INTRODUCTION

The advent of laparoscopy has brought in major changes in surgical practice in the past few decades. One of the major developments is the extensive evolution of electrosurgery, which has become almost synonymous with laparoscopy. This makes it imperative for the surgical team to have a good basic understanding of the principles of electrosurgical technology and tissue effects for optimum patient safety.¹,²

The market is inundated with different energy sources, each product claiming superiority over the other. On one hand, we have the traditional monopolar and bipolar devices, used almost universally; on the other hand we have newer vessel sealing systems. The traditional devices score over the new vessel sealers in terms of availability, re-usability and inexpensive nature. The latter have revolutionized the concept of surgical hemostasis. From the viewpoint of a surgeon, a comprehensive knowledge of different energy sources is mandatory to decide the appropriateness of an instrument for a procedure.

In this article, the principles of electrosurgical techniques have been elaborated. Various laparoscopic energy sources used in gynecology have been reviewed and compared in terms of mechanism of action, efficacy, safety, relative merits and demerits.

DATA COLLECTION

The PubMed, Medline and Cochrane electronic databases were searched for original articles, along with product specifications from the manufacturers. The search was restricted to articles from 2000 to January 2019 and the English language. The databases were searched using the relevant MeSH terms, including all subheadings and this was combined with a

HISTORY

The original usage of heat for purpose of treatment can be traced as far back in human history as Neolithic times. It was popularized by Ancient Egyptians (c. 3000 BC), Hippocrates (469-370 BC) and Albucasis (c. 980) in different forms. Benjamin Franklin and John Wesley described usage of Direct Current (DC) in medical therapeutics. However, it was only in the latter part of nineteenth century that researchers began experimenting with biological effects of Alternating Current (AC) on tissue. P. Bozzini, in 1877, is credited with the concept of electrosurgery when he described the construction of a device for electro-cauterization. The concept gained increasing acclaim in the following decades, with investigators adding additional touches to the available devices. Eventually in 1933, Fervers, a general surgeon used electrosurgery to divide intra-abdominal adhesions during laparoscopy. In 1941, the first laparoscopic female sterilization using monopolar energy was performed. Bipolar devices came into vogue around 1970, described by Frangenheim (Germany), Rioux and Clotier (North America).

UNDERSTANDING THE WAVEFORM

The tissue response is determined by the type of waveform used. A proper knowledge of the waveform will ensure that a surgeon uses electrosurgery in a scientific manner (Fig. 1). There are three main waveforms used in electrosurgery: cutting, coagulation and blend. The electrosurgical generator has ‘cut’, ‘coag’ and ‘blend’ settings.

Cutting Waveform

Cutting waveform is sinusoidal, unmodulated and utilizes high frequency continuous current with minimum voltage (power setting of 50-80 watt). This leads to a sudden rise in temperature (over 100°C) resulting in vaporizing of intracellular fluid, generation of a steam bubble and finally rupture of cell membranes which causes cleavage of tissue with great precision.

Blended Waveform

A blended waveform is a modification done to the cutting waveform for situations wherein hemostasis is needed along with cutting. It consists of a combination of both cutting and coagulation waves. Blend settings can be customized to deliver a combination of cutting and coagulation currents. Table 1 shows type of blend settings used commonly. Higher blend settings imply

### Table 1: Types of Waveform

<table>
<thead>
<tr>
<th>Waveform</th>
<th>Power Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low voltage</td>
<td>50% on, 50% off</td>
</tr>
<tr>
<td>BLEND 1</td>
<td>40% on, 60% off</td>
</tr>
<tr>
<td>BLEND 2</td>
<td>25% on, 75% off</td>
</tr>
<tr>
<td>BLEND 3</td>
<td>12% on, 88% off</td>
</tr>
<tr>
<td>COAG</td>
<td>0% on, 100% off</td>
</tr>
</tbody>
</table>

**Fig. 1: Types of Waveform**

The depth of tissue necrosis with this waveform is minimal due to negligible coagulation effect, thus causing minimal smoke production. However, as the waveform is non-contact, there is considerable loss of energy into air.

