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Review

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

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Introduction

Electrosurgery has gained popularity in recent years and is now the most widely used form of energy in both open and laparoscopic surgery. This can be attributed to its lower cost over other forms of surgical energy, widespread availability and versatile applications.[1] Advanced technology has led to the design of more sophisticated electrosurgical devices as laparoscopic procedures become more complex.

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 shows that many surgeons have gaps in their knowledge of the basic principles of electrosurgery, which can compromise patient safety. In response, the profession is calling for formal training programmes in the safe use of surgical energy for all staff required to use it.[3] Additionally, the industry is addressing design flaws in electrosurgery to provide safer devices.[2]

History

Cautery (direct heating of tissues) has been used therapeutically 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 BCE. Hippocrates (469–370 BCE) was a strong advocate of cautery. Later, in the 10th Century, Albucasis – the father of surgery in the Middle Ages – used heated instruments to treat diseases and stop bleeding.[4] In the early 19th Century, Becquerel was the first to use electricity in the form of direct electrical 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 neuromuscular stimulation or electric shock. A decade later, d'Arsonval reported that the above current also caused a heating effect in the tissue. The first person to use electrosurgery was Rivere, who used it to treat a hand ulcer in 1900. Later, Bovie developed his generator, which in 1926 was used successfully by Cushing to excise a vascular myeloma. Their work was published with a detailed description of the various electrosurgical tissue effects of cutting, desiccation and coagulation, paving the way for modern applications of electrosurgery.[1]

Applied physics

Electrosurgery is the application of high-frequency alternating current (AC) in surgery to achieve various thermal tissue effects including 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), which moves in one direction (unidirectional), and AC, which periodically reverses direction (bidirectional). Electrocautery uses DC, whereas electrosurgery uses AC to avoid electrolysis and a 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 (RF), the term RF electrosurgery is used. The electrosurgical circuit includes a generator, two electrodes and the patient (Figure 2). All electrosurgery is bipolar because it involves two electrodes.[4]

Electrosurgery can be delivered through monopolar or bipolar instruments. The main difference between them is where the two electrodes are placed. With monopolar instruments, the dispersive electrode is placed on the patient away from the active electrode, while bipolar instruments have two electrodes at the tip and 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; and
3. control of the duty cycle.

Advancing technology means that newer smart generators have other functions as well as the above.

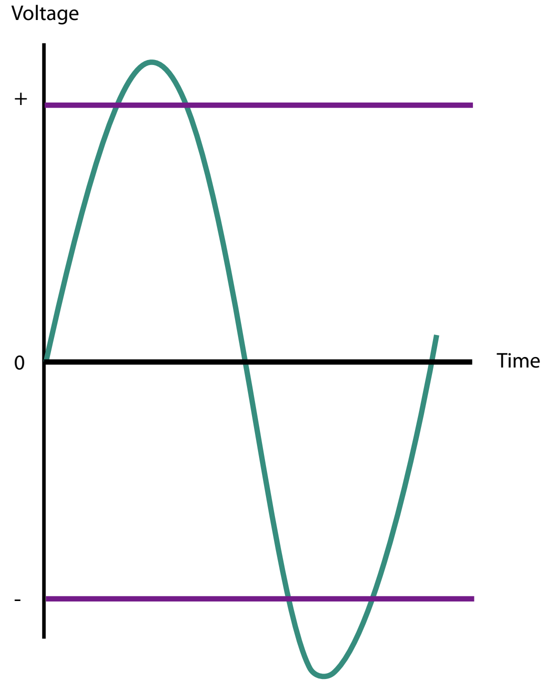

Figure 1. Direct and alternating currents as shown on the oscilloscope. Purple straight line: direct current with fixed polarity (unidirectional). Green sine wave: alternating current with oscillating polarity (bidirectional).

