**ELECTROSURGERY IN MODERN ERA**

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**INTRODUCTION**

Electrosurgery has emerged as a necessary tool and is used widely in most of the surgeries. As more complex laparoscopic procedures are being done nowadays, more sophisticated electrosurgical devices have come into application. Although their lower cost, easier availability and versatile use has an enormous advantage but due to gaps in knowledge of their basic principles, there can be disastrous life-threatening complications as well. Electrosurgery is the use of high-frequency alternating current to achieve various thermal tissue effects whereas electrocautery is the passive transfer of heat to the tissue with no passage of current through it, therefore these terms are not synonymous.

**HISTORY**

The Edwin Smith Papyrus, an Ancient Egyptian medical text cited its use in ulcers and trauma surgeries as far back as 1600 BCE. The first person to use electrosurgery was Rivere, who used it to treat a hand ulcer in 1900. Later, Bovie developed a generator, which in 1926 was used successfully by Cushing to excise 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.

**PRINCIPLE**

Electrosurgery follows the physical rules of electricity and is the application of high-frequency alternating current (AC) to achieve various thermal tissue effects. Alternating current prevents electrolysis and high frequency avoids the Faradic effect of nerve and muscle stimulation.

Electrosurgery can be delivered through monopolar or bipolar instruments. The main difference depends on the placement of electrodes. 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 there is no need for a dispersive electrode.

The electrosurgical circuit includes a generator, two electrodes and the patient (Figure 1)[1]. All electrosurgery is bipolar because it involves two electrodes. [2]

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.

ESU

Patient

Patient

Monopolar

Bipolar

Figure 1: 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.

**MECHANISM OF ELECTROSURGERY**

Radiofrequency current while flowing through tissues leads to intracellular conversion of electromagnetic energy to mechanical energy to thermal energy. The resultant heat causes the various tissue effects of electrosurgery. Table 1[1]shows the effect of temperature on cells and tissues.

Table 1. 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)

A gradual rise in temperature between 60°C and 95°C leads to simultaneous tissue desiccation and coagulation whereas cellular vapourization with explosion resulting into cutting occurs due to rapid rise in intracellular temperature to more than 100°C. Noncontact sparking with coagulation output is known as fulguration which produces a superficial layer of black coagulation. Fulguration uses high voltage, as compared to cutting, to overcome impedance of the intervening air between the active electrode and the tissue which in turn increases the risk of stray current burns in laparoscopic surgery.[3]

When electrical arcs hit the tissue, they produce high temperature and carbonization; 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.

**MONOPOLAR ELECTROSURGICAL INSTRUMENTS**

These have widespread applications as summarized in Table 2[1].

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variables** | **Cutting** | **Coagulation** | **Coaptive Coagulation****(<2 mm vessel)** | **Fulguration** |
| Tissue Temperature | >100 | 60-95 | 60-95 | >200 |
| Tissue Effect | Vaporization | White Coagulation | Vessel Sealing | Black Coagulation |
| Best Achieved with (Output type) | Cut | Cut | Cut | Coagulation |
| Electrode position | Near Contact | Contact | Compressing | Non contact |
| Electrode shape | Needle | wider | Jaws of forceps | Needle |

**Table 2: ELECTROSURGICAL EFFECTS OF MONOPOLAR INSTRUMENTATION**

**THE ART OF MONOPOLAR INSTRUMENTATION**

Monopolar cautery works by concentrating the current (increasing its density) at the active electrode which then produces the desired thermal tissue effect. A dispersive electrode is also used 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 9 *R* 9 *T*, where *A* refers to the electrode surface area.

Thermal effect may be increased by various techniques instead of steeping up the ESU wattage which could lead to unintended tissue burns. Reducing the active electrode’s radius by just half results in a 16-fold rise in thermal change and also by removing conductive fluids like blood, compressing the arteries or stretching tissues, we can increase the thermal effect.[4]

**FACTORS MODIFYING ELECTROSURGICAL TISSUE EFFECTS**

**WAVEFORM**

Electrosurgical generators produce various electrical waveforms which results in differnt tissue effects (Figure 2)[1].

