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Review article

"Energy devices in gynecological laparoscopy – Archaic to modern era"

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ABSTRACT

The introduction of newer vessel sealing systems has revolutionized techniques of hemostasis during laparoscopic surgery. These devices allow for rapid sequential tissue and vessel sealing, coagulation, and transection. Despite of widespread use of newer advanced bipolar and ultrasonic devices, monopolar and conventional bipolar electro-surgery still carry weightage due to wider range of tissue effect, dissection capabilities, cost effectiveness, and ease of availability. Here in we discussed different types of commonly available energy sources in terms of mechanism, efficacy and safety as thorough knowledge is utmost important for surgeon to choose appropriate instrument for surgical procedure.

Introduction

The origin of electro-surgery dates back to 1877, when P. Bozzini described the construction of a device for electro-cauterization. In 1893 the high-frequency electric current was first used for treatment purposes. Several decades later in 1928, Bovie organized a production of electrosurgical equipment and described three different effects of this energy type: desiccation, dissection, and coagulation, which led to the establishment of fundamentals in modern electro-surgery and converted diagnostic laparoscopy into operative.[1,2] In 1933 fervers, a general surgeon used laparoscopy with electro-surgery to divide intra-abdominal adhesions.[3] Later in 1941, first laparoscopic female sterilization using monopolar energy was performed. 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[4] in Germany and by Rioux and Cloutier[5] in North America. The same technique was further refined by Kleppinger,[6] then conventional bipolar devices came into use around 1970.[7]

Hemostasis is basic in all surgical procedures. Traditional methods of staples and clips have gradually been abandoned due to cost, difficulty with repeated applications, and problems of displacement. Standard energy devices monopolar and bipolar coagulation are currently widely used due to their inexpensive nature and reusability. Also the new vessel sealing technologies are so successful that they have largely made the need for laparoscopic suturing of vascular pedicles redundant. However, this involves high instrument cost, thermal spread, and sticking and charring of tissues.[8,9] Monopolar electrosurgery is most commonly used modality in laparoscopic surgeries because of its low cost, general availability, and diverse range of available tissue effects. However, potential shortcomings of monopolar electro-surgery, including 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, led to the development of conventional bipolar electro-surgery.[10]

Commonly used electrosurgical devices in minimally invasive gynecology surgery (Table 1)

Monopolar

Monopolar energy is the most commonly used electrosurgical modality because of its versatility and clinical effectiveness. Electrosurgical generator has "cut" and "coag" settings, cut refers to

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Table 1
Different types of available energy sources and tissue effect produce by them.[23,43]

Type		Tissue effect
Monopolar		Vaporization, fulguration, desiccation, coaptation
Conventional bipolar		Desiccation, coaptation
Advanced bipolar	Ligasure, pk gyrus, ENSEAL	Desiccation, coaptation, tissue transection
Ultrasonic technology	Ultracision harmonic scalpel, Harmonic ACE, Harmonic focus, SonoSurg, AutoSonix	Desiccation, coaptation, mechanical tissue transection
Hybrid device	Thunderbeat	
Laser energy	Nd: YAG laser, Argon laser, CO_2 laser	
Argon beam coagulator	System 7550TM ABC, Cardioblate	
Radiofrequency (RF) energy	RF 3000, starburst, cardioblate	

unmodulated continuous waveform and coagulation refers modulated interrupted waveform. During laparoscopic surgeries continuous waveform results in flow of low energy electron thus minimal smoke production with tissue cutting whereas interrupted waveform is associated with high energy electron flow and more smoke production with high temperature but better hemostasis.[11]
Monopolar energy is based on the use of active and passive electrodes. In monopolar electro-surgery, the active electrode is located on the surgical site. The return electrode is located on the patient, at site away from surgical site to complete electrical circuit (cautery plate). The current passes through the patient as it completes the circuit from the active electrode to the patient return electrode.[7,10]
It has the ability to use continuous and "mix/blend" current to dissect tissue while providing some hemostasis, fulguration in the interrupted mode which results in adequate hemostasis by carbonizing tissues with high capillary or small vessel density, and coagulation of grasped tissue can be achieved where desiccation occurs and proteins denature resulting in a coagulum formation. Maximum temperature reached after activation is >100 °C.[11–13] The tissue effects possible with monopolar electro-surgery include tissue vaporization and transection, fulguration, desiccation, and small vessel coaptation.

