Safe use of electrosurgery in gynaecological laparoscopic surgery

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Key content

- It is crucial to understand the basics of electrosurgery to deliver safe and effective laparoscopic surgery.
- Electrosurgical tissue effects include vaporisation, desiccation and coagulation, which help to achieve cutting, dissection, ablation and haemostasis during surgery.
- Electrosurgery is delivered through monopolar and bipolar instruments.
- Surgeons can avoid complications of electrosurgery by understanding the mechanisms underlying them.
- Establishment of a formal training programme in surgical energy is needed for surgeons and theatre staff to provide safe laparoscopic surgery.

Learning objectives

- To understand the applied physics of electrosurgery.
- To describe the various electrosurgical tissue effects and the variables controlling them.
- To identify the differences between monopolar and bipolar instruments.
- To know the mechanisms of various electrosurgical complications and safety measures to avoid them.

Ethical issues

- Is it ethical to use energy devices in laparoscopic surgery with little or no formal training about their appropriate use and safety?
- Do surgeons need to know about all energy devices they use in operating theatres?
- Should all allied healthcare professionals working in operating theatres undergo formal training on the use of electrosurgery?

Keywords: complications / electrosurgery / laparoscopic surgery / physics / safety

Introduction

Over the years, electrosurgery has gained popularity as the most widely used form of energy in both open and laparoscopic surgery. This is mainly due to its lower cost, widespread availability, and versatile applications[1]. Advanced technology has led to the design of more sophisticated electrosurgical devices with the development of more complex laparoscopic procedures.

Although electrosurgery has improved the efficiency of laparoscopic surgery, it can potentially cause devastating life-threatening complications. These complications can be attributed to the surgeon's technique and/or inherent flaws in the design of the electrosurgical devices used[2]. Evidence showed that many surgeons have knowledge gaps in the basic principles of electrosurgery, which can compromise patient safety. In response to that, the profession is calling for formal training programmes in the safe use of surgical energy for all involved staff[3]. The industry on the other hand, is addressing the design flaws in electrosurgery to provide safer devices[2].

History

Cautery (direct heating of tissues) has been practiced as a therapeutic tool for thousands of years. In the Edwin Smith Papyrus, the oldest surgical text, Ancient Egyptians documented its use to treat ulcers and tumours of the breast as far back as 3000 BC. Hippocrates (469 –370 BC.) was a strong advocate of cautery. Later, Albucasis, the father of surgery in the middle ages, used heated instruments to treat diseases and to stop bleeding in the tenth century[4]. In the early 19th century, Becquerel was the first to use electricity in the form of direct electric current to heat a wire that was used in electrocautery. In 1881, Morton discovered a safe alternating current with high frequency (> 100 KHz) that passed through the human body without neuro-muscular stimulation or electric shock. A decade later, d'Arsonval reported that the above current caused a heating effect in the tissue as well. Rivere was the first to use electrosurgery in treating a hand ulcer in 1900. Later, Bovie developed his generator that was used successfully by Cushing to excise a vascular myeloma in 1926. They published their work with a detailed description of the various electrosurgical tissue effects of cutting, desiccation, and coagulation. This paved the way for the modern applications of electrosurgery[1].

Applied physics

Electrosurgery is the application of high-frequency alternating current in surgery to achieve the various thermal tissue effects of cutting, desiccation, and coagulation. It is different from electrocautery, which is the passive transfer of heat to the tissue with no current passing through it.

Figure 1 shows the two types of electric current: direct current (DC) that moves in one direction (unidirectional) and alternating current (AC) that reverses direction periodically (bidirectional). Electrocautery uses direct current whereas electrosurgery uses alternating current to avoid electrolysis and with high frequency to avoid the Faradic effect of nerve and muscle stimulation. This effect ceases at frequencies above 100 KHz. Because the frequencies commonly used in electrosurgery are greater than 500 KHz, which are similar to radiofrequency, the term radio frequency (RF) electrosurgery is used. The electrosurgical circuit includes a generator, two electrodes and the patient (Figure 2). All electrosurgery is bipolar as it has two electrodes[4].

Electrosurgery can be delivered through monopolar or bipolar instruments. The main difference between them is where the two electrodes are placed. The monopolar instrument has the active electrode whereas the dispersive electrode is placed on the patient away from active electrode. On the other hand, the bipolar instrument has the two electrodes at its tip with no need for a dispersive electrode (Figure 2).

Electrosurgery follows the physical rules of electricity. Table 1 defines the basic electrical terms with their relevant formulae.

The generator or electrosurgical unit (ESU) has three main functions:

1) Conversion of the low electrical frequency of the mains (50-60 Hz) to higher frequencies (500 KHz – 3 MHz).
2) Adjustment of the wattage and indirectly the voltage.
3) Control of the duty cycle.

With advanced technology, the newer smart generators have other functions in addition to the above.

