Surgical Innovation
2020, Vol. 27(5) 492–498

Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/1553350620904610
journals.sagepub.com/home/sri
SAGE

An Unmodulated Very-Low-Voltage Electrosurgical Technology Creates Predictable and Ultimate Tissue Coagulation: From Experimental Data to Clinical Use

Yusuke Watanabe, MD, PhD[1,2], Pascal Fuchshuber, MD, PhD[3], Takafumi Homma, MD[4], Elif Bilgic, PhD[5], Amin Madani, MD, PhD[6], Naoki Hiki, MD, PhD[7], Ivor Cammack, MBChB[2], Takehiro Noji, MD, PhD[1], Yo Kurashima, MD, PhD[1], Toshiaki Shichinohe, MD, PhD[1], and Satoshi Hirano, MD, PhD[1]

Abstract

Objective. We analyzed the underlying principles of an unmodulated very-low-voltage (VLV) mode, designated as "soft coagulation" in hemostasis, and demonstrate its clinical applications. *Summary Background Data*. While the advantage of the VLV mode has been reported across surgical specialties, the basic principle has not been well described and remains ambiguous. *Methods*. Characteristics of major electrosurgical modes were measured in different settings. For the VLV mode, the tissue effect and electrical parameters were assessed in simulated environments. *Results*. The VLV mode achieved tissue coagulation with the lowest voltage compared with the other modes in any settings. With increasing impedance, the voltage of the VLV mode stayed very low at under 200 V compared with other modes. The VLV mode constantly produced effective tissue coagulation without carbonization. We have demonstrated the clinical applications of the method. *Conclusions*. The voltage of the VLV mode consistently stays under 200 V, resulting in tissue coagulation with minimal vaporization or carbonization. Therefore, the VLV mode produces more predictable tissue coagulation and minimizes undesirable collateral thermal tissue effects, enabling nerve- and function-preserving surgery. The use of VLV mode through better understanding of minimally invasive way of using electrosurgery may lead to better surgical outcomes.

Keywords

soft coagulation, robotic surgery, laparoscopic surgery, surgical education

Introduction

Electrosurgery (ES) is widely accepted as a highly effective method to obtain hemostasis during surgery. ES is the application of radiofrequency alternating current to raise the intracellular temperature in order to attain the desired tissue effects such as vaporization, desiccation, and coagulation. Despite using ES every day on their patients, many surgeons and surgical trainees are not familiar with the underlying physics and basic principles associated with the use of ES devices.[1-3] To address this knowledge gap, the Society of American Gastrointestinal Endoscopic Surgeons has established a web-based didactic curriculum known as the Fundamental Use of Surgical Energy to teach the principles and use of surgical energy devices.[4,5]

The key to successful surgery is accomplishing optimal hemostasis, which requires effective tissue desiccation and coagulation. When the cellular temperature

[1]Hokkaido University, Sapporo, Hokkaido, Japan
[2]Teine Keijinkai Hospital, Sapporo, Hokkaido, Japan
[3]The Permanente Medical Group, Walnut Creek, CA, USA
[4]University of Toyama, Toyama, Japan
[5]McGill University, Montreal, Quebec, Canada
[6]University Health Network --Toronto General Hospital, Toronto, Ontario, Canada
[7]Kitasato University, Tokyo, Japan

Corresponding Author:
Yusuke Watanabe, Department of Gastroenterological Surgery II, Hokkaido University Faculty of Medicine, Kita 15, Nishi 7, Kita-ku, Sapporo, Hokkaido 060-8638, Japan.
Email: ywatanabe328@gmail.com

reaches between approximately 60°C and 95°C, instantaneous desiccation and coagulation occur. However, in reality, vaporization, desiccation, and coagulation, and even carbonization can occur simultaneously when applying radiofrequency energy. In fact, any waveforms such as unmodulated and modulated outputs could be used for tissue desiccation and coagulation. An unmodulated low-voltage output labeled "cut" could theoretically result in suitable and predictable homogeneous tissue coagulation of higher quality than that achieved with the modulated output labeled "coagulation."

