Journal of Hepatology and Gastroenterology

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Morris ML et al., J Hepatol Gastroenterol. 2016, 1(1):1-5
http://dx.doi.org/10.14312/2399-8199.2016-1

Methodology

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Math, myth and the fundamentals of electrosurgery

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Abstract

An electrosurgery generator (ESU) is a critical piece of equipment found in every therapeutic endoscopic setting. The high frequency (RF or Radio Frequency) alternating currents produced by these ubiquitous generators provide the thermal energy used for the treatment of gut diseases from polyps to bile duct stones, strictures, tumors and more. A frequent physician complaint is that even though this technology is widely used, it is not widely understood. Standing in the way of understanding is a lack of education, inconsistency in terminology, persistent myths and incorrect explanations, and unnecessarily confusing and/or outdated teachings. This article attempts to explain in a straightforward manner, using clearly defined terms, some of the basic principles of electrosurgery as applied to gastroenterology. Common myths are highlighted and important mathematical principles critical to the technology are presented.

Keywords: electrosurgery; RF energy; electrocautery; ESU; RF generator; thermal therapy; radio frequency; argon coagulation; argon beam; current density

The therapeutic basis of electrosurgery

The therapeutic basis of electrosurgery is the production of heat at the cellular level. High frequency (RF or Radio Frequency) alternating current is generated by an electrosurgery generator unit (ESU) and flows to tissue via an assortment of suitable accessories. Water within cells heated very quickly vaporizes and causes the cell membranes to rupture. These vaporized cells separate tissue along a cleavage plane directed by the accessory. We say the separated tissue has been electrosurgically 'cut' [1]. Cells that are heated more slowly desiccate or coagulate without vaporizing. The proportions of how many cells coagulate and how many vaporize, as well as how much tissue is involved is referred to as the 'tissue effect' [2].

Current density and tissue effect variables

Current density is the arbiter of the final tissue effect. It is a measure of current concentration or intensity. Many variables contribute to the ultimate current density. Some of these contributors are independent of the ESU as they are patient, tissue and/or technique dependent (Figure 1).

Non- ESU variables can play a definitive role in the final outcome. The time that current is delivered to a target site (how long the foot pedal is depressed) is a strongly influential variable over which the physician has total control. Time multiplied by watts equal total joules of heat delivered (Energy in Joules = Power in watts X Time in seconds). A very rapid closing of a snare or a slow controlled close is an example of how time can influence the amount of energy that flows through any one area [3].

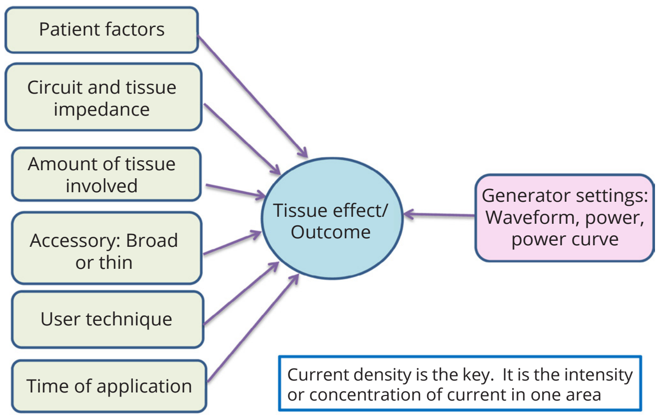

Figure 1 Variables that affect the current density and thus the final tissue result.

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Received 4 April 2016 *Revised* 8 June 2016 *Accepted* 16 June 2016 *Published* 23 June 2016

Citation: Morris ML, Bowers WJ. Math, Myth and the Fundamentals of Electrosurgery. J Hepatol Gastroenterol. 2016; 1(1):1-5. DOI: 10.14312/2399-8199.2016-1

Other variables include the amount of target tissue, such as a large polyp versus a small one. Resection attempts of very large amounts of tissue decrease the current density and slow the cutting initiation. A technique of tightly strangling a large amount of tissue may exacerbate this effect as the snare wire is totally embedded and surrounded by large amounts of low impedance tissue. More coagulation will be produced until tissue temperatures rise to the point of rapid cell vaporization and cutting. A snug and smooth resection technique may help initiate the cutting action more effectively. The thickness of cutting wires and the composition of different tissues are also factors. Bleeding risk is greatly influenced by patient factors such as anticoagulant use [4, 5].

Generator manufacturers give guidance as to suggested settings and output choices for various procedures but because of these many variables that are outside of the manufacturer's knowing and the generator's impact, there can be no one 'magic' setting that is guaranteed to always produce a known result. This is why physician discretion and knowledge remains important.