Mechanism of electrosurgery

On flowing through tissues, radiofrequency current leads to intracellular conversion of electromagnetic energy to mechanical to thermal energy. The resultant heat will cause the various tissue effects of electrosurgery. Table 2 shows the effect of temperature on cells and tissues. When the intracellular temperature rises rapidly to more than 100 ^{o}C, cellular vaporisation with explosion occurs and leads to a cutting effect. On the other hand, a gradual rise of temperature between 60 - 95^{o} C leads to simultaneous tissue desiccation and coagulation. Fulguration is non-contact sparking with the coagulation output to produce a superficial layer of black coagulation over a wide oozing surface. In contrast to cutting, fulguration uses high voltage with a low duty cycle of 6 %. When electrical arcs hit the tissue they produce high temperature and carbonisation then the temperature returns toward normal during the long off period of the duty cycle. This results in a thin layer of black coagulation that insulates deeper tissue and reduces lateral thermal spread. The high voltage of fulguration helps overcome the impedance of the intervening air between the active electrode and the tissue. This would increase the risk of stray current burns in laparoscopic surgery[5].

Monopolar electrosurgical instruments

They are the most commonly used energy devices. Table 3 summarises the versatile functions of such devices.

The *ART* of monopolar instrumentation

Electrosurgery works by concentrating the current (increasing its density) at the active electrode to produce the desired thermal tissue effect and dispersing it at the dispersive electrode to prevent unintended tissue burns. The thermal tissue effect is directly proportional to current density squared, tissue impedance (R) and application time (T) i.e. thermal effect = $(I/A)^2 \times R \times T$ where A refers to the electrode surface area. To increase the thermal effect, it is important to avoid the temptation of stepping up the ESU wattage to increase the current, which would increase the risk of unintended tissue burns. Reducing the radius of the active electrode by half can result in a 16-fold increase in thermal change without changing the power setting. Modifying the surgical technique to increase tissue impedance by removing conductive fluid like blood, compressing arteries or stretching tissue, also increases the thermal effect without increasing the power setting[6].

Factors modifying electrosurgical tissue effects

Waveform

Electrosurgical generators produce different electrical waveforms with distinct tissue effects (Figure 3). A continuous sinusoidal waveform with a high current and low voltage causes a rapid rise in tissue temperature to more than 100 ^{o}C, which vaporises or cuts tissue with minimal coagulation. On the other hand, an interrupted waveform with a low current and high voltage causes a slow rise of temperature less than 100 °C, which desiccates and coagulates tissue. These two waveforms are inaccurately known as "cut" (yellow coded) and "coagulation" (blue coded) modes respectively. Blend waveform is a modulated cut waveform with a variable duty cycle, current, and voltage (Table 1). The blend mode can vary the duty cycle and the rate of temperature rise to produce variable degrees of cutting and coagulation (haemostasis). The factor that makes a waveform cut or coagulate is the rate of heat produced in the tissue. Rapidly increasing temperature (>100 °C) produces a cutting effect whereas slowly increasing temperature (<100 °C) produces coagulation and desiccation effects. Any of the above waveforms can produce both effects (cutting and coagulation) by modifying other factors that impact tissue effect; hence the "cut" and "coagulation" modes are misnomers. They are better referred to as continuous low-voltage and interrupted high-voltage respectively, with the blend waveform referred to as interrupted low-voltage[7].

Power output
It is displayed in Watts. Generally, surgeons should use the lowest effective power setting to achieve the desired effects as higher wattage is associated with increased risk of unintended tissue burns. A power setting between 50 – 80 W is recommended for effective cut mode whereas a setting between 30 – 50 W is recommended for effective coagulation mode[8]. The patient's condition can dictate the appropriate power setting, as muscular patients will require lower settings compared to obese or emaciated patients.

Electrode surface area
The smaller the electrode, the higher is the current concentration. Reducing the contact area of the active electrode by a factor of 10 would increase the current density by a factor of 100 without changing the power setting[9]. Surgeons should exploit this variable to achieve the desired tissue effects without increasing the power setting[6].

Activation time
Long activation time increases the extent of tissue damage whereas too short a time may result in inadequate tissue effect[8].

Tissue contact
With cutting and fulguration, the current sparks from the active electrode to the tissue with no contact. On the other hand, coagulation and desiccation occur when the active electrode contacts the tissue. Coaptive coagulation can occur with both monopolar and bipolar forceps where tissue is compressed between the jaws of the instrument thus coapting the blood vessel to prevent the sink effect (losing heat to flowing blood) and to achieve haemostatic sealing. In monopolar coaptive coagulation, it is recommended to use the "cut" rather than the "coagulation" waveform, as it results in a complete homogenous seal with reduced electrosurgical risks due to the associated low voltage[4].

Tissue impedance
Tissues vary widely in their impedance. Thermal change increases with increased tissue impedance. Tissues with high water content such as muscles and skin pose less impedance to current flow. On the other hand, scarred tissue, skin, and fat pose very high impedance[6].

Eschar
It has a high impedance to current therefore cleaning the active electrode of eschar would reduce impedance and enhance the electrosurgical effect. Using a moist electrode to cut a wet tissue will facilitate the production of the steam envelope necessary for effective cutting[4].