Modern electrosurgical units (ESUs) are equipped with a variety of output modes based on proprietary algorithms beyond the simple "cut" (unmodulated output) and "coagulation" (modulated output) modes. With the technical advancements, some modern ESUs can provide constant voltage and variable wattage depending on tissue resistance, whereas conventional devices produce variable voltage and constant wattage (wattage-based ESUs). ESUs with this voltage control technology are known as "voltage-controlled ESUs" and can impose less tissue damage. In addition, modern ESUs control voltage and current by instantaneously monitoring tissue resistance in order to achieve anticipated tissue effects.

Furthermore, major modern ESUs currently have an unmodulated very-low-voltage (VLV) mode designated as "soft coagulation," which is an extension of the voltage control technology to achieve better hemostasis. Numerous reports have described the benefit of using the VLV mode in hepatopancreatobiliary surgery[6-8] and thoracic surgery,[9-11] as well as in the field of therapeutic endoscopic procedures.[12-15] The use of the VLV mode has also increased in the field of minimally invasive surgery[16-18] and robotic surgery.[19] Although the advantage of the VLV mode in hemostasis has been reported, there is a lack of information on the fundamental principles of the VLV mode. We describe the underlying principles and basic features of the VLV mode, and sought to demonstrate technical descriptions of applying this mode in clinically relevant environments.

Methods

A simple hand-activated 5-mm-ball electrode was used with the latest computer-controlled ES generator (Valleylab FT10, Medtronic, Dublin, Ireland). For measuring the electrical characteristics of each mode including the unmodulated mode labeled "cut," various modulated modes labeled "blend," "coagulation," and the VLV mode, root mean square currents (Irms), and peak voltages (Vp) were analyzed under simulated impedances using a digital voltmeter (R&SURE3 RMS Voltmeter, Rohde & Schwarz, Munich, Germany; see Figure, Supplemental Digital Content 1a, which demonstrates the experimental setup; available online). A digital oscilloscope (Fluke 196C Scope Meters, Fulke, Everett, WA) was used to display the waveform of any given mode. For the VLV mode, the tissue effect and electrical performance were assessed using a piece of flank steak with a simulated electrical resistance in the range of human tissue (see Figure, Supplemental Digital Content 1b, which demonstrates the experimental setup; available online). To achieve this, 200 Ω were added using metal resistors (Power Type Metal Clad Wire-Wound Resistors, PCN Corporation, Sado, Japan) as a default load resistance based on pilot data. When activating the electrosurgical ball tip pencil (Medtronic, Dublin, Ireland) with the VLV mode, Irms, Vp, and tissue impedance (Ω) were analyzed. For the VLV mode, Vp was measured 10 times under each simulated impedance (25 to 1000 Ω) to calculate the intraclass correlation coefficients as a measurement of accuracy. Data analysis was performed using JMP version 11 (SAS Institute Inc, Cary, NC). This study did not involve human subjects and was exempt from ethical approval requirements.

Results

The output of the VLV mode is in the form of a continuous unmodulated sine wave similar to "cut" mode (Figure 1). Intraclass correlation coefficients of the measured Vp were 0.99 (95% confidence interval = 0.99-1.00). The measured Vp and Irms of each mode under 200 Ω are shown in Table 1. The VLV mode demonstrated the lowest voltage compared with other modes at any given power settings. The difference between the VLV mode and "cut" mode under a given simulated resistance at 60 W is described in Figure 2. As the impedance increased, the Vp of the cut mode increased as well in order to maintain tissue effect, but in the VLV mode, the voltage stayed consistently below 200 V.

The electrical characteristics of the VLV mode are shown in Figure 3, which suggest that a higher power output setting causes rapid tissue effect. The tissue effect of the VLV mode using a ball electrode is shown in Figure 4, demonstrating tissue desiccation and coagulation with minimum carbonization. Using the lower power setting, a deeper tissue effect occurred with longer activation times. The clinical situations in which the VLV mode was used with different active electrodes are demonstrated in the video (see Video, Supplemental Digital Content 2, which includes idiopathic hemothorax, laparoscopic distal gastrectomy, laparoscopic cholecystectomy, laparoscopic partial liver resection,

