, 60 W	Forced mode, 60 W	Forced mode, 40 W
ERBE VIO 300D/APC2*	Pulsed mode, effect 2, 20 W	Forced mode, 30 W	Pulsed mode, effect 2, 20 W	Pulsed mode, effect 1, 20 W	Pulsed mode, effect 1, 20 W	Pulsed mode, effect 2, 20 W
ConMed Beamer Plus*	30 W	20 W	35 W	30 W	30 W	30-40 W
Genii GI4000	40-45 W (hemostasis) 45-60 W (tumor ablation)	45-60 W	45 W	60 W	60 W	45 W

ESG, Electrosurgical generator unit.
The selected power setting is influenced by the clinical indication and desired therapeutic effect and may differ from the initial default settings shown in this table. In general, for traditional ESUs without amplified power profiles, settings of 40-60 W are commonly used for hemostasis of superficial vascular lesions and higher power settings (eg, 70-90 W) may be required for tissue/tumor debulking. Lower initial power settings are generally recommended when using ESUs with amplified power profiles (denoted by an asterisk).

When monopolar current is used, the large surface area of the return electrode disperses the current density to prevent skin burns. Many current ESUs incorporate a contact quality monitoring system feature that monitors the patient-to-return electrode interface. If the contact quality monitoring system detects a change (reduced contact with the surface, increased resistance to current flow), the ESU may emit an alert and can trigger the unit to shut off to reduce the risk of return electrode pad site burns. Since the introduction of effective contact quality monitoring systems and contemporary dual-foil (split)-plate return electrodes, burns associated with well-positioned and appropriately affixed return electrodes have virtually been eliminated.[39] There are no peer-reviewed studies regarding the optimal placement location of the return electrode. It is reasonable to avoid placing structures that can potentially be harmed (ie, the uterus in a pregnant woman, implantable cardiac devices) between the active and return electrodes whenever monopolar electrosurgical energy is being used. Placement of return electrodes over metal-tipped objects that can conduct electricity (eg, electrocardiography lead electrodes or monitor cables) poses the risk of cutaneous burns. Care should be taken to avoid placement over areas prone to pad failure, such as areas with moisture (sweat, creams, ointments) or other factors that may reduce conduction of current into the return electrode (eg, scars, hair, foreign bodies, artificial joints). Although patient preparation policies in many endoscopy units continue to advocate burn-avoidance practices such as removing all patient jewelry, avoiding placement of return electrodes over sites of skin creases, and ensuring that none of the patient's body parts are in contact with the bedside rails, they are probably unnecessary when using modern, isolated (as opposed to older ground-referenced) ESUs.

The high-frequency currents produced by ESUs do not cause neuromuscular stimulation when used in GI endoscopy. Thus, stimulation of skeletal, smooth, or cardiac muscle should not occur. During endoscopic electrosurgery, such as application of APC, endoscopists occasionally notice striated muscular fasciculation caused by neuromuscular stimulation. These are not known to be associated with long-term effects.[1,40] However, when observed during endoscopy, it is advisable to check the instruments and wire connections being used. Users are also advised by manufacturers to switch from pulsed to forced mode when neuromuscular stimulation occurs.

Most modern cardiac pacemakers are unaffected by ESU current, provided the return electrode pad and the active electrode tip are remote from the pacemaker site.[41] However, pacemaker defibrillators can be inhibited by electromagnetic fields of greater than 0.1 V/m, significantly less than an ESU is capable of generating (up to 60 V/m). This can damage the protective circuitry within the implanted device or require it to be reprogrammed. Whenever possible, bipolar electrosurgical circuits are preferred because they complete the electrical circuit locally, thereby reducing dispersion of current into the patient's body. ASGE guidelines for endoscopy in patients with implanted electronic devices are available.[42] Use of deep brain electrode stimulation in patients with neurologic movement disorders (eg, Parkinson's disease) is uncommonly encountered, but poses a clinical conundrum when such patients require electrosurgical interventions. Coordination of endoscopic interventions with neurologic specialists is advisable in these unique clinical settings.

Regarding the safety of APC, a common misconception is it that depth of injury is somehow inherently limited to a few millimeters, as if the generator unit knows when to

stop. In reality, as with any form of electrosurgery, power output and time of application affect the thermal effects on tissue. As such, APC (at any power setting) applied to the same area for a prolonged period of time can cause transmural injury and perforation. Higher power settings amplify the potential tissue effect, regardless of whichever APC mode is selected (ie, forced/steady or pulsed).

FINANCIAL CONSIDERATIONS

Electrosurgical generators vary in cost, dependent on manufacturer and features. List prices for several commercially available ESUs are provided in Table 4. Most argon-capable ESUs are modular systems, requiring separate purchase of the electrosurgical generator unit and the argon module (Table 4). The new Genii GI 4000 (Genii Inc) is the only currently marketed argon-capable ESU that does not require purchase of a separate argon module. Return electrodes are available from ESU manufacturers and other distributors. Multipurpose ESUs are commonly used in operating rooms, and opportunities for sharing equipment with endoscopy units exist.