Conventional bipolar devices
These instruments were introduced to overcome the limitations and complications of their monopolar counterparts (Table 4). They are designed with the two electrodes situated at the tip of the instrument. The current flows through the grasped tissue between the two electrodes with less used voltage and energy and without a dispersive electrode. So, they are generally safer than monopolar instruments. They use continuous low-voltage waveform. Bipolar instruments achieve their haemostatic vessel-sealing effect through mechanical compression and the electrosurgical effects of desiccation and coagulation of the grasped tissue in between the two electrodes. Mechanical compression obstructs the vessel, helps develop a proximal thrombus and eliminates the heat sink where heat is carried away by the flow of blood. Figure 2 shows the circuit of a bipolar instrument.

Mushroom (outside loop) effect
As the grasped tissue desiccates and coagulates, its impedance increases forcing the current to take a path of least impedance outside the jaws of the bipolar instrument. This can result in collateral thermal injury to close vital structures (Figure 4).

Electrical bypass effect
Over-compression of the tissue between the jaws of the bipolar instrument may make them touch and lead to electrical bypass and deficient tissue coagulation (Figure 4).

In spite of their technical advantages, conventional bipolar devices may not always produce adequate haemostasis and may require repeated applications with an increased risk of lateral thermal spread. Surgeons rely on subjective visual clues such as the change of tissue colour and vapour bubbles to judge the adequacy of tissue effects[10].

Advanced bipolar devices
The limitations of conventional bipolar devices coupled with the increased uptake of complex laparoscopic surgery have led to the development of advanced bipolar devices to seal vessels up to 7 mm in diameter through optimal energy delivery and mechanical compression. Their smart generators use tissue impedance feedback to continually adjust the delivered voltage and current to achieve the optimal tissue effects with minimal lateral thermal spread, charring, and plumes. They have an audio signal to alert the surgeon when the desired effect is achieved. They use about one-tenth the voltage of conventional bipolar devices and deliver current in a pulsed manner to allow tissue cooling during the off period[5].

The detailed accounts of the individual advanced bipolar devices are beyond the scope of this review. There are limited comparative studies of such devices[11-14]. Jaiswal and Huang[15] summarised several comparative studies of different bipolar devices in terms of operative time, blood loss, postoperative pain, complications, and hospital stay. Other studies looked at the cost-effectiveness of such devices[16,17].

Complications
The incidence of laparoscopic electrosurgical injuries is 2-5 per thousand procedures[9,18]. About 40,000 patients have electrosurgical burns each year[19]. Nearly 70% of such injuries are not recognised during surgery. The delayed diagnosis of these complications is associated with increased morbidity and mortality. Medico-legally, significant financial compensations are paid in claims related to such injuries[19]. Most of these claims were due to bowel and ureter injuries[20]. Consequently, guidelines for safe use of electrosurgery were developed to address this serious safety issue[21.22]. Table 5 shows the common patterns of such complications.

Direct application
This injury results from lateral thermal spread to unintended tissue near the tip of the electrosurgical instrument during activation. It is the most common electrosurgical injury with potential thermal burn to the bowel, ureter or blood vessels[23]. The extent of lateral thermal spread depends on the energy device used, power setting, tissue impedance and the activation time (Table 6). Monopolar devices can result in high temperature and the greatest degree of lateral thermal spread compared to bipolar and ultrasonic ones[24]. To reduce such injury, avoid close proximity of electrosurgical devices to vital tissues such as bowel, ureter and blood vessels. Shorter activation time is recommended to reduce lateral thermal spread. To secure haemostasis near such structures, use sutures, clips or staples rather than electrosurgical devices.

The pedicle effect is another mechanism of electrosurgical burn. It may occur when a monopolar instrument is applied to a structure with a narrow vascular pedicle or adhesion. An unintended burn occurs at the remote narrow pedicle or adhesion where the current density is higher.

Inadvertent activation
This can lead to unintentional patient burn.
Prevention strategy:

- Avoid accidental stepping on the foot pedal
- When the active electrode is not in use:
  - Remove it from the body
  - Place it in a dry rigid plastic holder (not plastic sleeves) with no other instruments
- Use audible activation tone to be heard by the team

Residual heat
Energy devices can maintain the heat at their tips after deactivation for a variable time. Govekar et al. found that ultrasonic energy instruments have higher residual heat than electrosurgical instruments[25]. Surgeons should avoid touching vital structures with the tip of an electrosurgical device immediately after deactivation. If you inadvertently touched the bowel with a hot device, examine it for blanching and consider suturing it to avoid delayed perforation.

Insulation failure
It is a breakdown of the insulation layer around the active electrode. Its incidence is about 20% in reusable laparoscopic instruments and 3% in the disposable with the distal third of the instrument being the most commonly affected site[26]. Robotic instruments are more affected than their laparoscopic counterpat[27]. Repeated cleaning and sterilisation, normal wear and tear as well as the use of high-voltage output are possible causes of insulation failure. Although it is recommended to inspect the instrument before use, the majority of such defects are not visible to the naked eye[28]. The smaller the hole in insulation the higher the stray current density with an increased risk of catastrophic tissue burns. One hundred percent of the energy can be delivered to unintended tissue[2]. The use of electrical scans can detect insulation defects already present before surgery but not the ones that might happen during the surgery. As it is difficult to visualise very tiny holes with the naked eye, an active electrode with an indicator shaft was designed with two layers of insulation (black outer and yellow inner). The shaft is replaced once the yellow layer is exposed indicating insulation defect. Active electrode monitoring (AEM) technology prevents stray current burns from insulation failure and capacitive coupling.