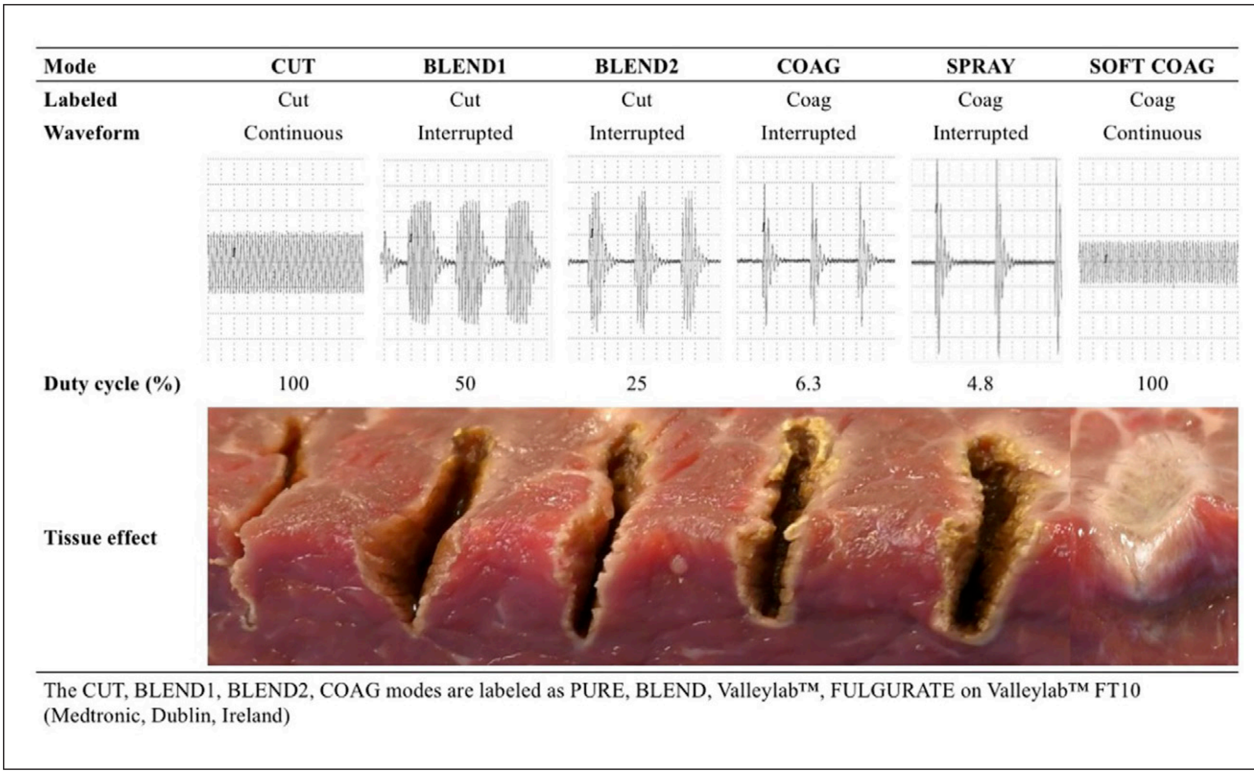

Figure 1. The characteristics of electrosurgical unit modes: waveform, duty cycle, and tissue effect.

Table 1. The Measured Voltage and Current of Electrosurgical Modes Under Simulated Human Resistance (200 Ω).

		20 W		30 W		40 W		50 W		60 W		70 W		80 W	
Mode[a]	Duty Cycle[b] (%)	Vp	Irms	Vp	Irms	Vp	Irms	Vp	Irms	Vp	Irms	Vp	Irms	Vp	Irms
CUT	100	92	307	112	377	128	433	144	484	159	533	172	577	184	616
BLEND1	50	126	150	150	376	176	433	198	485	229	534	249	577	268	617
BLEND2	25	182	209	209	375	245	432	280	484	327	528	334	572	359	612
COAG	6.3	271	310	310	375	364	433	412	484	451	530	490	572	526	612
SPRAY*	4.8	311	360	360	375	420	433	401	483	520	530	567	573	605	612
VLV	100	80	271	100	337	115	388	127	431	139	470	151	507	161	542

Abbreviations: Vp, peak voltage (V); Irms, root mean square current (mA); VLV, very-low-voltage.
[a]The CUT, BLEND1, BLEND2, COAG, and VLV modes are labeled as PURE, BLEND, Valleylab, FULGURATE, SOFT COAG modes on Valleylab FT10 (Medtronic, Medtronic, Dublin, Ireland).
[b]Duty cycle: the proportion of time that the electrosurgical unit produces current.

laparoscopic high anterior resection, and an open procedure; available online).

