REVIEW ARTICLE

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Is electrosurgery a revolution? Mechanism, benefits, complications and precautions

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ABSTRACT

Approximately one and a half-century ago, it was revealed that high-frequency alternating current flows through the tissue without causing a painful electrical shock and produces heat instead of muscle stimulation. The application of electrical current to the tissue produces effects such as fulguration, desiccation/coagulation, or vaporization/ablation. Devices that use high-frequency electric current are called energy devices. The development of these devices that facilitated dissection and bleeding control pioneered a new era in surgery. After the Bovie units, which have monopolar and bipolar modes, advanced energy devices were also developed. Advanced bipolar devices use pulsed bipolar energy and feedback control of the energy output during tissue coagulation. There is an electrosurgical unit in each operating theater now. However, these devices are not exempted from complications. Complications related to energy devices occur in 2 to 5 per 1000 procedures. The leading causes of these complications are the thermal diffusion effect, smoke plumes, and stray current. As the surgical experience increases, complications decrease and reach a plateau. Surgeons should understand the mechanism of action; they should have knowledge about the prevention and treatment of potential complications.

1. INTRODUCTION

The concept of electrosurgery was born with the use of the high-frequency electrical current in cutting and hemostasis. Devices that use high-frequency electric current are also called energy devices. The development of these devices that facilitated dissection and bleeding control pioneered a new era in surgery [1]. Devices developed using electrical current have enabled the performance of operations that were previously considered inoperable, shortened the operation times, and reduced postoperative complications such as hematoma and seroma. Nevertheless, it was not easy to reach this level. Many surgeons have made severe criticisms of new devices and users. However, increasing number of surgeons used these devices and proved their benefits. Thus, energy devices became widespread and are extensively used today [2].

The development of energy devices follows a parallel course to the development of the electrical current. Firstly becquerel tried using direct current for coagulation rather than pouring hot oil. It passed direct current through a wire and cauterized the tissue after the wire was warmed up. D'arsonval revealed that high-frequency alternating current flows through the tissue without causing a painful electrical shock and produces heat instead of muscle stimulation [3]. In the early 1900s, French physician Joseph Rivere observed that the electrical current coagulated the skin in a limited area while treating a patient with insomnia using electrical current [4]. Whereupon he used this current to treat a carcinomatous ulcer on the hand of a patient. This application was the first correct use of electricity in surgery [2]. Later, its use in tissues with intense blood supply such as skin, oral cavity, and hemorrhoids became commonplace. Doyen placed the grounding pad under the patient for the first time [5]. In 1926, the first electrosurgery unit, based on high-frequency electrical current, was constructed in Boston by William Bovie. Dr. Harvey Cushing used this unit for the first time to remove vascular myeloma from the head of a 64-year-old patient [6]. Cushing had tried to resect this tumor with traditional methods several days earlier but failed due to the vascularity of the mass [7]. After this experience, surgeons were heartened more about electrosurgery [8].

2. BIOPHYSICS

Low-frequency electrical current below 10000 Hz. can cause muscle and nerve stimulation. Therefore, high-frequency electrical current is used in energy devices (200000-3000000 Hz) [4,9]. The application of electrical current to the tissue produces effects such as fulguration, desiccation/coagulation, or vaporization/ablation [10].

Electrosurgery is performed with monopolar or bipolar instruments. The difference between them is the pathway traveled by the current. In a monopolar instrument, electrical current is obtained from the electrosurgical unit. The current continues from the tip of the monopolar device through the tissue and leaves the patient's body from the lowest resistance zone. A ground pad is attached to the patient for easy and safe passage of the current [2,4]. In bipolar instruments, the electrical current proceeds to the tissue from the positive tip of the device and completes the circuit by leaving the tissue from the negative tip (return electrode) [11,12]. In bipolar instruments, electrodes have a structure that resembles forceps [2,4,13].

3. CUT AND COAGULATION

The surgeon could adjust the electrosurgical unit and use the device in cutting or coagulation modes. In cutting mode, high-frequency current is applied continuously and at low voltage. In this way, high energy is given to a small area in a short time. The temperature rises to 400 degrees, vaporization develops, and cutting occurs [14,15]. To cut tissue, the tip of the electrode should be kept very close but and should not direct contact with the tissue. In the coagulation mode, a high voltage current is given intermittently (94% off, 6% on). Hence a lower density current occurs in a wider area. The tissue temperature increases moderately. Dehydration and protein denaturation takes place in the tissue. Vascular structures below a specific diameter are sealed by tissue dehydration and protein denaturation. Coagulation mode is an effective mode to control leaks on large surfaces [14].

Several "blend" options are also available, combining various proportions of the two main modalities. As electrical current is applied to the tissue, heat is generated due to the tissue's resistance. Desiccation, vaporization, or fulguration occurs depending on the contact time of the surgical instrument with the tissue and the nature of the voltage from the electrosurgery unit [3,16].