Antenna coupling
This phenomenon happens when the active electrode cord (transmitting antenna) emits electromagnetic energy in the air, which is captured by a nearby inactive cord or wire (receiving antenna). It can be regarded as a type of capacitive coupling. It could result in unintended tissue burns. The receiving antenna can be the camera cord or wires of monitoring devices such as Electrocardiography (ECG)[29] and neuromonitoring[30]. Robinson et al.[31] found that separating laparoscopy tower from ESU, avoiding parallel arrangement of cords and lowering power setting reduced antenna coupling (Figure 5). In contrast to all other complications that happen in the surgical field, this complication is initiated with the cords and wires bundled off the surgical field.

Direct coupling
This injury occurs when the active electrode touches another metal instrument such as suction irrigator and camera telescope. Current from the active electrode flows to the second instrument and potentially burns any tissue touching it. Direct coupling is technique related hence it is the responsibility of the surgeon to prevent it. To reduce this risk, do not activate energy unless the instrument is out of the metal trocar and its tip is in view. Place ports so as to avoid shafts of instruments touching bowels. Keep the active electrode and other metal instruments in a panoramic view to reduce this injury. Also, the surgeon should be the only person to activate the energy. In the event that an arc to an adjacent instrument is seen, the surgeon should examine the length of that instrument looking for any contact with vital tissue. If there is evidence of a burn in that tissue, corrective measures such as suturing should be taken, and the patient informed under the duty of candour.

Capacitive coupling
This is the transfer of electric current from the active electrode through intact insulation into adjacent conductive materials without direct contact (Figure 6). The design of laparoscopic monopolar instruments creates a large capacitor, which causes capacitive coupling. Unlike insulation failure, capacitive coupling may transfer a percentage of the energy to unintended tissue or adjacent instrument. This depends on the capacitor size, the activation mode, and voltage output[2,32]. Some examples of situations where capacitive coupling can pose a risk to the patient:

1. When you pass the active electrode down:
    a. A metal suction irrigator
    b. An operative laparoscope
    c. A metal cannula with a plastic gripper (hybrid cannula)
2. When the insulated active electrode touches non-targeted tissue as bowel or adhesion.
3. When the active electrode induces a current in a nearby cold instrument.
4. In single-port laparoscopy where current is induced into adjacent tissue and instruments.

Surgeons can reduce capacitive coupling injuries by avoiding hybrid cannulas; lowering the ESU power setting; using the cut rather than coagulation mode; using short interrupted activation; avoiding open activation and not operating close to metals in the operative field[33,34]. The industry, on the other hand, has developed adaptive electrosurgical technology within most ESUs, which allows tissue impedance to be measured during activation to modify the output voltage accordingly and produce consistent tissue effect. This technology reduces capacitive coupling but has no effect on insulation failure. On the other hand, AEM technology eliminates injuries caused by both insulation failure and capacitive coupling[2].

Technological development and safe electrosurgery

During the early use of electrosurgery in open surgery, unintended alternate site burns (ground point burns and dispersive electrode burns) were the most common complications of electrosurgery. The introduction of isolated ESUs in the 1970s and contact quality monitoring (CQM) of the dispersive electrode in the 1980s has addressed the electrosurgical design flaws responsible for such burns and has significantly minimised them[2].

Active electrode monitoring

The use of electrosurgery in operative laparoscopy has introduced a different type of alternate site burns (insulation failure and capacitive coupling). In contrast to the early alternate site burns in open surgery, the laparoscopic counterparts are internal, usually unrecognised at the time of surgery and potentially fatal[35].

This technological innovation was introduced in the 1990s to address the design flaws of monopolar instrumentation regarding insulation failure and capacitive coupling. The conventional monopolar device has its active electrode covered by an outer insulation layer along its shaft. However, AEM instrument has two extra coaxial layers; a conductive (protective) shield and a second outer insulation layer (Figure 7). These two extra layers do not affect the dimension of AEM instruments as they can fit the standard 5 mm cannulas. A circuit is then established between the conductive shield, the AEM monitor and the ESU (Figure 7). The AEM monitor can be fitted to most ESUs. This AEM system continuously monitors the conductive shield for stray currents due to insulation failure and capacitive coupling[36]. This protective shield is considered a second dispersive electrode, which returns stray currents safely to AEM monitor then back to the ESU. If the AEM monitor detects a dangerous level of stray energy (about 2 Watts), it deactivates the ESU to prevent any tissue burns. AEM is surgeon independent and is the most effective method to deal with stray currents of insulation failure and capacitive coupling[2]. The three technological innovations of isolated ESUs, CQM, and AEM systems have significantly reduced most electrosurgical burns. Formal training of surgeons and relevant staff in safe electrosurgery should complement these technologies.

