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Review article

Electrosurgical technology: Quintessence of the laparoscopic armamentarium

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ABSTRACT

One of the biggest enemies of minimally invasive surgery is bleeding. The ongoing desire to improve hemostasis and thus its efficacy has led to the rapid evolution of electrosurgical technology. In this review we discuss the yet evolving science of electrosurgery. For the optimal use of available tools, it is of utmost importance for the laparoscopic surgeon to understand that different electrosurgical instruments have different properties and thus their use has to be tailored. To understand the concept well, we review the important landmarks in the evolution of electrosurgery related to gynecological laparoscopy, revisit the basic principles, and then proceed on to discuss the modern tools in the electrosurgical armamentarium.

Introduction

Use of laparoscopic surgery in gynecological practice is increasing worldwide. A recent review exploring surgical trends in Taiwan over the past 2 decades,[1] confirmed that operative laparoscopy is widely accepted as an efficacious technique in the treatment of gynecological lesions. According to a nationwide population-based data in Taiwan, use of laparoscopic approach for hysterectomy increased dramatically from 5.2% to 40.4%, with a simultaneous decrease in the open approach from 77.3% to 45.7% in a span of 10 years.[2] It is noteworthy to say that this aggrandizement in laparoscopy was possible owing to the advancement of technology and human desire to explore and exploit the possibilities.[3] One of the biggest enemies of minimally invasive surgery is bleeding. The ongoing desire to improve hemostasis and thus its efficacy has led to rapid evolution of electrosurgical technology. Indispensability of electrosurgical technology in a laparoscopic armamentarium is well known to surgeons. In a recent publication, the incidence of electrosurgical injuries, mechanisms of injury, and recognition and management of electrosurgical complications were discussed.[4] In this review we discuss the evolving science of electrosurgery. The main aim is to focus on various energy sources available today.

Methodology

This review includes a search of electronic resources, namely Medline, PubMed, CINAHL, the Cochrane Library, Current Contents, and EMBASE. The Medical Subject Headings (MeSH) including all subheadings and keywords used included *Electrosurgery*, *Electrosurgery in laparoscopy*, *Electrocoagulation*, *Monopolar electrosurgery*, *Bipolar electrosurgery*, *Vessel sealing system*, and *Ultrasonic electrosurgery*. Articles were screened for historical facts as well as recent advances about electrosurgery. Web searches were performed using educational sources if appropriate.

Results and discussion

Electrosurgery was incorporated in the armamentarium of gynecological laparoscopic surgeries around 8 decades ago and has exponentially evolved with time. Indeed electrical energy is the most common form of energy used in gynecological laparoscopies

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today; unfortunately it still remains one of the least understood sciences among the users.[5]

Historical overview

In 1911 Jacobaeus[6] of Stockholm introduced the concept of diagnostic visualization of the peritoneal cavity and termed this new procedure *laparoscopy*. However, the first reported use of laparoscopy in conjunction with electrosurgery was by Fervers,[7] a general surgeon, way back in 1933 when he attempted laparoscopic adhesiolysis. Power and Barnes[8] in 1941, reported the first ever human performance of laparoscopic electrosurgical female sterilization using a monopolar instrument. The concerns related to the considerable morbidity due to thermal injuries on using monopolar energy contributed to the evolution of bipolar devices in around 1970 by Frangenheim[9] in Germany and Rioux and Cloutier[10] in North America. The same technique was further refined by Kleppinger[11] in 1977 and thus originated the still famous Kleppinger bipolar forceps. These designs were used mostly unchanged until the early 21st century, when a number of proprietary bipolar systems emerged based on the recognition that high radiofrequency—electrosurgical coagulation and desiccation could be used to seal vessels of substantial size predictably, and with much reduced lateral thermal injury. In 1993, Amaral[12] first described the ultrasonic scalpel for laparoscopy as having the ability to provide both vessel sealing and tissue transection. However it gained practical popularity only from 2010 onwards. A hybrid of advance bipolar and ultrasonic technology to maximize the efficacy of electrosurgery has currently brought hopes to herald a new era in the electrosurgical armamentarium; it has yet to prove itself efficiently in the surgical battlefield (Fig. 1).

Mini revisit to electrosurgical biophysics and basic principles

In simple terms, the source of electrical energy in the operating room actually originates from surrounding power generation facilities and is delivered to the operating room through wires. In the operation room, this energy is modulated by the electrosurgical unit (ESU) or power generator in order to imbue current with appropriate and specific characteristics to produce the desired tissue effects during surgical procedures.