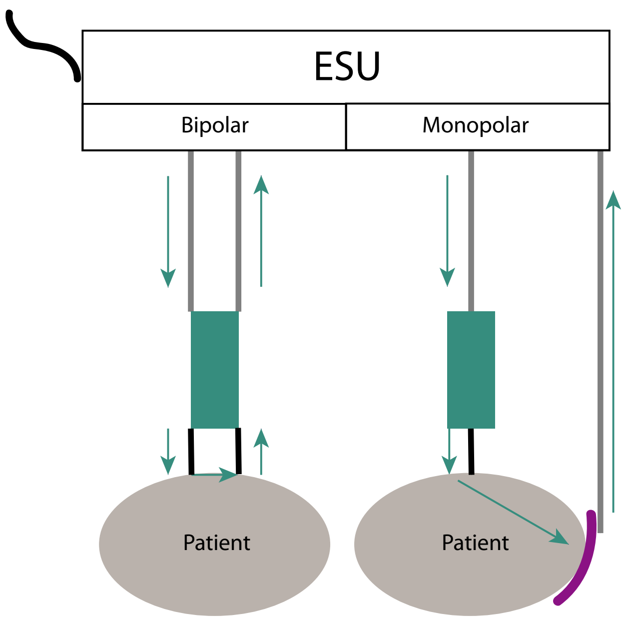

Figure 2. Monopolar and bipolar instrumentation. The green rectangles represent the instruments. The purple line represents the return electrode. The arrows represent the current pathway (circuit). ESU = electrosurgical unit.

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 = 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 × I	Watt (W) Joule/second (J/s)
Energy (Q) (Thermal)	The ability to do work Q = P × T = $(I/A)^2$ X R × 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

Mechanism of electrosurgery

On flowing through tissues, radiofrequency current leads to intracellular conversion of electromagnetic energy to mechanical energy to thermal energy. The resultant heat causes 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°C, cellular vaporisation with explosion occurs and leads to a cutting effect. A gradual increase in temperature of between 60°C and 95°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. By contrast with cutting, fulguration uses high voltage with a low duty cycle of 6%. When electrical arcs hit the tissue, they produce high temperature and carbonisation; the temperature then returns towards 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 to overcome impedance of the intervening air between the active electrode and the tissue. This increases the risk of stray current burns in laparoscopic surgery.[5]

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)

Monopolar electrosurgical instruments

Monopolar electrosurgical instruments are the most commonly used energy devices. Table 3 summarises the versatile functions of these devices.

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	Needle	Jaws of forceps

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 ($[I/A]^2$), 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 to step 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 such as 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°C, which vaporises or cuts tissue with minimal coagulation. An interrupted waveform with a low current and high voltage causes a slow increase in temperature to 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 rate of heat produced in the tissue is what makes a waveform cut or coagulate. 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 '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

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

Electrode surface area

The smaller the electrode, the higher the current concentration. Reducing the contact area of the active electrode by a factor of 10 increases 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]