The ESU variables

Important variables that change the tissue effect are selections the user makes on the ESU. One of these is the type of current waveform, often called "cut" or "coag" or "blend". These names are not standardized but can be compared by using quantitative measures. This information is contained in the user manual making it possible to determine which output name most closely resembles another (Table 1). The selection name on the ESU interface is the means by which users can choose different waveform outputs. Current waveforms that deliver energy constantly at high enough voltages create a lot of cell vaporization or cutting [1]. Interrupting the waveform (modulating the current) heats cells more slowly thus reducing the cutting and increasing the amount of coagulation. How high the voltage spikes within the waveform helps determine how deeply coagulation penetrates. Higher voltages are more powerful in driving a deeper and wider thermal effect. Waveforms held below 200Vp (volt peak) can never heat living tissue fast enough to produce any cutting. These very low voltage continuous waveforms produce soft coagulation outputs which are ideal for contact coagulation in both monopolar and bipolar applications (Figure 2). Monopolar accessories complete the electrical circuit with the aid of a return 'dispersive' or 'grounding'

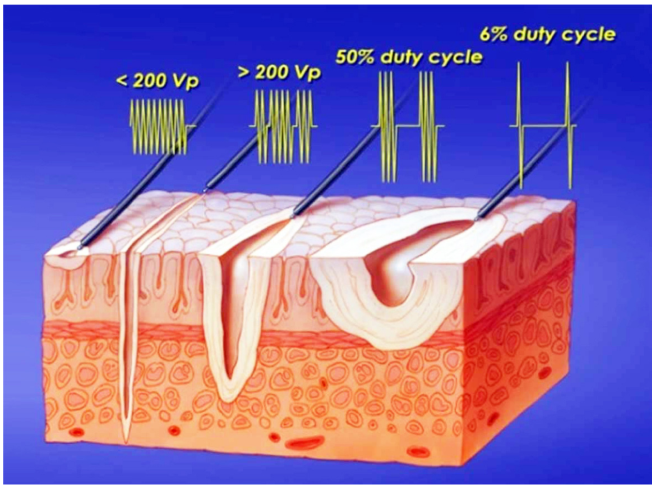

Figure 2 Different waveforms change the tissue effect.

Table 1 available output names for generator units most commonly marketed to US flexible endoscopy.

							
ConMed BiCap® III	*ConMed Beamer™ Mate*	*ERBE VIO300D*	*ERBE VIO200S*	*ERBE ICC200*	*ERBE VIO100C*	*Genii gi4000*	*Olympus ESG100*
		Soft Coag®	Soft Coag®	Soft Coag®	Soft Coag®	TouchSoft®	Soft Coag®
Coag	Coag (Hot biopsy & pure coag)	Forced Coag	Forced Coag	Forced Coag	Forced Coag	Coag	Forced Coag 1 & 2
		Swift Coag®				Blend Coag	
Pulse blend						Pulse Blend Cut	
Blend	Blend cuts 1&2	Dry Cut			Dry Cut	Blend Cut	
Pulse cut	Pulse cut (polyp and papilla)	EndoCut I or Q®	EndoCut I or Q®	EndoCut®		Pulse Cut	Pulse Cut Slow/ Fast
Pure cut	Pure cut	Auto Cut®	Auto Cut®	Auto Cut®	Auto Cut®	Cut	Cut 1,2,3
Bipolar	BiCap® & cut	Bipolar	Bipolar	Bipolar	Bipolar	Bipolar	Bipolar
		Spray Coag					
	Beamer plus: Argon steady, slow, fast, super (amplified beam) (Requires an additional unit at additional cost)	APC 2 forced, pulse 1 &2, precise (amplified beam) (Requires an additional unit at additional cost)	APC 2 Forced (amplified beam) (Requires an additional unit at additional cost)	APC300 Forced (standard beam) (Requires an additional unit at additional cost)		ArC Smart Beam™'(linear beam)(included in unit)	

Color code: White: Monopolar Contact Outputs; Blue: Bipolar Coagulation Outputs; Pink: Non-Contact Coagulation Modes

Genii and TouchSoft are US Registered Trademarks of Genii, Inc. VIO, EndoCut, Swift Coag and SoftCoag are Trademarks of Erbe Electromedizine. BIcap and Beamer are Trademarks of ConMed Corporation. All information taken from Operator's Manuals.