CONCLUSIONS

The application of electrosurgical energy facilitates therapeutic endoscopy. A variety of ESUs are available. Familiarity with the basic principles of electrosurgical energy and the functions and settings of ESUs is required for safe and effective performance of electrosurgery.

DISCLOSURE

The authors disclosed no financial relationships relevant to this publication.

Abbreviations: APC, argon plasma coagulation; ES, endoscopic sphincterotomy; ESU, electrosurgical generator unit.

REFERENCES

1. Tucker R. Principles of electrosurgery. In: Sivak MV, editor. Gastroenterologic endoscopy. 2nd ed. Philadelphia (Pa): WB Saunders; 2000. p. 125-35.
2. Curtiss LE. High frequency currents in endoscopy: a review of principles and precautions. Gastrointest Endosc 1973;20:9-12.
3. Rey JF, Beilenhoff U, Neumann CS, et al. European Society of Gastrointestinal Endoscopy (ESGE) guideline: the use of electrosurgical units. Endoscopy 2010;42:764-72.
4. Morris ML, Tucker RD, Baron TH, et al. Electrosurgery in gastrointestinal endoscopy: principles to practice. Am J Gastroenterol 2009;104: 1563-74.
5. Barlow DE. Endoscopic applications of electrosurgery: a review of basic principles. Gastrointest Endosc 1982;28:73-6.
6. Ginsberg GG, Barkun AN, Bosco JJ, et al. The argon plasma coagulator: February 2002. Gastrointest Endosc 2002;55:807-10.
7. Morris M, Norton ID. Electrosurgery in Therapeutic Endoscopy. In: Ginsberg GG, Kochman ML, Norton ID, et al, editors. Clinical gastrointestinal endoscopy. 2nd ed. St. Louis (Mo): Saunders/Elsevier; 2011. p. 69-77.
8. Chino A, Karasawa T, Uragami N, et al. A comparison of depth of tissue injury caused by different modes of electrosurgical current in a pig colon model. Gastrointest Endosc 2004;59:374-9.
9. Binmoeller KF, Bohnacker S, Seifert H, et al. Endoscopic snare excision of "giant" colorectal polyps. Gastrointest Endosc 1996;43: 183-8.
10. Brooker JC, Saunders BP, Shah SG, et al. Endoscopic resection of large sessile colonic polyps by specialist and non-specialist endoscopists. Br J Surg 2002;89:1020-4.
11. Van Gossum A, Cozzoli A, Adler M, et al. Colonoscopic snare polypectomy: analysis of 1485 resections comparing two types of current. Gastrointest Endosc 1992;38:472-5.
12. Kim HS, Kim TI, Kim WH, et al. Risk factors for immediate postpolypectomy bleeding of the colon: a multicenter study. Am J Gastroenterol 2006;101:1333-41.
13. Fry LC, Lazenby AJ, Mikolaenko I, et al. Diagnostic quality of: polyps resected by snare polypectomy: does the type of electrosurgical current used matter? Am J Gastroenterol 2006;101:2123-7.
14. Elta GH, Barnett JL, Wille RT, et al. Pure cut electrocautery current for sphincterotomy causes less post-procedure pancreatitis than blended current. Gastrointest Endosc 1998;47:149-53.
15. Macintosh DG, Love J, Abraham NS. Endoscopic sphincterotomy by using pure-cut electrosurgical current and the risk of post-ERCP pancreatitis: a prospective randomized trial. Gastrointest Endosc 2004;60:551-6.
16. Gorelick A, Cannon M, Barnett J, et al. First cut, then blend: an electrocautery technique affecting bleeding at sphincterotomy. Endoscopy 2001;33:976-80.
17. Stefanidis G, Karamanolis G, Viazis N, et al. A comparative study of postendoscopic sphincterotomy complications with various types of electrosurgical current in patients with choledocholithiasis. Gastrointest Endosc 2003;57:192-7.
18. Totta FJ, David J, Ramirez F. Complications of endoscopic sphincterotomy (ES): the role of the electrocautery unit [abstract]. Gastrointest Endosc 2002;55:AB155.
19. Akiho H, Sumida Y, Akahoshi K, et al. Safety advantage of endocut mode over endoscopic sphincterotomy for choledocholithiasis. World J Gastroenterol 2006;12:2086-8.
20. Norton ID, Petersen BT, Bosco J, et al. A randomized trial of endoscopic biliary sphincterotomy using pure-cut versus combined cut and coagulation waveforms. Clin Gastroenterol Hepatol 2005;3: 1029-33.
21. Perini RF, Sadurski R, Cotton PB, et al. Post-sphincterotomy bleeding after the introduction of microprocessor-controlled electrosurgery: does the new technology make the difference? Gastrointest Endosc 2005;61:53-7.
22. Kida M, Kikuchi H, Araki M, et al. Randomized control trial of EST with either endocut mode or conventional pure cut mode [abstract]. Gastrointest Endosc 2004;59:P201.
23. Ellahi W, Kasmin FE, Cohen SA, et al. "Endocut" technique versus pure cutting current for endoscopic sphincterotomy: a comparison of complication rates [abstract]. Gastrointest Endosc 2001;53:AB95.
24. Kohler A, Maier M, Benz C, et al. A new HF current generator with automatically controlled system (Endocut mode) for endoscopic sphincterotomy–preliminary experience. Endoscopy 1998;30:351-5.
25. Gilbert DA, DiMarino AJ, Jensen DM, et al. Status evaluation: hot biopsy forceps. American Society for Gastrointestinal Endoscopy. Technology Assessment Committee. Gastrointest Endosc 1992;38:753-6.
26. Carr-Locke DL, al-Kawas FH, Branch MS, et al. Technology assessment status evaluation: bipolar and multipolar accessories, February 1996. Gastroenterol Nurs 1998;21:187-9.
27. Carpenter S, Petersen BT, Chuttani R, et al. Polypectomy devices. Gastrointest Endosc 2007;65:741-9.