A continuous sinusoidal waveform with a **high current and low voltage** causes a rapid rise in tissue temperature to more than 100°C, which 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 types of waveforms are erroneously known as ‘cut’ (yellow-coded) and ‘coagulation’ (blue-coded) modes, respectively. A blend waveform is a modulated cut waveform with a variable duty cycle, current, and voltage. The blend mode can vary the duty cycle and the rate of temperature rise to produce variable degrees of cutting and coagulation (hemostasis).

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’.[5]

Figure 2. Waveforms and tissue effects.

Waveform

Continuous low-volt Continuous low-volt

‘cut’

‘cut’

Blend ‘cut’

Interrupted high-volt Interrupted high-volt ‘coagulation’ ‘coagulation’

Duty cycle

Tissue contact

100% 100% 50% 6%

Non-contact Contact Non-contact Contact

Clean cut White coagulation Cutting with haemostasis White coagulation Cut Coagulation Cut with coagulation Coagulation

6%

Non-contact

Fulguration

Diagram

**POWER OUTPUT**

The lowest effective power setting should be used to achieve the desired effects and to prevent unintended tissue burns. 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 mode5. Muscular patients require lower settings compared with obese or emaciated patients.

**ELECTRODE SURFACE AREA**

Reducing the contact area of the active electrode by a factor of 10 increases the current density by a factor of 100 as a smaller electrode leads to higher current concentration.[7]

**ACTIVATION TIME**

Long activation time increases the extent of tissue damage, whereas too short a time may result in inadequate tissue effect.[6]

**TISSUE CONTACT**

Monopolar, as well as bipolar forceps, may cause coaptive coagulation to prevent the sink effect by compressing tissue between their jaws. The sink effect means heat being carried away by blood flow. It is recommended to prefer ‘cut’ rather than the ‘coagulation’ waveform ensuring a complete homogenous seal along with lower electrosurgical risks caused by the associated low voltage.[2]

**TISSUE IMPEDANCE**

Higher tissue impedance results in an increase in thermal change. Tissues with high water content, such as muscles and skin, pose less impedance to current flow whereas scarred tissue and fat pose very high impedance.[4]

**ESCHAR**

Removing eschar from the active electrode intensifies the electrosurgical effect by reducing impedance.[2]

**CONVENTIONAL BIPOLAR DEVICES**

Bipolar devices use continuous low-voltage waveform and are therefore safer than their monopolar counterparts.

Their hemostatic vessel-sealing effect is achieved via mechanical compression that obstructs the vessel and helps to develop a proximal thrombus thus eliminating the heat sink.

**MUSHROOM (OUTSIDE LOOP) EFFECT**

Once the grasped tissue desiccates and coagulates, its impedance rises and current takes the path of least impedance outside the jaws of the bipolar instrument. The consequence is a collateral thermal injury to nearby vital structures.

**ELECTRICAL BYPASS EFFECT**

Inadequate tissue coagulation might occur due to electrical bypass if tissues are over-compressed between the jaws of the instrument leading to touching of the jaws.

**ADVANCED BIPOLAR DEVICES**

Advanced bipolar devices have various advantages over conventional ones

1. Can effectively seal vessels up to 7 mm in diameter.
2. Have smart generators that use tissue impedance feedback to ensure continuous adjustment of the delivered voltage and current resulting in optimal tissue effects. This mechanism prevents lateral thermal spread, charring as well as plumes.
3. Have an audio signal indicating that desired effect has been achieved.
4. Use one-tenth of the voltage of conventional bipolar devices permitting tissue cooling during the off-period by delivering pulsed manner current. [3]

**COMPLICATIONS**

The incidence of laparoscopic electrosurgical injuries is 2–5 per thousand procedures.[7] Around 70% of such injuries are not recognized intraoperatively. Most of these were associated with bowel and ureter injuries.[8]

**DIRECT APPLICATION**

It is the most common type and results from injury to nearby tissues like bowel, ureter, or blood vessels.[9] Monopolar devices can cause a greater degree of lateral thermal spread compared to bipolar and ultrasonic ones by their ability to generate high temperatures.[10] Such injuries may be prevented by avoiding close proximity to vital structures, and by using a shorter activation time (Table 3)[1].

|  |  |
| --- | --- |
|  **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** |

**TABLE 3: FACTORS AFFECTING LATERAL THERMAL SPREAD**

**PEDICLE EFFECT**

 If a monopolar instrument comes in contact with structures having a narrow vascular pedicle or adhesion, an unintended burn occurs due to higher current density.