Myth: *It is NOT true that if a waveform is named "Coag" it will not have any cutting effect, or if named "Pure Cut" it has no coag effect. The only coagulation waveforms that cannot cut (a truly 'pure' coag) are those with Vp less than 200. Even 'Pure Cut ' waveforms leave some margin of coagulation. The only Pure cut is a cold cut!*

pad. Bipolar accessories have both the positive and the return electrodes built into the accessory and therefore are able to complete the circuit to the generator without the use of a return dispersive pad. Waveform choices that produce a little cutting and reliable coagulation are popular choices for polypectomy (Figure 3). Waveforms with mostly cutting and only a little coagulation are usually chosen for sphincterotomy (Figure 4) [6, 7].

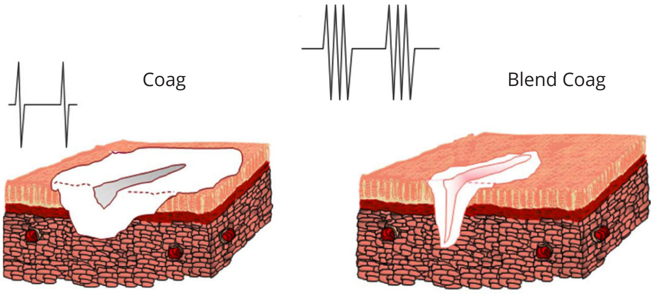

Figure 3 Commonly chosen waveforms for polypectomy [17].

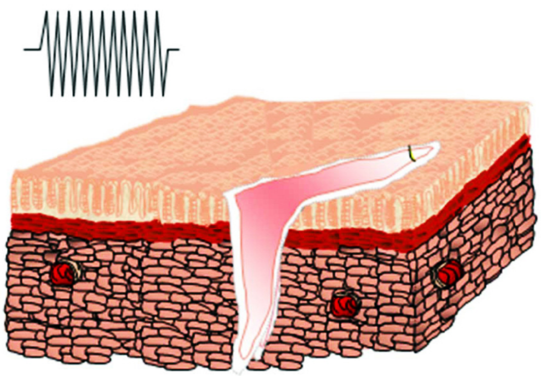

Figure 4 Physicians usually choose outputs that promote more cutting than coagulation for sphincterotomy.

Microprocessor control and power curves

Since the 1980s, ESUs have been produced with microprocessor technology [4]. This continually advancing technology has made possible dispersive (grounding pad) sensing and other safety alarms as well as computerized feedback monitoring of tissue impedance (resistance) and the microprocessor control of output power as tissue impedance changes when it is electrosurgically cut and coagulated.

Myth: *It is NOT true that only one brand of electrosurgical generator has microprocessor control. All modern generators use these ubiquitous electronic components and most have feedback tissue sensing and impedance monitoring.*

Ohm's law is the primary physical and mathematical law that governs electrosurgical technology. The most useful observation of this law for the clinician is Ohm's proof that as tissue becomes coagulated it becomes more resistant to current flow. With microprocessor monitoring, an ESU can track an impedance baseline and subsequent changes in the impedance during the electrosurgical activation. Some new ESUs take an impedance measure every 250 micro seconds [8]. Using these millions of data points, the generator's software programing (algorithm) tells the generator how to regulate the current and/or voltage (power) being delivered during the activation. A graphic representation of how a particular output is designed to react to changes in impedance is called a "Power to Impedance Curve" or "Power Curve". Some people use marketing terms such as "power dosing" as less correct technical terms to describe this action [5].

The first patent for dual (split) grounding pad safety using microprocessor control was US Pat. No. 4,416,276 by David Newton for ValleyLab, 1983.
The first patent describing the use of a microprocessor to control output characteristics was filed in 1986 by Michael Manes of Aspen Labs. US Pat No. 4,574,801.

The power curves associated with each output selection are so important to understanding the operation of any generator that in the USA, FDA requires that these graphs be included in every generator's user manual. International standards also require them. Clinicians would be well served to read and understand this section of the user manual before putting a new generator into service.

Most GI physicians are familiar with this automatic control in bipolar methods. A "narrow" curve is the most commonly suggested for use with GI bipolar endostasis accessories, such as the Boston Scientific "GoldProbe™. When coupled with a very low voltage, continuous wave form, this power curve is often referred to as a "GI Ideal Bipolar Output".

This narrow curve depicts the generator 'ramping up' toward the selected power setting very quickly at the start of the application. It is clinically important to deliver power quickly into the low impedance, bleeding tissue. Once the tissue is adequately coagulated (usually at about 700 to 1200 Ohms of resistance) the starting power has automatically dropped off to only a few watts. (Ohm's math: Current= Voltage/Resistance and Power= Voltage × Current. Therefore with voltage capped at a low 200Vp, power drops quickly as resistance rises). This curve gives this output its characteristic self-limiting nature. Coupled with bipolar hemostasis probes, this method is a well-studied, first line therapy for large upper GI bleeds and other indications for bleeding control [9].