Bipolar

In bipolar energy sources current passes between two active electrodes which are in close proximity to each other unlike the monopolar in which it travels through patient body. As current passes between tips of instrument, it only affects tissue grasped between electrodes. These are relatively safe and more useful as compared to monopolar as it causes minimum collateral spread, reduce risk of interference with other devices and better coagulation.[1] The disadvantage of using conventional electrosurgery are it cannot cut tissue and requires more time to coagulate causing more tissue charring and adherence of tissue which may lead tearing of adjacent vessel causing more bleed.[7] These shortcomings were overcome by advanced new generation bipolar and ultrasonic devices. Conventional electrosurgical devices (monopolar and bipolar) use are associated with stray current injuries like capacitive coupling, insulation coupling, and direct coupling.[13]

Ligasure

The Ligasure™ (Valleylab Inc., Boulder, CO, USA) (LS) vessel sealing instruments use a high-current, low-voltage continuous bipolar radiofrequency energy in combination with a feedback controlled response system that automatically delivers and disrupts the power according to the composition and impedance of the tissue between the jaws of the instruments. It fuses collagen and elastin within the vessel walls, resulting in a permanent seal that can withstand three times the normal systolic pressure, and seals vessels up to 7 mm. Maximum temperature during activation is below 100 °C,[14–17] thus reduces thermal spread to 1 mm with LS Precise and to 1.5 mm with LS V.

Plasma kinetic gyrus

The Plasma Kinetic Gyrus™ (PK) (Gyrus ACMI, Southborough, MA) is a bipolar electrosurgical device that uses plasma kinetic technology to deliver a high current at a very low voltage to the tissue. It has two tier jaw design with serrated surfaces for secure grasping.
A series of rapid pulses allows a cooling phase during coagulation, thereby decreasing lateral thermal spread. It can seal vessel up to 7 mm by denaturing the protein within the vessel walls, forming a coagulum that occludes the lumen. It yields maximum temperature which is below 100 °C.[16] This technology does not have a feedback mechanism like LS and Enseal; however, it allows the physician to choose how long energy is applied with the aid of audible tone change, indicating tissue desiccation to the user. This system has two different modes (vapor pulse coagulation and plasma kinetic tissue cutting) delivering predetermined levels of energy matched to special surgical instruments.[10]

Enseal

ENSEAL™ (Ethicon Endo-surgery, US, LLC) this tissue-sealing and hemostasis system is a bipolar instrument that combines a high-compression jaw with a tissue dynamic energy delivery mechanism. Because of the configuration and the temperature sensitive matrix (Nanopolar thermostats) embedded within the jaws of the instrument, each tissue type within the jaws receives a different energy dose that is constantly changing as the tissue is being sealed and its impedance changes.[10,18] It is the first and only system that controls energy deposition at the electrode-tissue interface.[19] The instrument has a blade that simultaneously cuts the sealed tissue. It can seal vessels ranging in diameter from 1 mm to 7 mm, also sealed vessel walls are capable of withstanding greater than seven times normal systolic pressure.[1]