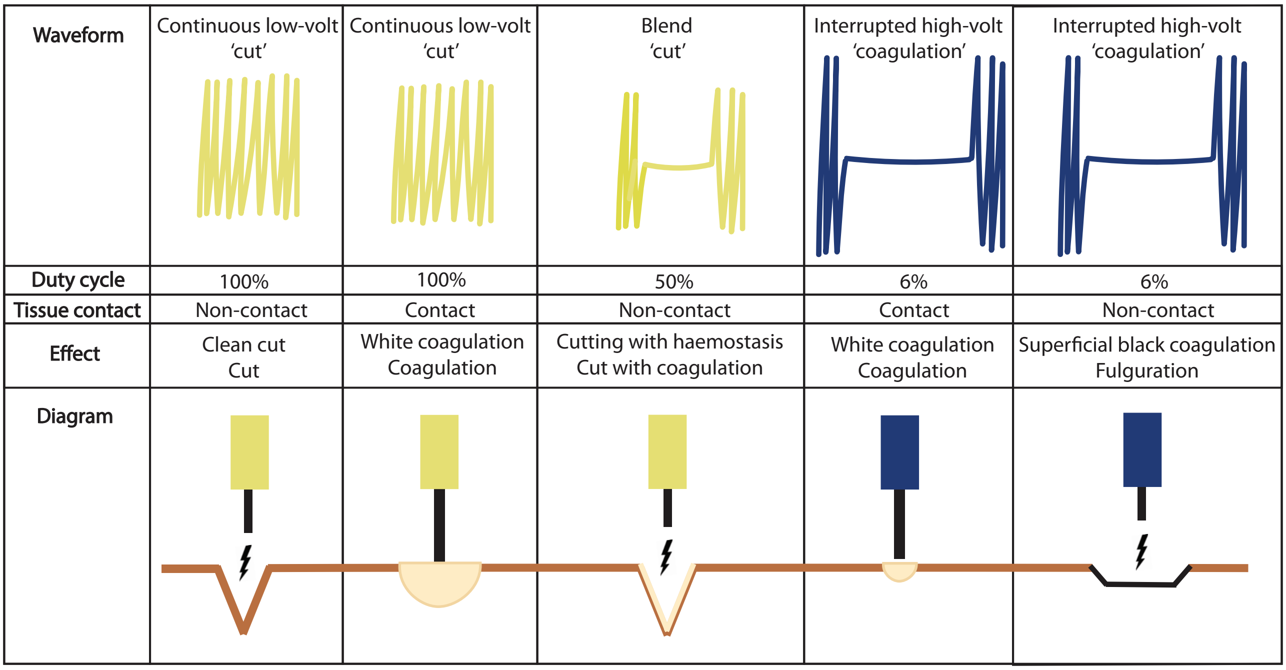

Figure 3. Waveforms and tissue effects.

Tissue contact

During cutting and fulguration, the current sparks from the active electrode to the tissue with no contact, while coagulation and desiccation occur when the active electrode contacts the tissue. Coaptive coagulation can occur with both monopolar and bipolar forceps; this is where tissue is compressed between the jaws of the instrument, thus coapting the blood vessel to prevent the 'sink effect' (where heat is carried away by the flow of blood) and to achieve haemostatic sealing. In monopolar coaptive coagulation, it is recommended to use the 'cut' rather than the 'coagulation' waveform because it results in a complete homogenous seal with reduced electrosurgical risks caused by the associated low voltage.[4]

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	✓	✓

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. By contrast, scarred tissue and fat pose very high impedance.[6]

Eschar

Eschar has high impedance to current, therefore cleaning the active electrode of eschar reduces impedance and enhances the electrosurgical effect. Using a moist electrode to cut a wet tissue facilitates the production of the steam envelope necessary for effective cutting.[4]

Conventional bipolar devices

Conventional bipolar 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. They are generally safer than monopolar instruments because the current flows between the two electrodes and through the grasped tissue with less used voltage and energy and without a dispersive electrode. 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 to develop a proximal thrombus and eliminates the heat sink. 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 nearby vital structures (Figure 4).

Electrical bypass effect

Overcompression of the tissue between the jaws of the bipolar instrument may cause them to touch, leading to electrical bypass and deficient tissue coagulation (Figure 4).

Despite 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 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 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 of the voltage of conventional bipolar devices and deliver current in a pulsed manner to allow tissue cooling during the off-period.[5]

Detailed accounts of 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 length of hospital stay. Other studies have looked at the cost-effectiveness of such devices.[16,17]

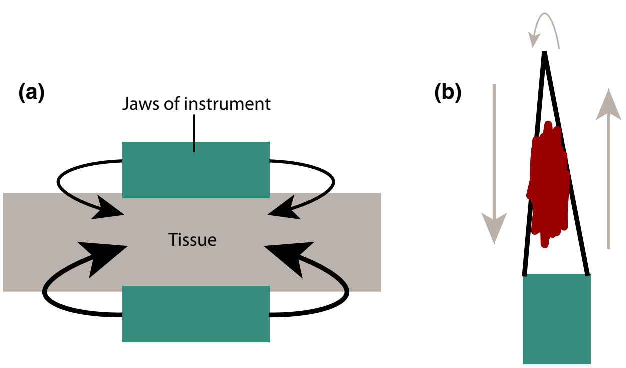

Figure 4. (a) Mushroom effect leads to increased lateral thermal spread. (b) Touched jaws results in electrical bypass and deficient coagulation. The black lines represent the jaws of a bipolar instrument. The red area indicates tissue coagulation.