Electrosurgery in single-port laparoscopy (SPL)

The recent resurgence of single-port laparoscopy where 3 or 4 instruments are passed through one port has heightened the potential risks of monopolar instrumentation (insulation failure, direct coupling, and capacitive coupling)[37]. This can be attributed to the increased length of zone 2 (Figure 8) where the instrument is not within laparoscopic view or inside the cannula and possibly touching vital tissues. In addition, the proximity and crossing of instruments (sword fighting) increases the possibility of the above risks in single-port compared to multi-port laparoscopy. To reduce such stray current injury in SPL[2]:

- Use alternative devices such as bipolar or ultrasonic.
- With monopolar instruments:
    - Use those with AEM technology.
    - Contact ESU manufacturer for the appropriate setting.
    - Use metal cannula to disperse capacitive charge into the abdominal wall.
    - Use 3 mm device to reduce capacitive coupling.

Electrosurgery and electromagnetic interference

Electrosurgery can interfere with cardiac implantable electronic devices (CIED) such as permanent pacemakers (PPM) and implantable cardioverter defibrillator (ICD) as well as other neurologic stimulators. This can damage or inhibit the CIED device, burn the myocardium or cause arrhythmias and asystole[38,39].

Prevention strategy[40,41]

- Liaise with cardiologist preoperatively.
- Use bipolar or ultrasonic devices in patients highly dependent on CIED.
- When using monopolar:
    - Place dispersive electrode as far as possible from CIED.
    - Avoid capacitively coupled return electrode.
    - Use lower power, cut mode to coagulate and short activation.
    - Avoid current vector crossing CIED.
    - Monitor PPM with ECG during surgery and reprogram after surgery if needed.
    - Deactivate ICD just before surgery then activate after surgery. A magnet can be used for deactivation if a cardiologist is unavailable
    - Perform ALS in case of cardiac arrest.

Electrosurgical smoke

It reduces laparoscopic visualisation, which may compromise patient safety. It contains toxic gasses, potentially carcinogenic chemicals, and viruses[42]. Excessive smoke can cause irritation of the eye and upper respiratory tract of theatre staff but there are no reported cases of cancer. Smoke evacuation systems should be used to reduce the above risks. Surgical masks are ineffective as they filter particles down to 5 μm whereas 77% of smoke particles are ≤ 1.1 μm[43].

Training programme

Effective and safe use of electrosurgical devices requires a sound understanding of how electrosurgery produces the various desired tissue effects, and how complications occur. In spite of the common use of electrosurgery for the last century, transatlantic evidence shows many surgeons of different specialities and grades poorly understand electrosurgery[3,44-46]. This knowledge gap may negatively affect patient outcomes and safety. As a response to this safety concern, the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) took the lead and developed the FUSE (Fundamental Use of Surgical Energy) programme. It is the first validated educational programme that includes an online didactic curriculum (free at www.fuseprogram.org), a standard textbook (The SAGES Manual on the Fundamental Use of Surgical Energy) and a computer-based test[47]. This programme is knowledge-based with no hands-on training or assessment. Madani et al.[48] found that the addition of a hands-on component to the FUSE curriculum further improved the learning of surgical energy. As we do not have such a programme in the UK, there is a pressing need to develop a similar programme with both theoretical and practical components to bridge the identified patient safety gap.

Conclusion

Unlike most medical devices, such as those powered by laser, most surgeons use electrosurgical devices without formal training and competency assessments, which can result in the misuse of such devices with potential serious complications. With the increasing number of new energy devices, surgeons should understand the basic biophysics and the limitations of such devices to deliver safe and efficient patient care. Table 7 outlines the main good practice points in the use of electrosurgery.

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Table 1. Electrical terms and their relevant formulae

Electrical term	**Definition/formula**	**Unit**
Current (I)	The rate of electron flow past a point in a circuit I = V/R (Ohm's law)	Ampere (Amp) Coulomb/second (C/s)
Current density (J)	The amount of current flowing across a given area J = current/area (I/A)	Amp/m^2
Voltage (V)	The force pushing electrons along a circuit V = I × R	Volt (V) Joule/Coulomb (J/C)
Resistance (R)	The opposition to the flow of current in a circuit R = V/I	Ohm (Ω)

Circuit	The path along which the current flows	–
Power (P)	The rate at which work (energy) is done $P = Q/T = V \times I$	Watt (W) Joule/second (J/s)
Energy (Q) (thermal)	The ability to do work $Q = P \times T = (I/A)^2 \times R \times T$ (Joule's first law)	Joule (J) Watt second
Duty cycle	The ratio of the on-time to the total on-and-off-time of a signal	Ratio or percentage (%)
Frequency	The number of cycles (waves) per second	Hertz (Hz)
Waveform	The pattern of electrical activity as displayed on an oscilloscope, showing how voltage varies over time	–

A = area; T = time.