Discussion

This study describes the basic principles of modern ESUs, especially regarding the VLV mode, in order to achieve adequate tissue effect. At the same wattage setting, the VLV mode demonstrated the same unmodulated waveform (100% duty cycle) as the so-called "cut" mode and the lowest voltage compared with other modes staying below 200 V on all power settings at any given simulated impedance. The VLV mode generates only Joule heat without electric arc discharge,[20] resulting in no or minimal tissue cutting. Thus, effective coagulation can occur only when the active electrode is in contact with the target tissue. Theoretically, ideal tissue coagulation can be achieved with voltages ranging between 20 V and a maximum of 190 V.[20] Consequently, tissue coagulation can be best achieved using the VLV mode, which is similar to that obtained with computer-controlled bipolar vessel sealing devices. This mode can be used not only for

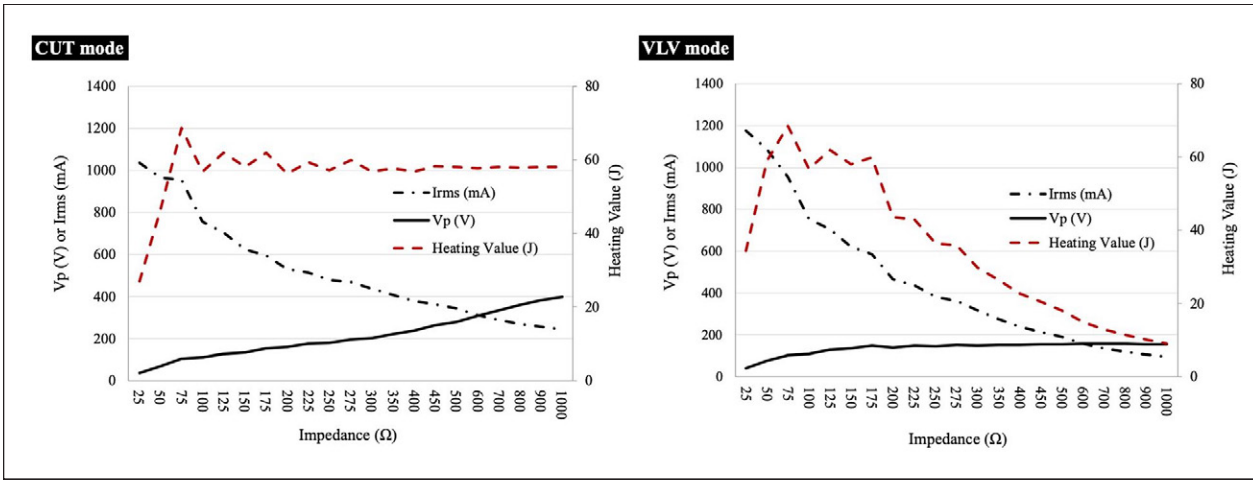

Figure 2. The features of "Cut" and "Very-low-voltage (VLV)" modes under given simulated resistances (output level: 60 W): voltage (V), current (mA), and heating value (J). The CUT and VLV modes are labeled as PURE and SOFT COAG on Valleylab FT10, Medtronic.