Coagulation Waveform

Coagulation waveform is low frequency, high-voltage, modulated current with periods of activation and de-activation. In between the intermittent bursts of current, heat dissipates into tissues, causing alteration of cellular proteins. A temperature of 60°C to 95°C results in protein denaturation, dehydration and finally leads to coagulum formation. The heating effect is wide, with considerable tissue damage as almost all the electrical energy is delivered to the tissue by direct contact. This leads to more smoke production when compared with cutting waveform. A power setting of 30-50 watt is considered ideal for an effective coagulation current.
that time between bursts of current is greater, which leads to greater coagulation.5,6

TISSUE EFFECT OF ENERGY SOURCES
The tissue effects vary depending on the type of current waveform used.
1. **Vaporization**: This effect results from a continuous cutting current waveform, with no tissue contact and generation of moderate degree of smoke.
2. **Fulguration or spray coagulation**: This results from an interrupted, coagulation current waveform, wherein there is no contact with tissue. The electrode is held some distance away from the tissue (3 to 4 mm) and very high voltages of current are used to elevate the temperature beyond 100° C. This results in significant scale charring and hemostasis (small vessels, <1mm) and appears as a spraying effect on the tissue.
3. **Desiccation**: This is a tissue effect which can be produced by both cutting and coagulation waveform. Direct tissue contact with the electrode converts electrical energy into heat within the tissue, resulting in deeper tissue necrosis and greater lateral thermal spread. This technique is utilized when dealing with large tumors or metastasis treatment in order to reach large tissue volumes.
4. **Coaptation** (sealing of small to medium vessels, <2mm): This is an effect of either cutting or coagulation current where there is contact with the electrode and compression of the vessel wall. The lateral spread is significant.

ELECTROSURGICAL TECHNIQUES OF CURRENT DELIVERY
There are many energy sources to choose from, depending on the requirement and surgeon preference. All of them work on the principle of causing tissue destruction and hemostasis. The two main methods of delivering current flow through tissue are either monopolar or bipolar electrosurgical technique.

### Table 1
Types of blend current7

<table>
<thead>
<tr>
<th>Type of Blend</th>
<th>Cutting waveform (%)</th>
<th>Coagulation waveform (%)</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blend 1</td>
<td>80</td>
<td>20</td>
<td>Predominantly cutting</td>
</tr>
<tr>
<td>Blend 2</td>
<td>60</td>
<td>40</td>
<td>Predominantly cutting + Hemostasis</td>
</tr>
<tr>
<td>Blend 3</td>
<td>50</td>
<td>50</td>
<td>Cutting with good hemostasis</td>
</tr>
</tbody>
</table>

MONOPOLAR ELECTROSURGERY
This is the most popular form of electrosurgical technique employed in laparoscopy due to its efficacy, versatility and least lateral spread of electrical current. The main highlight of monopolar energy is an electrical circuit with an active electrode at the surgical site, current flowing through the patient, and the return electrode (cautery plate) located on the patient. The current from the generator passes through the active electrode, spreads through the body tissues and goes out of the patient’s body through the return electrode and returns back to the electrosurgical generator, which completes the circuit.8-11

It is important to realize the importance of this arrangement so that one can understand how the tissue dynamics work and why there is no thermal injury. The active electrode has a small surface area which causes a high current density produced at its tip and the resultant tissue effect. This density of electrons diminishes with an increase in distance from the electrode. Where body tissue resists, the current abandons that path and flows down the path of least resistance. A return electrode provides that path of least resistance to the current. It is recommended that the dispersion pad be attached as close to the surgical field as possible in order to reduce the length of the circuit. As the dispersion pad has a large surface area, the current density at the attachment site is low, minimizing the risk of skin burns. As surgical scars, metal implants, hairs etc, increase the risk of burns, the dispersion pad should be carefully placed in a wellperfused, dry and hairless area of skin. Latest electrogenerators have sensors to measure pad-to-skin contact and current density. In case of any contact failure, they interrupt the circuit thus preventing the flow of current and hence any thermal injuries to the patient.
Disadvantages of Monopolar Electrosurgery
The most dreaded complication with monopolar electrosurgical techniques is arcing of the current resulting in undiagnosed severe injuries. They can also result in extensive diathermy burns if the return electrode is not properly applied. Monopolar electrosurgical techniques can interfere with pacemaker function and care should be taken to avoid them in such patients.