Complications

The incidence of laparoscopic electrosurgical injuries is 2–5 per thousand procedures.[9,18] About 40 000 patients each year receive electrosurgical burns.[19] Nearly 70% of such injuries are not recognised during surgery. The delayed diagnosis of these complications is associated with increased morbidity and mortality. Medicolegally, significant financial compensation is paid for claims related to such injuries.[19] Most of these claims were associated with bowel and ureter injuries.[20] Consequently, guidelines for the safe use of electrosurgery were developed to address this serious safety issue.[21,22] Box 1 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 type of electrosurgical injury, with potential thermal burn to the bowel, ureter or blood vessels.[23] The extent of lateral thermal spread depends on the device used, its power setting, tissue impedance and the activation time (Table 5). 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 the bowel, ureter and blood vessels. Shorter activation time is recommended to reduce lateral thermal

Box 1. Common patterns of electrosurgical complications

- Active electrode injury
  - o direct application
  - o inadvertent activation
  - o residual heat
- Insulation failure
- Antenna coupling
- Direct coupling
- Capacitive coupling

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

Inadvertent activation can lead to unintentional patient burn. A prevention strategy is as follows.

- Avoid accidentally stepping on the foot pedal.
- When the active electrode is not in use:
  - o remove it from the body and
  - o place it in a dry, rigid plastic holder (not plastic sleeves) with no other instruments.
- Use an audible activation tone to be heard by the team.

Residual heat

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

Insulation failure

Insulation failure is a breakdown of the insulation layer around the active electrode. Its incidence is about 20% in reusable laparoscopic instruments and 3% in disposable instruments, with the distal third of the instrument being the most commonly affected site.[26] Robotic instruments are more often affected than their laparoscopic counterparts.[27] Repeated cleaning and sterilisation, normal wear and tear and the use of high-voltage output are possible causes of insulation failure. Although it is recommended to inspect the instrument before use, most of these 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 those that might occur during surgery.

Because 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 as soon as the yellow layer is exposed, indicating an insulation defect. Active electrode monitoring (AEM) technology prevents stray current burns from insulation failure and capacitive coupling.

Table 5. Factors affecting lateral thermal spread

Variable	Lateral thermal spread: Increased	Lateral thermal spread: 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

Antenna coupling

This phenomenon occurs 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 may be regarded as a type of capacitive coupling and can result in unintended tissue burns. The receiving antenna may be the camera cord or wires of monitoring devices such as electrocardiography (ECG)[29] or neuromonitoring devices.[30] Robinson et al.[31] found that separating the laparoscopy tower from ESU, avoiding parallel arrangement of cords and lowering the power setting reduced antenna coupling (Figure 5). By contrast with all other complications that occur in the surgical field, this complication is initiated with the cords and wires bundled off the surgical field.

Direct coupling

Direct coupling injury occurs when the active electrode touches another metal instrument such as a suction irrigator or camera telescope. Current from the active electrode flows to the second instrument and potentially burns any tissue it touches. Direct coupling is technique-related; hence the responsibility of prevention lies with the surgeon. To reduce this risk, energy must not be activated until the instrument is out of the metal trocar and its tip is in view. Ports must be placed so as to avoid instrument shafts from touching the bowels. The active electrode and other metal instruments should be kept in panoramic view to reduce this injury. 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

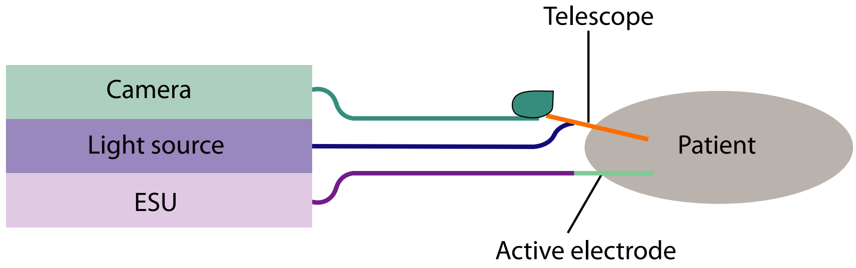

Figure 5. Antenna coupling due to the close proximity and parallel arrangements of the cords.