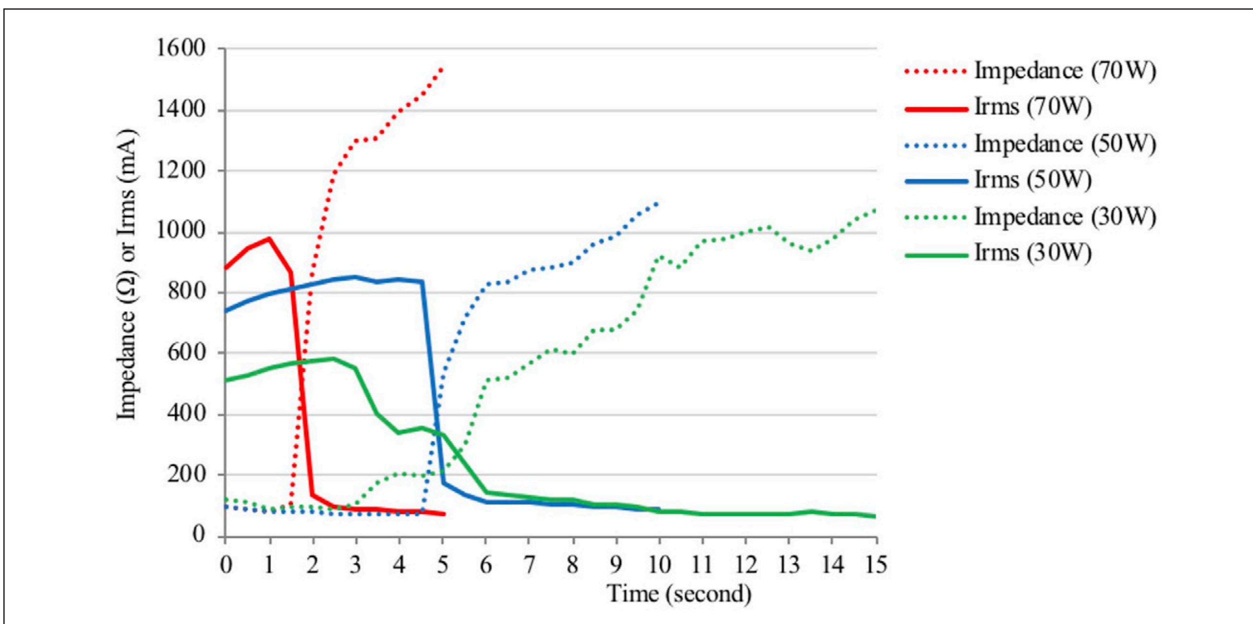

Figure 3. The performance changes of the very-low-voltage mode using a simulated tissue (Supplemental Digital Content 1b) with a simulated human resistance (200 Ω).

endoscopic and robotic surgery but also in open surgery across all specialties.

While any waveforms such as continuous low-voltage outputs and interrupted high-voltage outputs could be used to achieve tissue desiccation and coagulation, the quality of tissue coagulation is improved when using a continuous low-voltage output.[21] Using a standard continuous low-voltage "cut" mode, there is still a possibility that tissue vaporization and carbonization can occur with high current density or high power setting. In comparison, the VLV mode achieves better tissue desiccation and protein coagulation while maintaining tissue temperature between 65°C and 90°C. If tissue temperature exceeds 200°C, carbonization and adherence of the coagulated tissue to the electrode occur. A higher voltage also has a greater potential to generate deeply penetrative effects, causing unintended tissue damage and more collateral coagulation. Presumably, surgeons apply relatively high-power or high-voltage outputs for confirming tissue effect audibly and visibly; however, such outputs may cause

Figure 4. The tissue effect of the very-low-voltage mode using a ball electrode in each power setting. Tissue desiccation and coagulation with minimum carbonization. The higher the power setting, the more the superficial tissue desiccation and coagulation with some degree of carbonization.

lateral thermal tissue damage potentially increasing the risk of complications such as visceral organ injury, delayed leakage, or delayed bleeding.[21]

With regard to the VLV mode, the higher power setting achieves faster tissue effect. In the lower power output setting using the VLV mode, a deeper tissue effect occurs but this is relatively time-consuming; therefore, the lower power setting with the VLV mode is impractical in real environments. The VLV mode should be used on the high power setting (wattages) in most situations. As impedance increases, the voltage of the cut mode is boosted and the heating value is maintained to create tissue effect, but the VLV mode provided low-voltage outputs consistently and the heating value decreased. Hence, the VLV mode can minimize the risk of tissue carbonization and undesired lateral thermal damage.

Modern ESUs control voltage and current by monitoring tissue resistance to achieve desired tissue effects. Although currently available ESUs have different features and modes to create suitable tissue effects, they are classified broadly into voltage-controlled and wattage-based units. The VLV mode is an extended feature of voltage control technology, and is currently a feature of both voltage-controlled and wattage-based ESUs. This mode was originally equipped on the VIO300D/200D (Erbe Elektromedizin GmbH, Tuebingen, Germany) and since then has been introduced into most modern ESUs including the Valleylab FT10 (Medtronic); VIO3 (Erbe Elektromedizin GmbH); ESG-300/ESG-400 (Olympus, Tokyo, Japan); ARC400 (BOWA-Electronic GmbH & Co KG, Gomaringen, Germany); and maXium (KLS Martin Group, Tuttlingen, Germany). The VLV mode, a VLV unmodulated output (100% duty cycle) designated as "soft coagulation," is labeled as the so-called "coag" mode in all ESUs that include this feature. Surgeons need to know the features of modern ESUs to achieve better surgical outcomes.