Ultrasonic devices

In 1993, Amaral 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. It produces tissue effects by converting electrical energy into vibrations at more than 20,000 cycles per second which is above the audible range.[15,20] Instrument consist of transducer, hand grip, long shaft and blades. The upper blade, called tissue pad is an inactive one which helps in grasping the tissues and also prevents the vibrational energy from spreading further while lower active jaw vibrates and denatures protein in the tissue to form a sticky coagulum. One of the ultrasonic device, Harmonic ACE™ (Ethicon Endo-Surgery, Cincinnati, OH, USA) oscillates at frequency of 55,000 cycles per second. It has approval of United States food and drug administration to seal vessel up to 5 mm in diameter. Whereas ultrasonic devices operating at various other frequencies also exist. The mechanical vibrations are produced by the piezoelectric transducers embedded in the tools which convert the applied electrical energy to mechanical vibrations which are then transferred to the active blades for cutting or coagulation. It operates at a frequency of 55.5 kHz and has five power levels. Increasing the power level increases cutting speed and decreases coagulation. In contrast, less power decreases cutting speed and increases coagulation. However, the study had stated the ultrasonic devices reaching temperatures of up to 200°C which can cause lateral thermal damage to adjacent tissue. A new Harmonic ACE+7 is approved by the FDA to seal vessels up to 7-mm diameter.[21,22] General disadvantages of ultrasonic devices include slower coagulation compared with electrosurgery, altering of the frequency or impedance of the surgical system itself due to blade fatigue, temperature elevation, excessive applied pressure, or improper use.[23]

Thunderbeat

Thunderbeat™ (Olympus Medical Systems Corp., Tokyo, Japan) (TB) is the first device to integrate both ultrasonically generated frictional heat energy and advanced bipolar energy in one instrument. The ultrasonic technology rapidly cuts and precisely dissects tissue while the advanced bipolar technology provides reliable vessel sealing. It is multifunctional, as can seal and cut vessels up to 7 mm in size with minimal thermal spread. The generator has level 1 for cutting and sealing while level 3 for sealing mode. The jaw is designed to provide precise, controlled dissection and continuous bipolar support with grasping capability.[8,24]

Comparison of efficiency and efficacy of different electrosurgical devices

Preference for choosing any energy source differs between surgeons. It is difficult for one to have informed decision about relative merits of any energy sources. Efficiency of any energy source depends on seal time, lateral thermal spread, burst pressure, smoke production. There are animal studies comparing Ligasure V, Gyrus PK, an ultrasonic device, and ENSEAL. Newcomb et al showed a trend toward lower burst pressures and higher failure rates as vessel diameter increased for all 5 mm laparoscopic instruments tested. Gyrus PKS™ cutting forceps (PK), Gyrus Plasma Trissector™ (GP), Harmonic Scalpel™ (HS), EnSeal™ (RX), LigaSure V™ with LigaSure™ Vessel Sealing generator (LS), LigaSure V™ with Force Triad™ generator (FT), and Ligamax™ 5 endoscopic multiple clip applier (LM) were tested to compare burst pressure, sealing time, and failure rate. Overall highest burst pressures and lowest failure rates were seen with the RX, LS, and FT. Burst pressures for the RX, LS, and FT were not significantly different from surgical clips for any vessel size tested. However, according to them seal time was significantly faster for FT compared to LS for all vessel sizes ($P < 0.05$) and faster than RX for both 4–5 mm and 6–7 mm vessels ($P < 0.05$), making seal time a differentiating factor between devices with the highest burst pressures and lowest failure rates.[20]

In another animal study to compare TB vs. HS, Enseal and LS. Versatility score (depending on hemostasis, histologic sealing, cutting, dissection, and tissue manipulation) was higher ($P < 0.01$) and dissection time was shorter ($P < 0.01$) using TB compared with the other three devices. Bursting pressure was similar among TB and the other three instruments. Thermal spread was similar between TB and HA ($P = 0.4167$), TB and EnSeal ($P = 0.6817$), and TB and LIG ($P = 0.8254$). Difference in thermal spread was noted between EnSeal and HA ($P = 0.0087$) and HA and LIG ($P = 0.0167$).[25] Thus author concluded, TB has a higher versatility compared with the other instruments tested with faster dissection speed, similar bursting pressure, and acceptable thermal spread.