Electrosurgical procedures basically depend on a circuit that involves: an ESU (or power generator), an active electrode, target tissue (of the patient), and a return electrode. The flow of electricity or electrons in this circuit is alternating current (AC), which means that, in the ESU, anode and cathode are continuously interchanged. For safe application to the human body, a key characteristic that must be altered is the frequency of the AC. As with normal frequency of AC (i.e., 60 Hz) muscles and nerves are stimulated to produce muscle spasms and abnormal movements during surgery. However, the dreaded hazard of the 60-Hz frequency is interference with conductivity of heart muscle, resulting in cardiac arrest and death by electrocution.[5]

It has been observed that these adverse effects of AC can be overcome by the increasing the frequency exponentially. Modern-day ESUs use frequency ranges of 200 kHz to 50 MHz as this allows for desired thermal effects without muscle fasciculation or nerve stimulation.[13] This tissue effect is achieved by the conversion of flowing electric energy to thermal energy when it encounters resistance (target body tissue). Thermal energy can cause cutting, coagulation, desiccation, and fulguration, depending upon the electrodes and how they are manipulated. These varied effects can be achieved by adjusting the voltage and active time of the electrode that energy is applied to target tissues.

Evolution of technology

As the surgery becomes less invasive, and the technical difficulty increases, the demand for a reliable energy device becomes stronger.[14–17] The evolution of the ESU has been briefly discussed previously. This section basically deals with four generations of electrosurgical systems to maximize desired tissue effects while minimizing adverse effects.

Conventional monopolar electrosurgery

Monopolar electrosurgery refers to the arrangement of a single small electrode at the tip of the surgical instrument that delivers focused alternating electrical current to the target tissue for the desired surgical effect. The second electrode is placed on the patient at a site remote from the surgical site to complete the electrical circuit (conventionally referred to as cautery plate). Conventional monopolar electrosurgery remains a popular

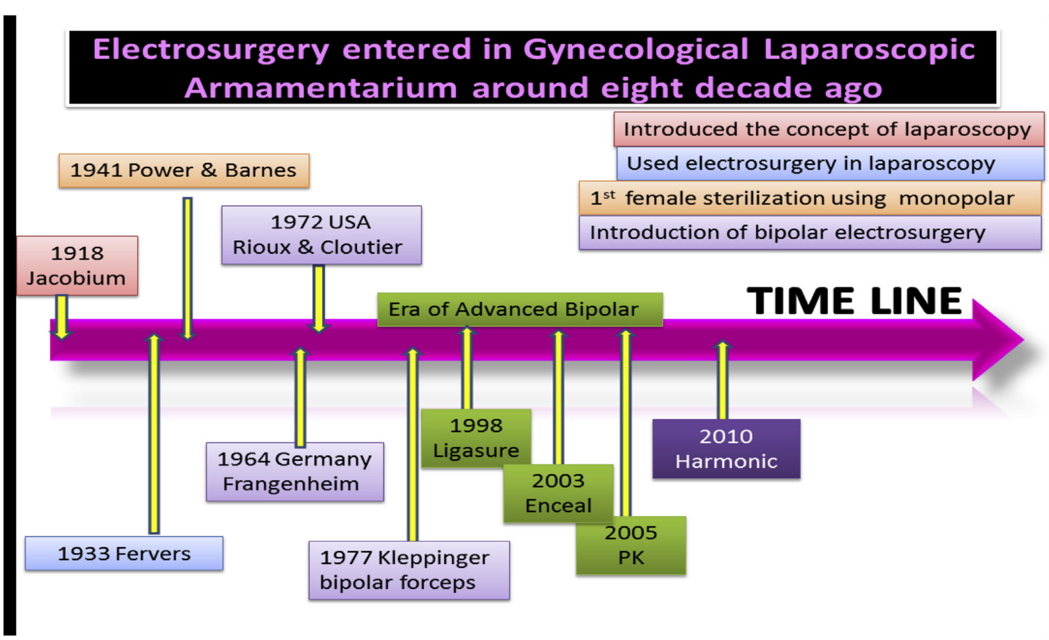

Fig. 1. Important landmarks in the evolution of electrosurgery in gynecological laparoscopy.

modality in laparoscopy because of its low cost, easy availability, and diverse range of available tissue effects. This is the only type of electrosurgery that can have tissue vaporization and fulguration effects. However, it has its own limitations, involving the need for a dispersive electrode, the relatively high power settings, the possibility of stray current injuries, and the inability to seal vessels larger than 1–2 mm diameter.[18]

Conventional bipolar electrosurgery

Bipolar electrosurgery means where both electrodes are contained at the tip of the surgical instrument itself. Current passes through tissue grasped between the electrodes to achieve the desired surgical effect. Contrary to the monopolar circuit, in bipolar electrosurgery, electrons do not dissipate throughout the patient's body because the active and return electrode are in close proximity to each other and only those tissues that are interposed are included in the circuit. Thus, only the tissues of interest and those immediately surrounding are affected by the heat generated.

However, bipolar electrosurgery needs increased time for coagulation due to a low power setting, which leads to charring and tissue adherence with incidental tearing of adjacent blood vessels.[19]

The great disadvantage of the bipolar system is that the electrodes cannot cut tissue. Even if a continuous (cut) waveform is applied to bipolar instruments, cutting is inefficient.[20] In lieu of this shortcoming, bipolar devices were incorporated with a mechanical cutting blade at the electrode site allowing for virtually bloodless dissection after excellent tissue desiccation, and that pioneered a new era of advanced bipolar technology.