BIPOLAR ELECTROSURGERY
In Bipolar electrosurgical devices, the active and return electrode are formed by the two jaws of the energy source. The concept was initially introduced in 1974 and the initial usage of bipolar devices was confined to the coagulation or sealing of small blood vessels with a maximum diameter of 2-3 mm. The main advantage of bipolar over monopolar electrosurgery is the ability to seal vessels up to 5 mm in diameter vis-a-vis monopolar which is generally suited for vessels 1-2 mm. The dissection capability of bipolar forceps is also good.

Disadvantages of Bipolar Electrosurgery
Bipolar devices use only coagulation current, which is responsible for their major drawback of lateral thermal spread. This can result in inadvertent electrical burns. Other technical drawbacks include tissue adherence to instrument jaws and requirement of another instrument for tissue cutting, which is cumbersome and increases operating time. Current leakage, damage to another tissue which comes into contact with heated tissue, and interference with pacemaker function are other common drawbacks.

ADVANCED BIPOLAR DEVICES
In the past couple of decades, with the introduction of newer bipolar instruments, the entire concept of electrosurgery has undergone a profound change. These devices allow high current delivery to target tissue, which causes denaturing of collagen and elastin in vessel wall. This injury to parietal collagen seals the vessels. Newer Bipolar devices combine the principle of thermo-fusion, with application of optimal mechanical pressure to ensure that the denatured protein forms a coagulum and a strong seal is achieved. Large vessels, up to a diameter of 7 mm, and large tissue bundles can now be surgically sealed.

Advanced electrogenerators are available which sense tissue impedance and automatically control current flow by adjusting voltage and current continuously. Once the intended sealing level has been reached, an audio signal alerts the surgeon that the result has been achieved. This guards against prolonged device activation, decreases tissue charring and adherence to the instrument. It also reduces lateral spread of current, which makes these devices extremely safe to use especially in pelvic dissection.

1. **Enseal (Ethicon Endo-surgery, US, LLC):** It combines a high compression jaw with a tissue dynamic energy delivery system that results in tissue sealing and hemostasis. It has a blade that can seal vessels and lymphatics up to a diameter of 7 mm, and simultaneously cuts the sealed tissue.12

2. **LigaSure Vessel Sealing Technology (Medtronic) (Fig. 2):** It has the ability to sense when the sealing effect is achieved and automatically cuts off energy supply. It can efficiently seal blood vessels and undissected tissue bundles up to a diameter of 7 mm. The device provides a combination of pressure and energy to denature proteins, forming a true, permanent, seal rather than just creating a proximal thrombus (as happens in traditional bipolar electrocautery). Its lateral thermal spread is purported to be 2 mm.13-15

DEVELOPMENT OF ULTRASONIC DEVICES
Although traditional electrosurgical instruments revolutionized laparoscopic surgery, they did have inherent disadvantages such as generation of considerable smoke plume, which absorbs light and results in obscuration of vision. To counteract this, high flow suction is required during surgery, which lead to rapid loss of pneumoperitoneum, and further restricts the field of vision.

In order to overcome shortcomings of traditional devices, investigators continued to look for alternative options. It was in 1993, that Amaral introduced the first ultrasonic energy source and dubbed it ‘laparoscopic scalpel’ owing to its double functions of tissue cutting and vessel sealing. Ultrasonic energy sources work on the principle of conversion of electrical energy into vibrations in hand piece of device. These vibrations are above the audible range, with a frequency of more than 20,000 cycles per second.
This results in oscillation of the non-articulating jaws of the instrument, which impart tissue effects of heat and cutting. The tissue, which is compressed between an articulating and a non-articulating jaw, undergoes desiccation and vessel sealing at lower frequencies and tissue cutting at higher frequencies. Tissue effects are essentially the same as achieved with contact monopolar or bipolar electrosurgery with the additional function of tissue cutting. However, ultrasonic energy sources achieve these effects without passage of electrical current through the patient or through the grasped tissue.

Table 2 compares Ultrasonic devices with Newer Bipolar devices. The Ultrasonic instruments are a technological advancement and combine many of the best qualities of monopolar and bipolar instruments with enhanced safety. They offer the advantage of precise control of cutting and hemostasis without producing smoke or charring. The disadvantages are expenditure involved and limited lifespan of the ultrasound tip, which requires these instruments to be disposable.

