CHAPTER

1

Electrosurgery

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Among all the energy sources, electrosurgery is the most commonly used energy source during surgery. Mastery of this will significantly reduce surgery time, cause less blood loss, have faster recovery for the patient and reduce the number of safety hazards.

In this chapter, we will cover the fundamentals of this technology, get you familiar with the terms used commonly related to this technology, discuss the dos and don'ts and some basic troubleshooting techniques.

Energy

Energy is ability to do work and it is measured in Joules. **Power**, measured in watts, denotes the rate of delivery of energy. In most cases, the energy is converted from one form to another, e.g. flow of current (electrical energy) through any material causes generation of heat (heat energy) in it. Geysers and electric heaters use this principle.

Current is flow of electrons. Current is measured at a cross section and the unit of measurement is amperes. Flow of current is caused by potential difference between two points. That potential difference is voltage. Voltage is measured between two points and the unit of measurement is volts. The characteristic of material which opposes flow of current is called as resistance or Impedance. The impedance is measured between two points and the unit of measurement is ohm.

Ohms law says that

Current (I) = Voltage (V)/Impedance (R).

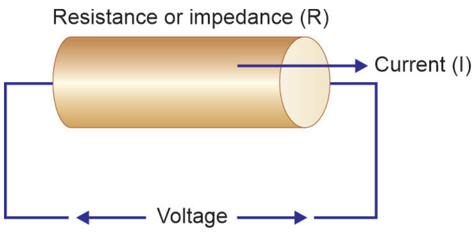

Fig. 1.1: Ohm's law

As seen in Fig. 1.1, an electrical circuit will have voltage, current and impedance. The relationship among these parameters is stated by Ohm's law.

Also, Power (W) = Voltage (V) × Current (I).

Now that we have covered basic physics terms, let's understand fundamentals of electrosurgery.

Electrosurgery

Electrosurgery is a technology that is used for cutting and coagulation effects by passing current through the patient tissue and thereby elevating temperature of the tissue for the desired effect. It has mainly two modes viz. *monopolar* and *bipolar*. The electrosurgery converts electrical energy into heat energy in a controlled manner to get the desired effect.

Monopolar Mode

Monopolar is a mode within electrosurgery which utilises combination of the instrument and dispersive electrode aka patient plate for completing the current path.

In monopolar mode, the current path is, as depicted in Fig. 1.2, as follows:

- Electrosurgical generator
- Electrode at the site of surgery
- Patient body
- Dispersive electrode
- Electrosurgical generator.

It is important to note that the amount of current flowing through the electrode and the dispersive electrode is exactly the same. We get effect on the tissue at the site of surgery because

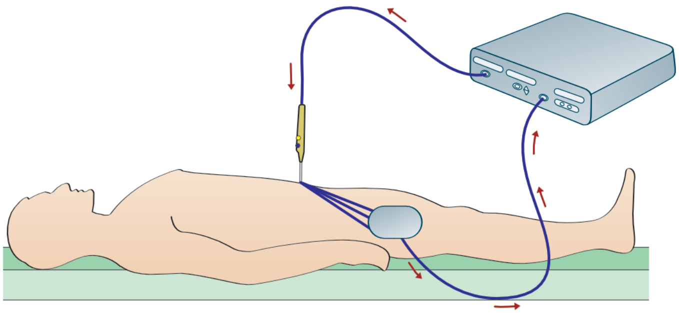

Fig. 1.2: Monopolar mode of electrosurgery

the current is concentrated and hardly any temerature elevation at the dispersive electrode because the current spread over a large area.

Since this has safety implication, let me elaborate this point further:

As shown in Fig. 1.3, when we place a piece of paper in the sunlight, it does not burn. However, when we concentrate the sunlight using a lens, it has the capability to burn it.

This is exacly what happens while using monopolar. The energy is concentrated at the electrode while it is dispersed at the dispersive electrode.

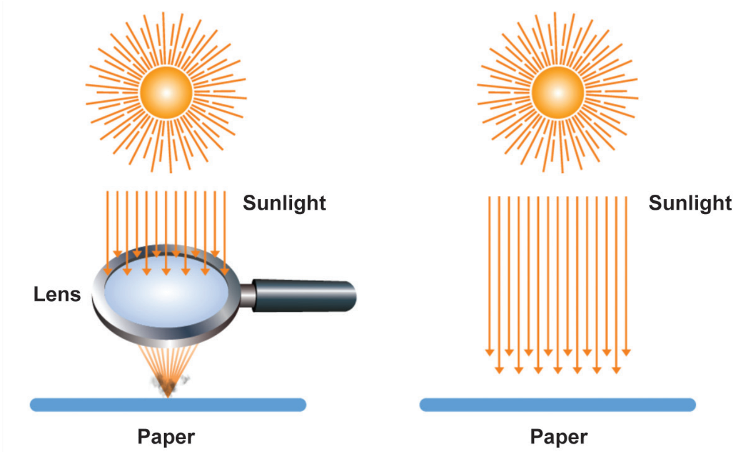

Fig. 1.3: Concentration of energy v/s dispersion of energy

Bipolar Mode

Biopolar is a mode within electrosurgery which utilises electrodes within the instrument for completing the current path.