An ex vivo study comparing LS vs. PK vs. Harmonic ace vs. Enseal in simulator with bovine arteries of 5 mm size found out burst pressure as LS > ES > HS, Smoke production as HS < LS < PK, Sealing time shorter for LS (10 s) < PK (11.1 s) < HS (14.3 s) < Enseal (19.2 s). Lateral thermal spread less with HS (49.9 °C) < PK (64.5 °C) but same for LS (55.5 °C) and Enseal (58.9 °C). LS has the highest burst pressure and fastest sealing time and was the highest rated overall. The HS produced the lowest thermal spread and smoke but had the lowest mean burst pressure. The GP had the highest smoke production, and variable burst pressures.[26] The burst pressure of the TB in the larger-artery category (5–7 mm) was superior to that of the HA. The highest mean burst pressure was measured in the TB group (734 ± 64 mmHg); this was slightly higher than in the LS (615 ± 40 mmHg) group and significantly higher than in the HA group (454 ± 50 mmHg), the dissection speed of the TB was significantly faster than that of the LS and slightly faster than HA. The temperature profile of the HA and the TB was similar with respect to the maximum heat production and the kinetics of cooling down to 60 °C. The maximum temperature during activation and shortly thereafter was around 200 °C in the HA and TB groups. In contrast, the temperature in the LS group during and after activation was constantly below 100 °C.[27]

Safety and efficacy of these newer instrument comparing with conventional bipolar in laparoscopy gynecology surgeries are studied by many authors comparing different factors like total operative time, blood loss, need for blood transfusion, mean hospital stay, postoperative pain, and postoperative complication (Table 2).[28–35] The results states that Thunderbeat, Ligasure, Gyrus PK, Harmonic and Enseal are better than or as reliable as conventional electrocoagulation.

Shortcomings of energy devices

Few limitations or complications related to energy devices are an inevitable reality of laparoscopy, it is important to have a systematic awareness of the types of complications, know how to respond appropriately, and know how to communicate and deal with complications. All laparoscopic energy sources, to a lesser or greater extent cause lateral thermal spread, irrespective of vaporization, fulguration, desiccation, or coaptation effect; a temperature beyond the "cell kill" threshold may occur causing inadvertent tissue damage increasing morbidity and mortality. Smoke or vapor plumes hampering visibility is mostly observed with monopolar, whereas least seen with ultrasonic devices.[36–38] Second most common complication associated with laparoscopy surgery after veress or trocar placement (41.8%) are related to use of electrosurgical devices (25.6%).[39] Possible mechanisms behind injuries are mistaken target application, stay current injury due to defective insulation, direct coupling (when active electrode touches another metal instrument), capacitive coupling, alternative site burns (due to defective dispersive pad).[39] Though rare, injury to ureter, bladder and bowel have been reported with insidious use of energy devices.[40–43] To prevent possible complications it is very important to understand mechanism, biophysics, functions and possible injuries of each instrument.[39]

Table 2
Comparative studies of different electrosurgical device.