Table 2. Thermal effects

Temperature (°C)	**Thermal effects**
37	Normal body temperature
40	No structural damage
50	Cell death within 6 minutes
60	Instant cell death
60–95	Instant cell death, desiccation, and coagulation (white coagulation)
100	Cellular vaporisation (cutting)
200	Carbonisation (black coagulation)

Table 3. Versatile monopolar applications

Variables	Electrosurgical effects of monopolar instrumentation			
	Cutting	**Coagulation**	**Fulguration**	**Coaptive coagulation (≤2 mm vessel)**
Tissue temperature (°C)	>100	60–95	>200	60–95
Tissue effect	Vaporisation	White coagulation	Black coagulation	Vessel sealing
Best achieved with (output type)	Cut	Cut	Coagulation	Cut
Electrode position	Near contact	Contact	Non-contact	Compressing
Electrode shape	Needle	Wider	Ball	Jaws of forceps

Table 4. Monopolar and bipolar complications

Complications	Monopolar	Bipolar
Lateral thermal spread	More	Less
Direct coupling	√	×
Insulation failure	√	√
Capacitive coupling	√	×
Alternate site injury	√	×
Inadvertent activation	√	√
Current leakage through cord	√	√

Box 1. Common patterns of electrosurgical complications

- Active electrode injury
  - Direct application
  - Inadvertent activation
  - Residual heat
- Insulation failure
- Antenna coupling
- Direct coupling
- Capacitive coupling

Table 5. Factors affecting lateral thermal spread

Variable	**Lateral thermal spread**	
	Increased	**Decreased**
Current	Continuous	Pulsed
Voltage	High	Low
Power setting	Higher setting	Lower setting
Tissue compression	Low (big pedicle)	High (small pedicle)
Application time	Longer application	Shorter application
Instrument type	Monopolar coagulation	Bipolar coagulation

Box 2. Good practice in electrosurgery

Monopolar devices

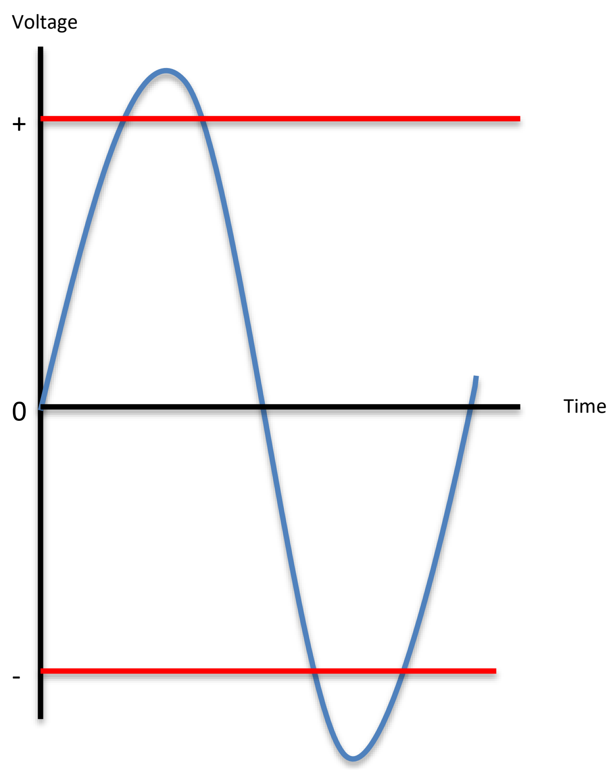
1) Use the lowest possible power setting.
2) Do not apply the dispersive electrode over bony prominences, metal prosthesis, scar tissue, hairy skin or pressure areas.
3) Vary the surface area of the active electrode to achieve the desired effect without increasing the power setting.
4) Use the continuous low-voltage waveform 'cut' mode for contact coagulation.
5) Use short intermittent activations.
6) Avoid open activation.
7) Avoid activation in close proximity to or in contact with another metal instrument.
8) Use return electrode monitoring and active electrode monitoring technology.

Bipolar devices

1) Allow a safety margin when close to vital structures because of lateral thermal spread.
2) Avoid tension on the tissue during activation because this compromises coagulation. In areas with anatomical tension, use several applications with overlapping of the seal, without leaving any unsealed tissue in between two seals.
3) Keep the jaws of the instrument clean at all times by wiping with a wet swab to achieve adequate tissue effects. To prevent tissue charring, activate the instrument in a short intermittent manner and release the tissue just before current flow is terminated at the vapour phase.[49] When stuck to tissue, reapproximate the jaws and reactivate before opening them. The tissue can also be irrigated with fluid before reactivation.
4) Do not use in tissues with metal clips or staples in situ because it may cause injury from unpredictable current migration.
5) Avoid over-compression of grasped tissue to prevent the bypass effect and do not include a big bundle of tissue in the jaws of the instrument for a good seal. Consider skeletonising vessels before application to achieve a good seal.
6) In patients with comorbidities such as liver cirrhosis, prolonged steroid use, atherosclerosis, diabetes, malnutrition and collagen diseases, be extra

cautious and consider alternative surgical methods because these conditions may affect the blood vessels.[50]

Figure 1. Direct and alternating currents as shown on the oscilloscope. Purple straight line: direct current with fixed polarity (unidirectional). Green sine wave: alternating current with oscillating polarity (bidirectional).