**INADVERTENT ACTIVATION**

It can be avoided via different ways like active electrode should be removed and placed in a dry rigid plastic holder after its use and being careful about stepping on the foot pedal.

**RESIDUAL HEAT**

Touching vital structures with tip should be avoided immediately after deactivation of energy devices as they retain heat for a variable amount of time.

**INSULATION FAILURE**

It is the breakdown of the insulation layer present around the active electrode usually caused by frequent cleaning and sterilization, wear, tear and the use of high-voltage output. A distal third of the instrument is affected most commonly.[11] The smaller the hole in insulation, the higher the stray current density, with an increased risk of catastrophic tissue burns. The use of electrical scans can detect insulation defects already present before surgery, but not those that might occur during surgery.

As tiny holes are not visible to the naked eye, an active electrode with an indicator shaft was designed with two layers of insulation (black outer and yellow inner). The exposed yellow layer indicates insulation defect and the need for shaft replacement. Active electrode monitoring (AEM) technology prevents stray current burns from insulation failure and capacitive coupling.

**ANTENNA COUPLING**

This phenomenon occurs when the active electrode cord (transmitting antenna) emits electromagnetic energy in the air, it may be captured by a nearby inactive cord or wire (receiving antenna) like camera cord or wires of electrocardiography (ECG)[12] or neuromonitoring devices[13] resulting in unintended tissue burns.According to Robinson et al.[14] it may be prevented by separating the laparoscopy tower from ESU, avoiding the parallel arrangement of cords and lowering the power setting. (Figure 3)[1].

Figure 3. Antenna coupling due to the close proximity and parallel arrangements of the cords

**DIRECT COUPLING**

Direct coupling is technique-related because it occurs when the active electrode touches another metal instrument.

Prevention techniques are as follows:

* Surgeon should be the only person to activate the energy and must not be done until the instrument is out of the metal trocar and its tip is in view.
* Ports must be placed in such a way so as to avoid instrument shafts from touching the bowels.
* The active electrode and other metal instruments should be kept in panoramic view.

**CAPACITIVE COUPLING**

It is the transfer of electric current from active electrode, through intact insulation, into adjacent conductive materials without direct contact (Figure 4)[1] in the following ways:

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



Figure 4: Capacitive coupling with a hybrid cannula.

Capacitive coupling injuries may be reduced 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.[15] Nowadays adaptive electrosurgical technology has been developed within most ESUs allowing tissue impedance to be measured during activation. This helps to modify the output voltage accordingly and therefore produce consistent tissue effects.

**ELECTROSURGICAL EFFECTS OF MONOPOLAR INSTRUMENTATION**

**TECHNOLOGICAL DEVELOPMENTS**

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.

**ACTIVE ELECTRODE MONITORING**

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 layer. A circuit is then established between the conductive shield, the AEM monitor and the ESU (Figure 5). [1]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.[16] 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.[17]

Inner insulation

Outer insulation

Conductive shield

Patient

Active electrode

AEM

Dispersive electrode

ESU

Figure 5: Diagram showing AEM circuit and its mechanism. AEM = active electrode monitoring; ESU = electrosurgical unit.

**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). These risks can be attributed to the increased length of zone 2 (Figure 6)[1], 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 increase the possibility of the above risks in single-port compared to multi-port laparoscopy. To reduce stray current injury in SPL.[17]

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



Figure 6: 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.

**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.[18] This may be prevented by consulting a cardiologist preoperatively and using bipolar or ultrasonic devices in patients with CIED. In case of monopolar devices, dispersive electrodes must be placed away from CIED.

# **ELECTROSURGICAL SMOKE**

# Electrosurgical smoke reduces laparoscopic visualization and is potentially carcinogenic. Smoke evacuation systems should be used as surgical masks are ineffective.

# **CONCLUSION**

# Electrosurgery has numerous advantages and modern applications but with proper understanding of biophysics and their limitations, more efficient patient care may be delivered.

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