28. Conway JD, Adler DG, Diehl D, et al. Endoscopic hemostatic devices. Gastrointest Endosc 2009;69:987-96.
29. American Society for Gastrointestinal Endoscopy Technology C. Mucosal ablation devices. Gastrointest Endosc 2008;68:1031-42.
30. Hwang JH, Fisher DA, Ben-Menachem T, et al. The role of endoscopy in the management of acute non-variceal upper GI bleeding. Gastrointest Endosc 2012;75:1132-8.
31. Qureshi W, Adler DG, Davila R, et al. ASGE Guideline: the role of endoscopy in the management of variceal hemorrhage, updated July 2005. Gastrointest Endosc 2005;62:651-5.
32. Davila RE, Rajan E, Adler DG, et al. ASGE Guideline: the role of endoscopy in the patient with lower-GI bleeding. Gastrointest Endosc 2005;62:656-60.
33. Kantsevoy SV, Adler DG, Conway J, et al. Endoscopic mucosal resection and endoscopic submucosal dissection. Gastrointest Endosc 2008;68: 11-8.
34. Deprez PH, Bergman JJ, Meisner S, et al. Current practice with endoscopic submucosal dissection in Europe: position statement from a panel of experts. Endoscopy 2010;42:853-8.
35. Nelson DB, Barkun AN, Block KP, et al. Technology status evaluation report. Endoscopic hemostatic devices. May 2001. Gastrointest Endosc 2001;54:833-40.
36. Fernandez-Esparrach G, Panes J. Radiofrequency ablation for nondysplastic Barrett's esophagus: to treat or not to treat? Gastroenterology 2011;140:2130-2; discussion 2132.
37. Shaheen NJ, Overholt BF, Sampliner RE, et al. Durability of radiofrequency ablation in Barrett's esophagus with dysplasia. Gastroenterology 2011;141:460-8.
38. Fleischer DE, Overholt BF, Sharma VK, et al. Endoscopic radiofrequency ablation for Barrett's esophagus: 5-year outcomes from a prospective multicenter trial. Endoscopy 2010;42:781-9.
39. Tucker R. Commentary on clinical applications of argon plasma coagulation in endoscopy. Gastroenterol Nurs 2007;30:129-30; author reply 130.
40. Tucker RD, Schmitt OH, Sievert CE, et al. Demodulated low frequency currents from electrosurgical procedures. Surg Gynecol Obstet 1984;159:39-43.
41. Kimmey MB, Al-Kawas FH, Burnett DA, et al. Technology Assessment: Electrocautery use in patients with implanted cardiac devices. Gastrointest Endosc 1994;40:794.
42. Petersen BT, Hussain N, Marine JE, et al. Endoscopy in patients with implanted electronic devices. Gastrointest Endosc 2007;65:561-8.

Prepared by:
ASGE TECHNOLOGY COMMITTEE
Jeffrey L. Tokar, MD
Bradley A. Barth, MD, NASPGHAN Representative
Subhas Banerjee, MD
Shailendra S. Chauhan, MD
Klaus T. Gottlieb, MD, MBA
Vani Konda, MD
John T. Maple, DO
Faris M. Murad, MD
Patrick R. Pfau, MD
Douglas K. Pleskow, MD
Uzma D. Siddiqui, MD
Amy Wang, MD
Sarah A. Rodriguez, Committee Chair