Table 2
Comparison of LigaSure and Harmonic Scalpel Shears

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Type of Device</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Harmonic Scalpel Shears</td>
</tr>
<tr>
<td>Instrument traffic</td>
<td>Lesser</td>
</tr>
<tr>
<td>Smoke generation</td>
<td>Lesser</td>
</tr>
<tr>
<td></td>
<td>‘a mist of tissue debris and moisture’ results</td>
</tr>
<tr>
<td>Dissection</td>
<td>Good, but less than monopolar scissors or Maryland bipolar forceps</td>
</tr>
<tr>
<td>Lateral thermal spread injuries</td>
<td>Lesser</td>
</tr>
<tr>
<td>Cost</td>
<td>Expensive</td>
</tr>
</tbody>
</table>

THUNDERBEAT (OLYMPUS MEDICAL SYSTEMS CORP., TOKYO, JAPAN)

It was the first device to integrate both advanced bipolar energy and ultrasonically generated frictional heat energy in one instrument. There are two modes in the generator, level 1 (ultrasonic technology) for precise dissection and cutting and level 3 (bipolar technology) for vessel sealing. It can seal vessels up to 7mm in size. When Thunderbeat was introduced, it was claimed to have the highest median burst pressure and the least lateral thermal spread.16,17

HARMONIC [ETHICON, JOHNSON & JOHNSON, US, L.L.C.]

The Harmonic Scalpel Shears was introduced in 1998 (Fig. 3).18 It is a hemostatic scalpel, which works at temperatures of 50 to 100°C to tamponade blood vessels and seal it with a protein coagulum. The original shears could coagulate vessels up to a diameter of 5 mm. It can also be used for fine dissection (termed Ultrasicon) and cutting of tissue simultaneously. This allows quicker surgery because the instrument need not be changed. Harmonic Shears have minimal lateral spread of current which allow the instrument to be used in areas where lateral spread can be critically damaging to tissues. (e.g. in the vicinity of ureter).19

The latest offering by Ethicon, that is hailed as a major advancement in Ultrasonic devices is Harmonic ACE+7 Shears. The makers claim that the median burst pressures in Advanced Hemostasis mode are much higher than other devices, including Thunderbeat, enabling the device to coagulate vessels up to 7 mm in diameter (FDA Approved). The refinement in blade designs has enhanced surgical precision and device...
Table 3
Newer devices and their features

<table>
<thead>
<tr>
<th>Device Name</th>
<th>Type</th>
<th>Manufacturer</th>
<th>Technological Advancement</th>
<th>Drawback</th>
</tr>
</thead>
<tbody>
<tr>
<td>LigaSure</td>
<td>Bipolar</td>
<td>Covidien</td>
<td>Advanced tissue monitoring of 4000 times per second. Jaw designed to optimize mechanical compression of vascular pedicle. A cutting blade is incorporated into the device jaws.</td>
<td>Bulky jaws are inferior dissectors as compared to Maryland forceps. Expensive</td>
</tr>
<tr>
<td>Enseal</td>
<td>Bipolar</td>
<td>Ethicon</td>
<td>Optimises temperature in the tissue held between jaws (around 100°C). Jaw designed to optimize mechanical compression of vascular pedicle. A cutting blade is incorporated into the device jaws.</td>
<td>Bulky jaws are inferior dissectors as compared to Maryland forceps. Expensive</td>
</tr>
<tr>
<td>PKS Lyons Dissecting Forceps</td>
<td>Bipolar</td>
<td>Olympus</td>
<td>Delivers pulsed energy with continuous feedback control to prevent tissue overheating. Good dissection capability</td>
<td>Despite better dissection as compared to other devices, it still requires an additional laparoscopic scissor for tissue cutting. Expensive</td>
</tr>
<tr>
<td>Harmonic</td>
<td>Ultrasonic</td>
<td>Johnson &amp; Johnson</td>
<td>HARMONIC ACE+7 Shears can coagulate vessels upto 7mm.</td>
<td>Expensive</td>
</tr>
<tr>
<td>Sonicision</td>
<td>Ultrasonic</td>
<td>Medtronic (Covidien)</td>
<td>Cordless Ultrasonic Dissection System. Short pistol grip device. Fast active blade cool down time to 60°C.</td>
<td>Expensive</td>
</tr>
<tr>
<td>Thunderbeat</td>
<td>Ultrasonic+Bipolar</td>
<td>Olympus</td>
<td>7mm vessel sealing. Improved tissue dissection</td>
<td>Expensive</td>
</tr>
</tbody>
</table>