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

Capacitive coupling 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 instruments. This depends on the capacitor size, the activation mode and voltage output.[2,32] Examples of situations in which capacitive coupling can pose a risk to the patient include:

1. when the active electrode is passed down a metal suction irrigator, an operative laparoscope or a metal cannula with a plastic gripper (hybrid cannula).
2. when the insulated shaft of the active electrode touches non-targeted tissue such as bowel or adhesion.
3. when the active electrode induces a current in a nearby cold instrument.

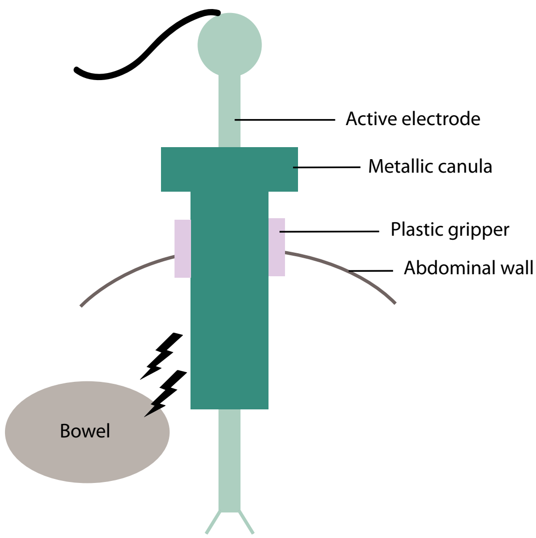

Figure 6. Capacitive coupling with a hybrid cannula.

4. when current is induced into adjacent tissue and instruments in single-port laparoscopy.

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, however, 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 effects. This technology reduces capacitive coupling but has no effect on insulation failure. AEM technology eliminates injuries caused by both insulation failure and capacitive coupling.[2]

Technological developments and safe electrosurgery

During the early use of electrosurgery in open surgery, the most common complications encountered were unintended alternate site burns (ground point burns and dispersive electrode burns). In the 1970s, isolated ESUs were introduced, followed by contact quality monitoring (CQM) of the dispersive electrode in the 1980s; these have addressed the electrosurgical design flaws responsible for such burns and have significantly minimised their occurrence.[2]

Active electrode monitoring

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

The technological innovation of AEM was introduced in the 1990s to address the design flaws of monopolar instrumentation in terms of insulation failure and capacitive coupling. With a conventional monopolar device, an outer insulation layer covers the shaft of the active electrode. However, AEM instruments have two extra coaxial layers: a conductive (protective) shield and a second outer insulation

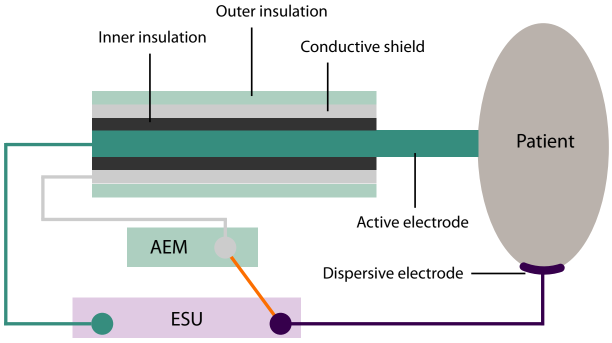

Figure 7. Diagram showing AEM circuit and its mechanism. AEM = active electrode monitoring; ESU = electrosurgical unit.

layer (Figure 7). Despite these two extra layers, AEM instruments can still fit 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 caused by insulation failure and capacitive coupling.[36] This protective shield is considered as a second dispersive electrode, which returns stray currents safely to the AEM monitor and then back to the ESU. If the AEM monitor detects a dangerous level of stray energy (about 2 W), it deactivates the ESU to prevent tissue burns. Use of AEM is surgeon-independent and is the most effective way of dealing with stray currents caused by insulation failure and capacitive coupling.[2]