A common bipolar 'starting' power setting is 15-20 watts [10, 11] (Figure 5). Even though the user does not see the display on the generator change during the activation, the actual power being delivered is not the full 20 watts over the entire time. These bipolar narrow curves with low voltage outputs are found on currently marketed Boston Scientific EndoStat™ generators; Conmed/KLS Martin Beamer®Mate and BiCap® III units; Erbe ICC™200, VIO® 300D and VIO®200S; and the Genii ®gi4000. There may be others.

Low voltage narrow power curves are also excellent choices for monopolar contact coagulation methods. (Recall

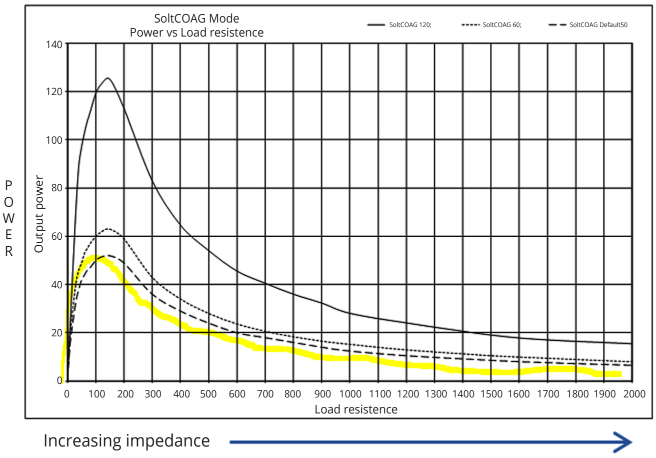

Figure 5 A representative narrow power curve showing three separate power settings.

that monopolar circuits require the use of a dispersive (grounding) pad to return the energy to the ESU to complete the circuit.) When used with a monopolar circuit these outputs are named "Soft Coag®" or "TouchSoft®". These are excellent outputs to pair with the Olympus Coagrasper™ or the Genii TouchSoft Coagulator®. At least one study [12] has described successful use of a snare tip with a soft coagulation output for touch ups during the resection of large colonic lesions.

The narrow power curves just described would NOT be effective for snare polypectomy or sphincterotomy. The low voltages don't produce any cut and the power drop during the resection would lead to stalling or snare entrapment. For these indications, higher voltage outputs which have at least some cutting ability are matched with "broad" power curves [4, 5, 13] (Figure 6). In these broad curves, as resistance rises during the resection, the ESU keeps the power being delivered to a tightly controlled and fairly constant range around a selected power setting. Some have likened this feature to 'cruise control'. Broad curves are a bit like an automobile cruise control which automatically adjusts fuel (current and voltage which together equal power) to keep the car going at a smooth speed either up or down hill.

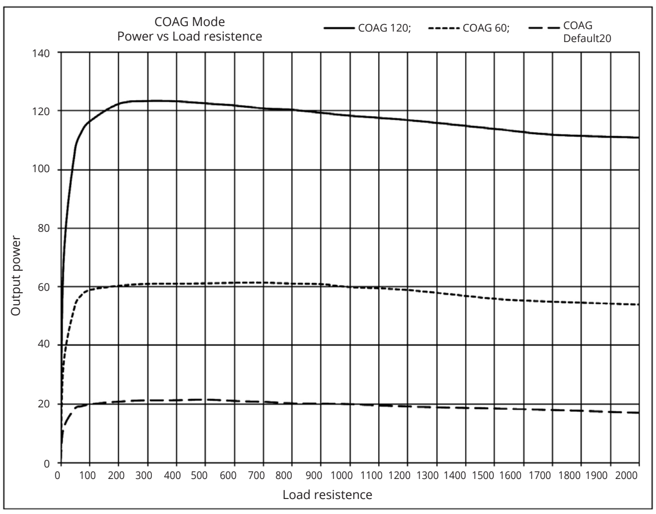

Figure 6 A "Broad" power to impedance curve at three target power settings.