performance with minimal lateral thermal spread of 1 mm.\textsuperscript{12,20}

**COMPICATIONS OF ELECTROSURGERY**

Electrosurgical complications are responsible for one fourth (25.6%) of the complications associated with laparoscopy.\textsuperscript{22} There are multiple mechanisms by which electrothermal injuries can be caused; important among them are defective insulation, direct or capacitative coupling, alternative site burns and mistaken target application. Smoke generation, hampering visibility is an important drawback of energy devices and can contribute to surgical mistakes.\textsuperscript{23}

One of the important hazards with laparoscopy energy sources, irrespective of the device or current used, is lateral thermal spread. This can lead to inadvertent tissue damage and increase surgical risks. The maximum lateral spread is seen with traditional bipolar devices followed by monopolar devices. The newer bipolar devices and Ultrasonic devices have minimal spread of current.
INSULATION FAILURE
Insulation failure is considered to be the most important cause of electrothermal injuries. In a usual case, presence of minute breaks or holes in the insulation coating provides an alternate pathway for current flow. As current follows the path of least resistance, it arcs over the electrode to complete the circuit and in this process damages an adjacent tissue. More often than not, this tissue is outside the surgeon's field of vision leading to the damage remaining undetected. The most common site of insulation failure is distal third of laparoscopic instruments. Reusable instruments become prone to insulation failure after prolonged usage, especially due to repetitive passage through trocars and sterilization. Uncommonly, coagulation waveform may contribute to insulation failure in an instrument with intact insulation prior to the procedure. The coagulation waveform primarily acts to fulgurate tissue, which literally implies 'pushing' electrons through the high impedance of air. To accomplish this, it operates at a high voltage, sometimes in excess of 10,000volts. This voltage is the 'force' that drives electrons through the electrical circuit and can occasionally result in 'break' or 'blow holes' in the insulation. If this point is touching any tissue, it may result in significant burns.

It is therefore, important to be cognizant of potential causes of insulation failure. The devices should be checked for insulation integrity. Use of disposable instruments can be considered as they have a lower incidence of insulation failure. Cutting waveform is inherently safer than coagulation waveform due to lower voltages and should be used preferably. An important precaution for surgeons is to refrain from activating the generator till the electrode is in proximity to, or touching the target tissue. This will reduce the incidence of 'blowing holes' in insulation, and if holes still occur, it will reduce the chances of current finding alternative paths.

DIRECT COUPLING
Accidental activation of the active electrode while in close proximity to another metal instrument can cause current to flow from the active electrode, through the adjacent metal instrument. This phenomenon is termed Direct Coupling and can lead to unintentional damage to tissues in direct contact with the secondary instrument.

To prevent this injury, the electrosurgical unit should not be activated till the electrode is in clear vision and in direct contact with the target tissue.

CAPACITATIVE COUPLING
This term is used for the phenomenon where electrical current is established in the metal instrument running parallel to the active electrode, and not in direct contact with it. There is transfer of current from one conductor (active electrode), through intact insulation, into adjacent tissue without any actual contact with the tissue, finally leading to trauma. The use of metal trocars can reduce this risk by allowing stored energy from a capacitor to dissipate over the large surface area of the patient's skin.

CONCLUSION
Electrosurgical technology is constantly being updated and newer devices being launched. However, for best utilization of the technology, the surgeon needs to master the basics of electrosurgery. We have a range of advanced energy devices at our disposal to assist in maintaining high standards of patient care. They decrease surgical time and increase range and versatility of surgical procedures. Having said that, it is the surgeon's comfort, nature of task, device availability and cost effectiveness that will ultimately determine which energy device is used. Traditional devices will nevertheless, continue to be used due to dissection capabilities, availability and best resource utilization.

Source of Support
Nil
Conflict of Interest

There are no conflict of interest.

REFERENCES