The 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

The recent resurgence of single-port laparoscopy (SPL), in which three or four instruments are passed through one port, has heightened awareness of the potential risks of monopolar instrumentation (insulation failure, direct coupling, and capacitive coupling).[37] These risks 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 might therefore touch vital tissues. Proximity and crossing of instruments ('sword fighting') also increases the possibility of the above risks in single-port compared to multi-port laparoscopy. To reduce stray current injury in SPL:[2]

- use alternative devices such as bipolar or ultrasonic instruments.
- with monopolar instruments:
  - o use those with AEM technology.
  - o contact the ESU manufacturer to determine the appropriate setting.
  - o use a metal cannula to disperse capacitive charge into the abdominal wall.
  - o use a 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 defibrillators (ICD), as well as other neurologic stimulators. Such interference can damage or inhibit the CIED device, burn the myocardium or cause arrhythmias and asystole.[38,39]

Prevention strategy[40,41]

The following steps should be followed to prevent electromagnetic interference.

- Liaise with cardiologist preoperatively.
- Use bipolar or ultrasonic devices in patients who are highly dependent on CIED.
- When using monopolar instruments:
  - o place the dispersive electrode as far away as possible from the CIED.

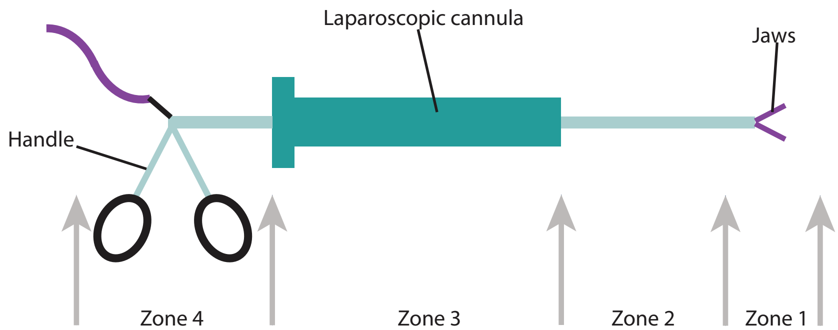

Figure 8. The four zones of a laparoscopic instrument. Zone 1 is the part of the instrument within monitor view. Zone 2 is the part of the instrument outside the cannula and out of monitor view. Zone 3 is the part of the instrument inside the cannula and out of monitor view. Zone 4 is the part of the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

o avoid the capacitively coupled return electrode.
o use lower power, cut mode to coagulate and short activation.
o avoid current vector crossing the CIED.
o monitor PPM with ECG during surgery and reprogram after surgery if needed.
o deactivate ICDs just before surgery, then activate after surgery – a magnet can be used for deactivation if a cardiologist is unavailable.
o perform advanced life support in case of cardiac arrest.

Electrosurgical smoke

Electrosurgical smoke reduces laparoscopic visualisation, which may compromise patient safety. It contains toxic gases, potentially carcinogenic chemicals and viruses.[42] Excessive smoke can cause irritation of the eyes 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 because they only filter particles down to 5 µm, whereas 77% of smoke particles are smaller than or equal to 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. Despite the fact that electrosurgery has been commonplace for the past century, transatlantic evidence shows that many surgeons of different specialties 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) developed the FUSE (Fundamental Use of Surgical Energy) programme. This is the first validated educational programme that includes an online didactic curriculum (available for free at www.fuseprogram.org), a standard textbook (*The SAGES Manual on the Fundamental Use of Surgical Energy*) and a computer-based test.[47] The 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 participants' learning. There is no such programme in the UK, therefore 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 other medical devices, such as those powered by laser, most surgeons use electrosurgical devices without formal training or competency assessments. This can result in the misuse of such devices and potentially give rise to serious complications. With the increasing number of new energy devices, surgeons should understand the basic biophysics and limitations of these devices to deliver safe and efficient patient care. Box 2 outlines the main points of good practice in the use of electrosurgery.

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, re-approximate 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]

Disclosure of interests

There are no conflicts of interest.

Contribution to authorship

ME-S conceived, researched and wrote the article. SM researched and edited the article. ES edited and critically revised the article for important intellectual content. All authors read and approved the final version of the manuscript.

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