Broad power curves paired with waveforms using a variety of output types are ideal for many clinical applications. Often paired with snares, sphinctertomes or needle knives, they are widely used for polypectomy, endoscopic mucosal resection (EMR), sphincterotomy (especially when the energy delivery is 'pulsed' or fractionated as in EndoCut® or Pulse Cut modes), endoscopic submucosal dissection (ESD) and other applications [2, 4, 5]. Broad type curves are found on many popular generator outputs including: (a) BSC EndoStat™ units: Cut, Control Cut, Blend and Coag outputs. (b) Conmed Beamer® and BiCap® III: Pure Cut, Pulse Cut (On Phase), Blend 2 and 3, Pulse Blend (On Phase), Standard Coag, Coag and Spray Coag. (c) Erbe ICC™ and VIO®300D and VIO®200S: AutoCut, EndoCut® I & Q (On Phase), Dry Cut effects 1-8, Swift Coag, Forced and Spray Coag. (d) Genii® gi4000: Cut, Pulse Cut (On Phase), Blend Cut, Pulse Blend Cut (On Phase), Blend Coag and Coag. (e) Olympus ESG 100: Cut, Pulse Cut Slow and Fast (On Phase), Forced 1 and 2. (f) Valley Lab Force 2 and Force FX: Cut, Low Cut, Pure Cut, Blend, Blend 1, 2 and 3, Desiccate Low 1, Fulgurate High, Low and Spray.

Refer to the particular generator's user manual for complete information. Microprocessor control elements are continually evolving in generator designs. In the 1990's Erbe introduced EndoCut® which alternated between cut and soft coagulation outputs. Several subsequent studies confirmed that this fractionation or 'pulsing' of the cut advance significantly reduced the likelihood of poorly controlled (zipper) incisions in sphincterotomy. Pulse Cut modes, with or without intervening soft coagulation are now commonly offered. Pulse Blend modes with varying levels of reliable hemostasis are also available. Table 1 generators with Pulse Cut and/or Pulse Blend Cuts are available from Boston Scientific, Conmed, Erbe, Genii and Olympus. Multiple studies to date have shown that no one algorithm is superior to the others for significantly reducing complications during sphincterotomy and no large comparative studies are available for polypectomy [4, 6, 13].

It is incorrect or a Myth to describe an entire generator as falling into either a 'voltage controlled' or a 'constant' or broad power output type. These terms refer to each of the many individual output selections on each generator. Output choices of both are found in most modern generators. All modern generators use microprocessors to adjust power by adjusting both voltage and current to achieve the power curve dictated by the algorithm design.

Argon assisted coagulation (APC, ABC, or ArC)

Electric current is a flow of electron charges. Most substances are not good conductors: their electrons are so tightly bound that they are not easily torn loose to flow from atom to atom in a current. The process of forcing electrons from their home atom is called ionization. Unlike most substances, cheap, safe, argon gas is quite easily ionized. In its ionized state, argon, like all ionized gases, is called a gas plasma. In the plasma state, argon provides a bridge that allows high frequency electric current to flow across a gap between the endoscopic accessory and the patient tissue. Once across, the current does its job of therapeutic heating. The eschar that results is fairly consistent in depth and quite soft and pliable so that it tends to heal quickly. Argon medical use was first patented by McGreevy in 1988 (US Pat. No. 4,781,175 for C.R. Bard) and it was used extensively in open surgery cases. In 1997 Erbe introduced its use to flexible endoscopy in the United States. Argon plasma coagulation is now routinely used throughout the gut for non-contact hemostasis and tissue ablation. ArC is also increasingly being used in the lung for the same indications. It is a monopolar application and requires the use of a dispersive (grounding) pad [14, 15].

Myth: It is true that argon coagulation produced eschars do grow wider with increased application time, but it is NOT true that they can never go 'too deep' because they 'continually seek areas of lower impedance'. Depending on the beam characteristics, the power setting and the application time, depth of injury can reach the muscularis propria [16].

In various widely distributed marketing materials, the Erbe ICC/APC300 argon capable system is referred to in the United States as the first generation argon system for flexible endoscopic use. Second generation systems are the Erbe VIO/APC2 and the KLS Martin/Conmed BeamerMate/Beamer Plus. The third generation is considered the Genii *gi4000* all in one unit.

The character of the argon beam has varied with each generation/system model. It is important to recognize that the manufacturer's recommendation for power setting also varies with each system. Argon assisted coagulation is a form of electrosurgery and is not a laser [15].

Conclusion

Electrosurgery is a constantly used but commonly misunderstood technology. Education received from reliable sources is a good start to more effective use and greater safety. Many variables contribute to the final tissue effect by contributing to the current density. Only some of the variables are produced by the ESU and these include the waveform, the starting power and the power curve.

Disclosures

Both authors have a financial interest in electrosurgery equipment manufactured and sold by Genii Inc.

Conflicts of interest

Authors declare no conflicts of interest.

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