When applying the VLV mode, the ball electrode is recommended as the surface area of the active electrode can be varied easily by adjusting the pressure on the target tissue. However, any shaped electrode such as a hook or standard blade electrode can be used. In principle, the tissue effect can be optimized by controlling the level of the electric voltage, current density, and the shape of the electrode. Maintaining the level of voltage <200 V plays a major role to achieve better tissue coagulation and minimum vaporization and prevent the unintended thermal effects. Removing conductive fluid such as blood using a suction coagulator helps surgeons achieve constant tissue effect.[18] The data collected in this analysis provides surgeons with practical insights for the use of the VLV mode in real environments.

The study has several limitations. The data were collected under controlled settings. In clinical practice, many factors including current density, activation time, tissue impedance, and the shape and movement of active electrodes influence tissue effects.[21] These factors dramatically change from moment to moment during the application of radiofrequency energy to the tissue, and it is difficult to simulate this in an experiment. Surgeons should also understand the tissue impedance according to macroscopic tissue changes for achieving desired tissue effects without unintended thermal injuries. Although these data illustrate the general features of the VLV mode, the performance of the VLV mode varies slightly depending on the ESU used.

In conclusion, understanding the basic features of the VLV mode enhances tissue coagulation and minimizes redundant collateral thermal effects. The VLV mode maintains a voltage of <200 V under all conditions, providing adequate and homogeneous tissue coagulation without unintended tissue vaporization and carbonization. When applying the VLV mode, the tissue effect can be precisely controlled by contacting the electrode with the target tissue. Although predicting the degree of lateral thermal effect is challenging, the minimally invasive way of using electrosurgical devices should be further considered for nerve- or function-preserving surgery, especially in the era of minimally invasive surgery. While any modes will achieve tissue coagulation, the VLV mode helps preserve organ function and decrease the risk of ES-related adverse events. Surgeons should consider such minimally invasive ways of using ES energy to improve outcomes.

Author Contributions

Study concept and design: Drs. Watanabe, Fuchshuber, Madani
Acquisition of data: Drs. Watanabe, Homma, Hiki, Cammack
Analysis and interpretation: Drs. Watanabe, Fuchshuber, Bilgic, Madani
Study supervision: Drs. Noji, Kurashima, Shichinohe, Hirano

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Dr Watanabe had other support from Johnson & Johnson, Medtronic, Olympus, and Amco outside the submitted work. The other authors have no conflicts of interest to disclose.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was partly funded by Grant-in-Aid for Young Scientists, Japan Society for the Promotion of Science (JSPS).

ORCID iD

Yusuke Watanabe https://orcid.org/0000-0002-2537-7053

Supplemental Material

Supplemental material for this article is available online.