Desiccation: It occurs by direct contact of the tip of the device and the tissue. It is a result of protein denaturation and dehydration. Desiccation could be created with cut or coagulation modes [17].

Vaporization: It occurs with the cut mode without the tip of the instrument contacting the tissue. The high heat generated suddenly by the current vaporizes the tissue immediately adjacent to the tip of the electrode. The cells explode, and cutting occurs.

Fulguration: The tip of the electrode in coagulation mode affects the large area without touching the tissue. Fulguration is useful for hemostasis in wide areas and it causes charring of the tissue [3].

4. THERMAL SPREAD

Energy devices have varying degrees of thermal diffusion effect [18]. The thermal spread could cause tissue necrosis in undesirable areas. Tissue necrosis in the surgical area might lead to prolonged postoperative recovery and wound nfection [19]. Due to thermal spread, adjacent organs such as the ureter, bladder, and bowel might also be damaged. Therefore, surgeons need to be aware of the potential thermal spread from specific electrosurgical devices and perform with caution [20].

Table 1. *Thermal spread of some devices* [21]

Device	Thermal Spread (mm)
Traditional bipolar device	2 to 22
Ultrasonic cutting and coagulation device (Harmonic Scalpel)	0 to 3
Vessel sealing devices	
EnSeal Tissue Sealing and Hemostasis System	1.1
10 mm Ligasure	1.8
5 mm Ligasure	4.4

Energy devices might generate smoke plumes during the process. The smoke plume contains potentially toxic and biohazardous substances [22]. In high concentrations, these plums could irritate the eyes and respiratory tracts of operation room staff [23]. In addition, as using energy devices during laparoscopy, there could be aerosolized blood -borne viral content in the smoke plume [24]. The probability of viral transmission is higher in ultrasonic devices that do not generate high temperatures [25-28]. 2020 is a year that the world struggles with the Covid-19 pandemic. According to recent studies, sars-cov-2 has been detected in some abdominal organs and peritoneal fluid [29,30]. However, it has not been proven to become aerosol during laparoscopy or using energy devices [31,32]. Nevertheless, it is reasonable to take precautions such as smoke evacuation systems and personal protective masks to minimize the risk. Many smoke evacuation systems available on the market could filter sars-cov-2 with approximately 0.06-0.14 microns. [32]. Thus, it is an important precaution to use appropriate smoke evacuation devices containing Ultra-Low Particulate Air (ULPA) or HEPA (High-Efficiency Particulate Air) filters [33].

5. SAFETY

In grounding systems used before the 1970s, the risk of current discharge from the patient through alternative pathways was higher. These alternative pathways could be the metals on the operation table, electrocardiogram leads, or tips of intravenous fluid sets. However, dispersion pads that are currently used are placed close to the surgical area. Thus they provide a safe outlet for the current, minimizing the risk of complications [34]. If the dispersion pad is not fully attached or partially peeled off, the risk of skin burn may increase. New modern electrosurgical devices have sensors that measure pad-to-skin contact and current density; these devices sound an alarm and automatically turn off the current if contact is poor [4].

To avoid complications caused by stray current, instruments used as monopolar should be inspected for insulation failure prior to surgery. Metals on the skin, such as piercings, should be removed if they are located close to the surgical area [35].

Cardiac implantable devices that use electric current may be affected by the use of energy devices. These are cardiac implantable electronic devices (CIED) (e.g., cardiac pacemaker, implantable cardioverter-defibrillator [ICD], cardiac resynchronization device, ventricular assist device), neurologic or spinal cord stimulators, and gastric neurostimulators. In such cases, the technical assistance of the devices should be necessary or alternative devices should be used (bipolar devices, ultrasonic scalpels, or topical hemostatic agents). In monopolar electrosurgery, current flows from the active electrode (hand-held electrode) to the dispersion pad. In bipolar electrosurgery, current flows between the two electrodes of the device, and the stray current is minimal [36,37]. If the monopolar device is necessary, the dispersion pad should be placed in the appropriate place closest to the surgical site, with the other magnetic devices outside the pathway [38].

6. ADVANCED ENERGY DEVICES

6.1. Advanced Bipolar Devices

Advanced bipolar devices use pulsed bipolar energy and feedback control of the energy output during tissue coagulation. Therefore, heat production is low compared to basic and other advanced electrical surgical devices. They minimize tissue sticking, smoke, and lateral thermal spread. Ensell (Ethicon, USA) and ligasure (Medtronic, USA), introduced in 1998, are the first and most commonly used devices. The energy flow to the tissue progressively increases up to approximately 100 degrees, and at this temperature, energy flow is stopped, and the tissue is cut with a blade. In advanced bipolar devices, electrodes are located inside the jaw, and lateral thermal damage is minimal compared to other devices[18]. It seals vessels up to 7 mm and produces smoke plumes less than other advanced energy devices [20,39].