Author	Type of study	Device	Sample size (N)	Procedure	Operative time (Min.) (Mean)	Blood loss (mL)	Postoperative pain score	Complication	Hospital stay (days)	Inference
Anna fagoti 2014 et al.[28]	Randomized, controlled trial	TB vs. standard electrosurgery (SES)	N = 71 (excluded 21 due to intraoperative criteria). TB = 25 SES = 25	Laparoscopic radical hysterectomy with bilateral pelvic lymphadenectomy	TB-85 SES-115 (P = 0.001)	TB-50 SES-50 (P = 0.52)	At 24 h TB-1.96 SES-3.35 (P = 0.005)	TB-0 SES-1 (P = 0.31)	TB-3 SES-3 (P = 0.82)	TB associated with short operative time and less postoperative pain
Hakan ayatan et al 2014.[33]	Randomized prospective study	LS vs. Enseal vs. PK	N = 45 LS = 15 PK = 15 Enseal = 15	Total laparoscopic hysterectomy	LS-52.4 Enseal-55.7 PK-51.9 (P = 0.73)	LS-138 Enseal-218 PK-118 (P = 0.004)	–	–	LS-1.1 Enseal-1.4 PK-1.2 (P = 0.22)	No significant difference except more blood loss in Enseal group
Ralf Rothmund et al 2013[29]	Prospective, randomized, controlled trial	Enseal vs. standard bipolar	N = 160, Enseal-80 bipolar – 80	Laparoscopic Supracervical hysterectomy	Enseal-78.18 Bipolar – 86.3 (P = 0.03)	Enseal-50 mL (n = 72) 50–100 mL (n = 8) Bipolar – 50 mL (n = 62) 50–100 mL (18) (P < 0.001)	No significant difference	No significant difference	Enseal-2.01 Bipolar – 2.17 (P = 0.03)	EnSeal device is at least as reliable as the conventional electrocoagulation technique in laparoscopic supracervical hysterectomy (LASH). Total resection time was shorter in the experimental group, and the other investigated clinical parameters were not inferior in the experimental group compared with the control group
Janssen et al. 2011[31]	Randomized controlled trial	LS vs. CB	N = 140 LS-70 CB-70	Laparoscopic hysterectomy	LS-148.1 CB-142.1 (P = 0.46)	LS-234.1 mL CB-273.1 (P = 0.46)	–	–	LS-2.9 CB-2.9 (P = 0.94)	No significant differences in operating time and blood loss
Hsuan su et al.2011[30]	Retrospective study	PK vs. CES	N-194 PK = 97 CES = 97	Laparoscopic myomectomy	PK-117.8 CES-116.6 (P = 0.906)	PK-190.4 CES-234.8 (P = 0.025)	–	–	PK-2.7 CES-2.8 (P = 0.315)	PK has advantage of less blood loss
Demirturk et al (2007)[34]	Retrospective study	HS vs. LS	N = 40 HS-19 LS-21	Total laparoscopic hysterectomy with salpingo-oophorectomy	HS-90.95 LS-59.57 (P < 0.001)	HS-152.63 LS-87.76 (P < 0.001)	–	–	HS-3.42 LS-3.24 (P = 0.436)	LS has advantage of less operative time and less blood loss compared to HS
Lee et al. 2007[32]	Retrospective case–control study	PK vs. CB	N = 76 PK-38 CB-38	Laparoscopic radical hysterectomy with pelvic lymphadenectomy	PK-172 CB-229 (P < 0.001)	PK-397 mL CB-564 mL (P < 0.03)	–	Less for PK (P < 0.01)	PK – 6.9 CB-7.5 (P = 0.1)	PK has advantage of less blood loss, shorter operative time and less post-operative complications
Wang et al. 2005[35]	Prospective, non randomized trial	PK vs. CB	N = 62 PK-31 CB-31	LAVH	PK-87.6 CB-93.4 (P = 0.368)	PK-196.8 CB-253.2 (P = 0.105)	–	–	PK-3.2 CB-3.0 (P = 0.499)	Operation time, blood loss, transfusion rate, length of hospital stay: no significant difference

Conventional bipolar- CB, Conventional Electrosurgery-CES, Harmonic scalpel- HS, Ligasure- LS, Plasma kinetic gyrus-PK, standard electrosurgery- SES, Thunderbeat-TB.

Conclusion

All these new energy devices are an appealing, safe alternative for cutting, coagulation, and tissue dissection during surgery and should decrease time and increase versatility during surgical procedures. Preference depends upon nature of surgical task, surgeons own experience with instrument, availability, and cost. All the available advanced bipolar devices are different although approved to seal vessels of 1–7 mm in diameter. It is every surgeons desire to incorporate multiple functions into one device so as to reduce surgical time and instrument traffic. However, monopolar and conventional bipolar electro-surgery are still used due to wider range of tissue effect, dissection capabilities, cost effectiveness, and ease of availability. In conclusion, there is insufficient evidence for one vessel sealing technology to be considered superior to the other. In future thermal imaging techniques with histological comparisons should be designed to determine the relationship between failure rates, thermal spread, coagulation necrosis, and presence or absence of apposed nucleated cells.

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