Advanced bipolar system

Owing to the inherent problems associated with the conventional bipolar electrosurgery, technological developments were achieved so as to provide more consistent and reliable hemostasis with significantly less lateral thermal damage.[21] The delivery of electrical energy by the advanced bipolar system is highly pulsatile, allowing for tissue cooling during activation in an attempt to minimize lateral thermal spread. There is also a computer-controlled tissue feedback response systems that monitors tissue impedance and/or temperature in order to adjust continuously the current and voltage generated by the unit. Advanced bipolar devices have been approved by the United States Food and Drug Administration to seal vessels up to 7 mm in diameter.[22] Moreover, all advanced bipolar devices are capable of tissue transection with an incorporated cutting mechanism. The cutting device is most commonly a retractable blade built into the jaws of the instrument. Currently available advanced bipolar technologies include LigaSure (Covidien, Mansfield, MD, USA), Starion Tissue Welding system (Sunnyvale, CA, USA),[23] EnSeal (Ethicon Endo-Surgery, Cincinnati, OH, USA), and Plasma Kinetic System (PKS; Gyrus ACMI, Southborough, MA, USA). Table 1 summarizes various features of these devices as per the available literature.[18,21,24]

Ultrasound devices

In this technological advancement, there is no electrosurgical current generated. Ultrasonic devices produce tissue effects by generating mechanical vibrations at over 20 kHz (i.e., above the audible range). This mechanical energy combined with the heat that is generated causes protein denaturation and formation of a coagulum that seals small blood vessels.[25] Most of the tissue effects produced by ultrasonic devices are the same as those for bipolar devices. Advantages of ultrasonic vessel sealers over the bipolar electrosurgical instruments include less tissue necrosis and charring, reduced lateral thermal spread, and less smoke generation.[26,27]

Initially the prototype Ultracision Harmonic Scalpel (Ethicon Endo-Surgery) was developed for commercial use, which was approved to seal vessels up to 3 mm in diameter.[28] The Harmonic ACE (Ethicon Endo-Surgery) was subsequently developed; with an active jaw frequency of 55 kHz, and has been approved by the United States Food and Drug Administration to seal vessels up to 5 mm in diameter.[22] Other examples of currently available laparoscopic ultrasonic devices include the AutoSonix (Covidien), Sonocision (Covidien), and SonoSurg (Olympus America, Center Valley, PA, USA). All these devices are almost similar to the Harmonic ACE.[29]

Hybrid technology (Thunderbeat)

This system is a newer innovation wherein ultrasonic and advanced bipolar energies have been coupled together. Using a single multi-functional instrument, the surgeon may simultaneously seal and cut vessels up to 7 mm in size with minimal thermal spread. Three clinical trials have already been able to prove the superiority of Thunderbeat over the existing gadgets.[30–32]

Future

The ultimate aim of electrosurgery in any field of surgery is the attainment of anatomic dissection and hemostasis with the least amount of collateral damage and subsequent scar tissue formation. At present, high radiofrequency newer bipolar devices and ultrasound-based technology seem to be near optimal practice during gynecologic laparoscopies. Hybrid technology to combine the advantageous effects of both advance bipolar and ultrasonic technology into a single instrument seems to be a new hope. However the time is not very far away when robotics will steal the stage. To handle the new challenges related to robotic surgeries as

Table 1
Harbinger of the new era in safe laparoscopic electrosurgical practice—currently available advanced bipolar technologies: an overall comparison based on available literature.[18,21,24]

Trade names (Commonly used)	LigaSure	EnSeal	Plasma kinetic system
Manufacturer	Valleylab, Covidien, Boulder, CO, USA	SurgRx, Inc, Palo Alto, CA, USA	Gyrus ACMI, Maple Grove, MN, USA
Year of availability	1998	2003	2005
Available configurations			
• Shaft diameter (mm)	5, 10	5	5, 10
• Shaft length (cm)	37, 44	14, 25, 35, 45	15, 24, 33, 45
Vessel seal (diameter in mm)	7	7	7
Time to seal (s)	10	19	11
Mean burst pressure (mmHg)	385	255	290
Lateral thermal spread (mm)	2–3	1	2–6
Unique feature	First such instrument to be developed Incorporates both advanced bipolar and monopolar technologies	Highest mean vessel burst pressures Controls energy deposition at the electrode–tissue interface	Only technology with a true bipolar cut

well as to empower the laparoscopic armamentarium,[33] we need to explore and re-explore the newer advancements or the known but less experienced techniques, and laser electrosurgery might prove to be one of those.

Conclusion

For all gynecological laparoscopic surgeons, it is fundamental to understand the basic principles of electrosurgery. Revisiting the related historical milestones and basic physics makes it easy to imbibe the concept. In the present scenario, advanced bipolar or ultrasonic devices are popularly being used. However, both of these have their advantages and pitfalls. Combining the two in a single instrument to maximize the potential benefits is the hope for the future. In the upcoming era of robotic surgery integration of laser in the electrosurgical armamentarium sounds promising.

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