6.2. Ultrasonic Scalpels

Ultrasonic scalpels have been used since the first half of the 1990s, and the most frequently used device is the harmonic (Ethicon, USA) scalpel. Ultrasonic devices which contain piezoelectric transducers convert electricity into mechanical energy and produce a high vibration frequency in the 55 kHz ultrasonic range. They increase the temperature up to 200 degrees in the tissue and cause protein denaturation. It safely closes vessels whose diameters are 5 mm or less [40]. Ultrasonic Devices are faster and smokeless than other devices but are more likely to cause lateral thermal damage [39,41].

6.3. Integrated Bipolar and Ultrasonic Devices

Integrated bipolar and ultrasonic devices combine the safety of advanced bipolar devices with the speed of ultrasonic devices [42]. Thunderbeat system (Olympus, Japan) is the most frequently used integrated system. In the Thunderbeat device, bipolar heat energy is applied laterally, while additional sealing and cutting are achieved by ultrasonic energy in the central part of the device. Integrated devices reach high burst pressures and seal even in large vessels and give superiority to other energy devices in terms of speed [43]. Integrated energy devices reach high-temperature degrees in the tissue like other ultrasonic devices [44]. Therefore, the probability of lateral thermal damage is higher than advanced bipolar devices [45].

6.4. Complications

Complications related to energy devices occur in 2 to 5 per 1000 procedures. As the surgical experience increases, complications decrease and reach a plateau. The most severe and fatal complications related to energy devices are small bowel or colon perforations. Symptoms of bowel perforation usually appear 4 to 10 days postoperatively. It could be fatal if not detected early [46]. Adjacent organs could be injured due to lateral thermal spread [47]. During dissection close to ureters and intestines, the possibility of injury to these organs should be kept in mind, and the voltage should be kept at the lowest level possible [4]. Some electrosurgical complications are more common during laparoscopic surgery [48].

Direct coupling: Inadvertent contacting or taking place very close of two non-insulated instruments (i.e., metal trocar and metal grasper) causes direct coupling in electrosurgery. Electrical current could flow to the secondary instrument. If the secondary instrument is in contact with the bowel, skin, or other sensitive organs, injury of these organs is highly probable. With direct coupling, bile duct injuries may occur in laparoscopic cholecystectomy; delayed bile leaks can be seen [49,50].

Capacitive coupling: If two conductors are separated by an insulator, a capacitor might appear in the electrical circuit. An example of this in surgery would be an insulative coated surgical instrument placed in a hybrid trocar [4]. Capacitor occurs with the alternating current given to the surgical instrument. Thus, tissues such as skin and intestines that contact or soo close with the second conductor may be injured [34,51]. The magnitude

Table 2. *Features of energy devices* [39]

	Monopolar	Bipolar	Ultrasonic	Advanced Bipolar	Integrated Bipolar + Ultrasonic
Sealing	Yes	Yes	Yes	Yes	Yes
Transection	Yes	Yes	Yes	Yes	Yes
Hemostasis	Yes	Yes	Yes	Yes	Yes
Burst pressure (5-7 mm vessel)	-	-	450 mmHg	615-720 mmHg	730 mmHg
Lateral thermal spread	++++	++	+++	+	+++
Maximum vessel size	2-3 mm	2-3 mm	5 mm	7 mm	7 mm
Important points	Cost-effective	Cost-effective optionally can add water irrigation tool	Fast High propensity of collateral tissue damage	Low lateral thermal spread	Fast, highest burs pressure, high propensity of collateral tissue damage

of the current induced from the capacitor depends on the proximity of the two conductors, the conductor, the amount and duration of the voltage.

During laparoscopic surgery, the electrosurgical unit is connected to laparoscopic instruments. Instruments such as graspers and scissors can be used as monopolar devices. The current flows from the shaft of the laparoscopic instruments to the tip. There might be insulation failures in the shaft of these instruments [52]. In this instance, the current could pass from the shaft to the intraabdominal organs. If reusable or disposable instruments are used by sterilizing repeatedly, the probability of injury to the abdominal organs increases. Reusable instruments should be checked before use, and disposable instruments should not be reused [52,53].

Technological improvements and developments of new devices are likely to continue. There is not enough contemporary information about new technologies in the current medical and residency education curriculum [54]. To address this gap, the Fundamental Use of Surgical Energy (FUSE) program was designed by a multidisciplinary team of doctors, engineers, nurses, and educators. The FUSE program aims to reduce the frequency of complications by filling the education gap [55].

7. CONCLUSION

Energy devices have revolutionized surgical practice since the first unit of BOVIE. They reduced complications and shortened operation time. Surgical procedures, which were previously considered impossible, have been performed. There is an electrosurgical unit in each operating theater now. However, these devices are not exempted from complications. Surgeons should understand the mechanism of action; they have knowledge about the prevention and treatment of potential complications. Therefore, it is beneficial to expand education programs.

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CONFLICT OF INTEREST DECLARATION

The authors report no conflict of interest. The authors alone are responsible for the content and the writing of the paper.

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