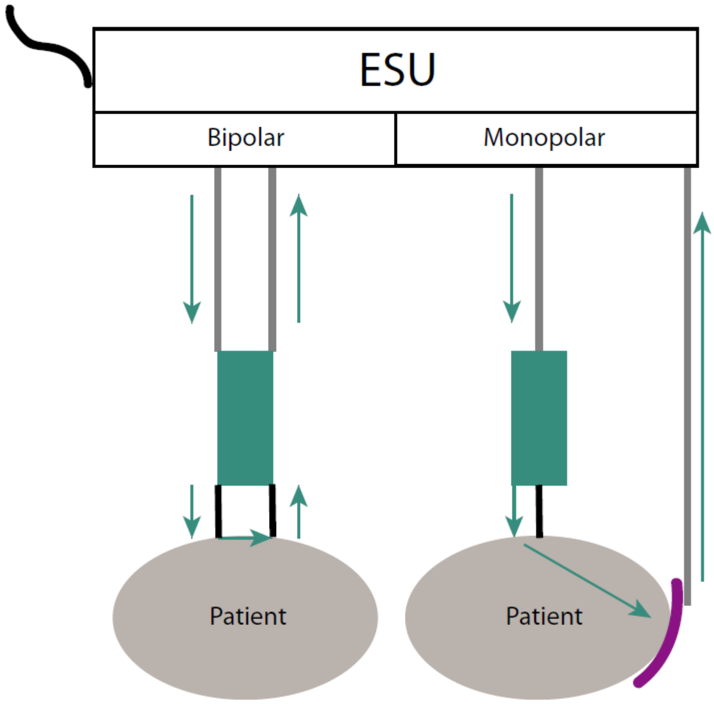


Figure 2. Monopolar and bipolar instrumentation. The green rectangles represent the instruments. The purple line represents the return electrode. The arrows represent the current pathway (circuit). ESU = electrosurgical unit.

Figure 3. Waveforms and tissue effects.

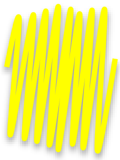
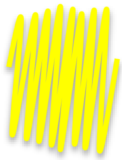
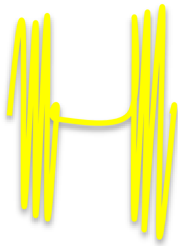
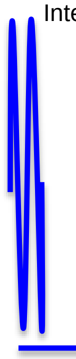
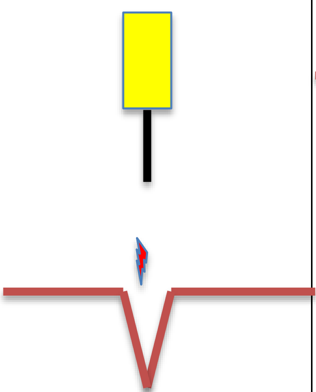
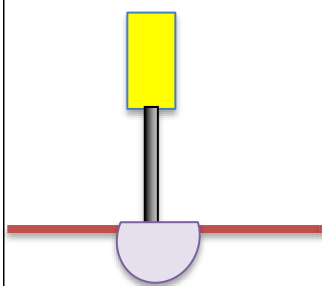
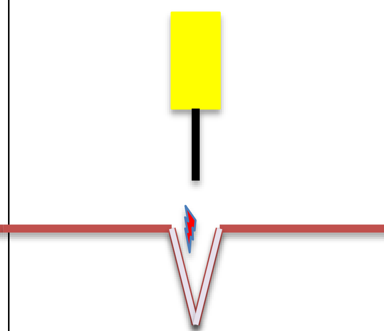
Waveform	Continuous low-volt “cut” 	Continuous low-volt “cut” 	Blend “cut” 	 Inte
Duty cycle	100%	100%	50%	
Tissue contact	Non-contact	Contact	Non-contact	
Effect	Clean cut Cut	White coagulation Coagulation	Cutting with haemostasis Cut with coagulation	W
Diagram				

Figure 4. (a)Mushroomeffect leads to increased lateral thermal spread. (b) Touched jaws results in electrical bypass and deficient coagulation. The black lines represent the jaws of a bipolar instrument. The red area indicates tissue coagulation.

Figure 5. Antenna coupling due to the close proximity and parallel arrangements of the cords.

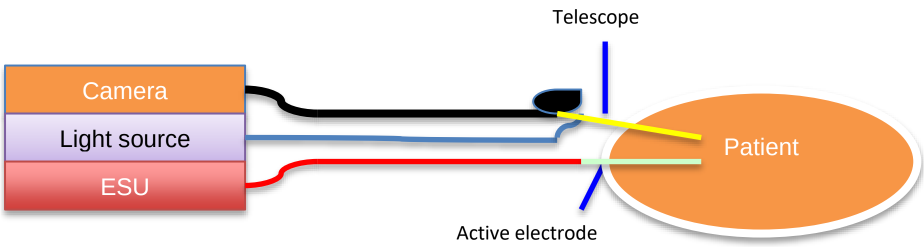


Figure 6. Capacitive coupling with a hybrid cannula.