References

1. Feldman LS, Fuchshuber P, Jones DB, Mischna J, Schwaitzberg SD; FUSE (Fundamental Use of Surgical Energy™) Task Force. Surgeons don't know what they don't know about the safe use of energy in surgery. *Surg Endosc*. 2012;26:2735-2739. doi:10.1007/s00464-012-2263-y
2. Madani A, Watanabe Y, Vassiliou MC, et al. Impact of a hands-on component on learning in the Fundamental Use of Surgical Energy™ (FUSE) curriculum: a randomized-controlled trial in surgical trainees. *Surg Endosc*. 2014;28:2772-2782. doi:10.1007/s00464-014-3544-4
3. Watanabe Y, Kurashima Y, Madani A, et al. Surgeons have knowledge gaps in the safe use of energy devices: a multicenter cross-sectional study. *Surg Endosc*. 2016;30:588-592. doi:10.1007/s00464-015-4243-5
4. Fuchshuber PR, Robinson TN, Feldman LS, et al. Fundamental Use of Surgical Energy (FUSE): closing a gap in medical education. *Ann Surg*. 2015;262:20-22. doi:10.1097/SLA.0000000000001256
5. Madani A, Jones DB, Fuchshuber P, Robinson TN, Feldman LS. Fundamental Use of Surgical Energy™ (FUSE): a curriculum on surgical energy-based devices. *Surg Endosc*. 2014;28:2509-2512. doi:10.1007/s00464-014-3623-6
6. Okamoto K, Koyama I, Toshimitsu Y, et al. Liver resection using a soft-coagulation system without the Pringle maneuver. *Hepatogastroenterology*. 2012;59:875-877. doi:10.5754/hge11101
7. Nagakawa Y, Tsuchida A, Saito H, et al. The VIO soft-coagulation system can prevent pancreatic fistula following pancreatectomy. *J Hepatobiliary Pancreat Surg*. 2008;15:359-365. doi:10.1007/s00534-008-1329-7
8. Hirokawa F, Hayashi M, Miyamoto Y, et al. A novel method using the VIO soft-coagulation system for liver resection. *Surgery*. 2011;149:438-444. doi:10.1016/j.surg.2009.11.015
9. Sakuragi T, Okazaki Y, Mitsuoka M, Itoh T. Dramatic hemostasis of the transected pulmonary artery model using SOFT COAG electrosurgical output. *Interact Cardiovasc Thorac Surg*. 2008;7:764-766. doi:10.1510/icvts.2008.177923
10. Sakuragi T, Ohma H, Ohteki H. Efficacy of SOFT COAG for intraoperative bleeding in thoracic surgery. *Interact Cardiovasc Thorac Surg*. 2009;9:767-768. doi:10.1510/icvts.2009.212696
11. Uchiyama A, Miyoshi K, Nakamura K. VIO soft-coagulation system for major pulmonary resections: results in 68 patients with primary lung cancer. *Gen Thorac Cardiovasc Surg*. 2011;59:175-178. doi:10.1007/s11748-010-0709-5
12. Fahrtash-Bahin F, Holt BA, Jayasekeran V, Williams SJ, Sonson R, Bourke MJ. Snare tip soft coagulation achieves effective and safe endoscopic hemostasis during wide-field endoscopic resection of large colonic lesions (with videos). *Gastrointest Endosc*. 2013;78:158-163.e1. doi:10.1016/j.gie.2013.02.030
13. Kim JW, Jang JY, Lee CK, Shim JJ, Chang YW. Comparison of hemostatic forceps with soft coagulation versus argon plasma coagulation for bleeding peptic ulcer—a randomized trial. *Endoscopy*. 2015;47:680-687. doi:10.1055/s-0034-1391565
14. Tate DJ, Bahin FF, Desomer L, Sidhu M, Gupta V, Bourke MJ. Cold-forceps avulsion with adjuvant snare-tip soft coagulation (CAST) is an effective and safe strategy for the management of non-lifting large laterally spreading colonic lesions. *Endoscopy*. 2018;50:52-62. doi:10.1055/s-0043-119215
15. Yamaguchi D, Sakata Y, Yoshida H, et al. Effectiveness of endoscopic hemostasis with soft coagulation for non-variceal upper gastrointestinal bleeding over a 12-year period. *Digestion*. 2017;95:319-326. doi:10.1159/000477439
16. Kitano S, Yang HK. *Laparoscopic Gastrectomy for Cancer: Standard Techniques and Clinical Evidences*. Vol 10. Tokyo, Japan: Springer Science & Business Media; 2012:171-387. doi:10.1111/ases.12374

17. Itano O, Ikoma N, Takei H, Oshima G, Kitagawa Y. The superficial precoagulation, sealing, and transection method: a "bloodless" and "ecofriendly" laparoscopic liver transection technique. *Surg Laparosc Endosc Percutan Tech*. 2015;25:e33-e36. doi:10.1097/SLE.0000000000000051
18. Miyazawa M, Aikawa M, Okada K, Watanabe Y, Okamoto K, Koyama I. Laparoscopic liver resection using a monopolar soft-coagulation device to provide maximum intraoperative bleeding control for the treatment of hepatocellular carcinoma. *Surg Endosc*. 2018;32:2157-2158. doi:10.1007/s00464-017-5829-x
19. Tohi Y, Murata S, Makita N, et al. Comparison of perioperative outcomes of robot-assisted partial nephrectomy without renorrhaphy: comparative outcomes of cT1a versus cT1b renal tumors. *Int J Urol*. 2019;26:885-889. doi:10.1111/iju.14046
20. Airan MC, Ko ST, eds. *Principles of Laparoscopic Surgery*. Berlin, Germany: Springer Science & Business Media; 2013:30-34.
21. Feldman L, Fuchshuber P, Jones DB. *The SAGES Manual on the Fundamental Use of Surgical Energy (FUSE)*. New York, NY: Springer Science & Business Media; 2012.