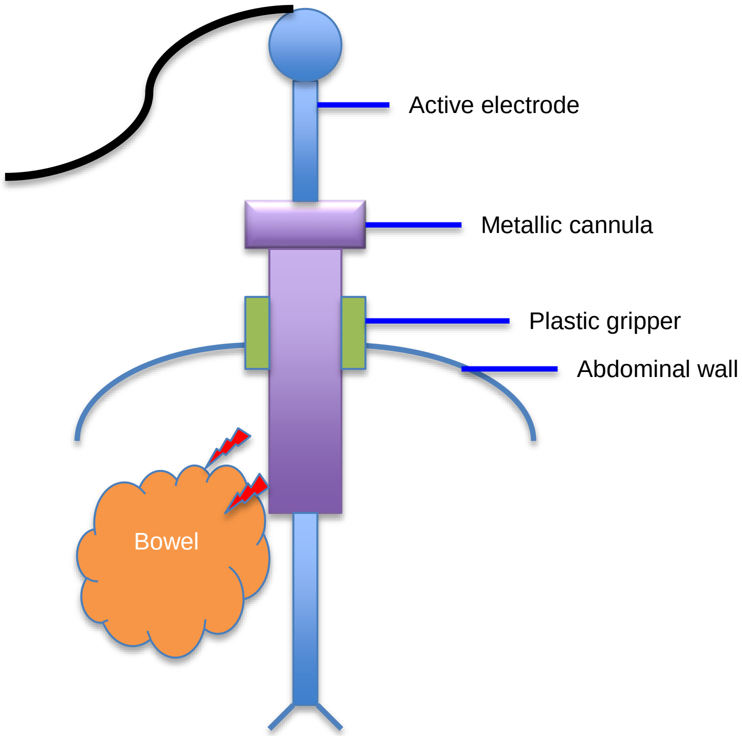


Figure 7. Diagram showing AEM circuit and its mechanism. AEM = active electrode monitoring; ESU = electrosurgical unit.

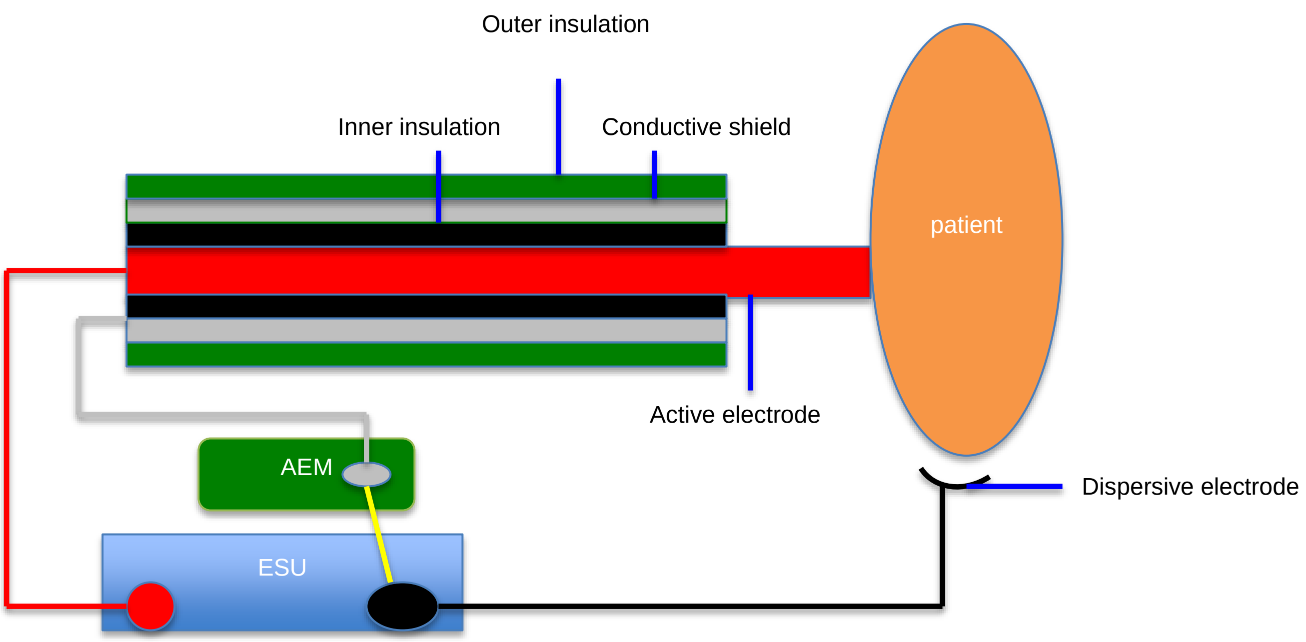


Figure 8. The four zones of a laparoscopic instrument. Zone 1 is the part of the instrument within monitor view. Zone 2 is the part of the instrument outside the cannula and out of monitor view. Zone 3 is the part of the instrument inside the cannula and out of monitor view. Zone 4 is the part of the instrument outside the cannula and abdomen.