In bipolar mode, as depicted in Fig. 1.4, the current path is as follows:
- Electrosurgical generator
- One electrode of the bipolar instrument
- Another electrode of the bipolar instrument
- Electrosurgical generator.

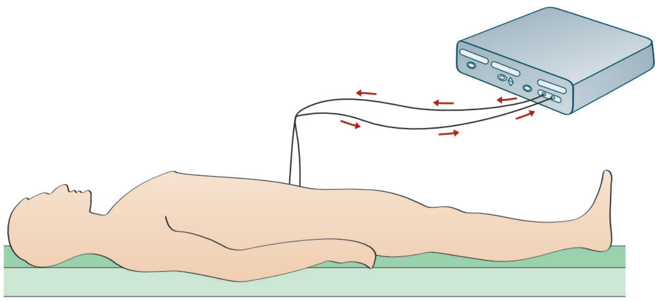

Fig. 1.4: Bipolar mode of electrosurgery

It is important to note that bipolar does not require dispersive electrode.

Vessel sealer and saline bipolar are special modes under the overall umbrella of bipolar modes.

Effect of Frequency on the Tissue

The regular power supply in our homes and offices can cause electrocution. However, the electrosurgery current causes only heat generation in the patient tissue. The difference is in the operating frequencies.

The mains supply has operating frequency of 50 Hz. These are typically known as low frequency, as depicted in Fig. 1.5. At this frequency, there can be neuromuscular stimulation. However, electrosurgery uses frequency of above 100 kHz, typically between 300 kHz and 700 kHz. These are high frequency, as depicted in Fig. 1.5. That is the reason the electrosurgery does not cause any neuromuscular stimulation.

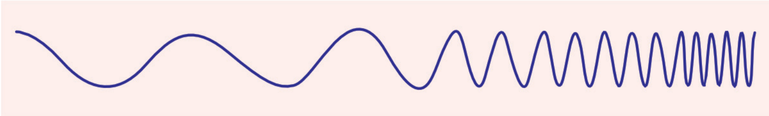

Fig. 1.5: Range of frequencies

Effect of Temperature Rise on the Tissue

There are various effects on the tissue as a response to heating. The temperature ranges and the corresponding effects are given in Table 1.1.

Table 1.1: Effect of temperature rise on the tissue

Temperature	*Effect on tissue*
<50°	Reversible changes in tissue
52° for >6 minutes	Irreversible change starts
60–80°	Desiccation and protein denaturation
120°	Tissue evaporation
>200°	Tissue charring

For temperatures below 50 degrees, there will be changes in the tissue like reducing water content. However, these changes are reversible and the body will replenish the water content.

For temperatures above 52 degrees for more than 6 minutes, irreversible changes start happening.

For temperatures between 60 and 80 degrees, two changes happen:

1. The water content in the cells reduces and the cells dry, know as desiccation.
2. The protein content of the cells gets denatured, i.e. protein gets converted from liquid to solid and changes its colour from colourless to white.

These two effects can be seen in Fig. 1.6.

The combined effect desiccation and protein denaturation is that the capillaries get blocked and thus coagulation is achieved.

For temperatures above 100 degrees and around 120 degrees, the water content of the cells start boiling, which causes cell evapouration, which causes cutting.

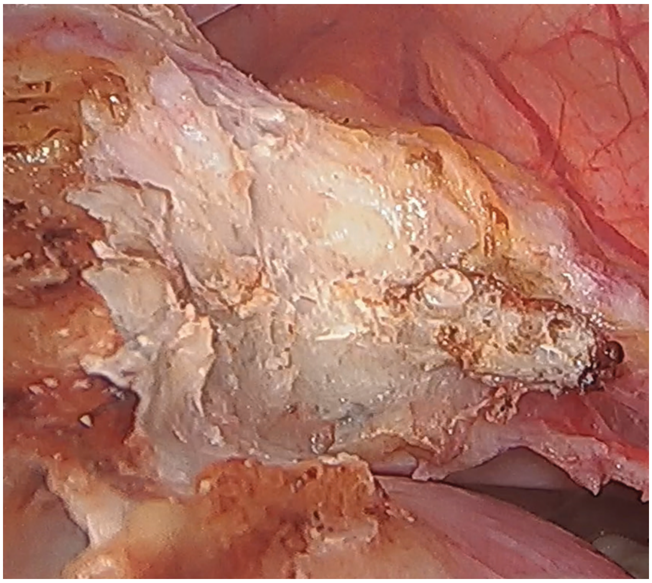

Fig 1.6: Protein denaturation and desiccation in tissue

The effect can be seen in Fig. 1.7.

Fig. 1.7: Tissue evaporation causing cut effect

Above 200 degrees, tissue charring starts happening and thus you can see tissue blackening, as can be seen in Fig. 1.8.

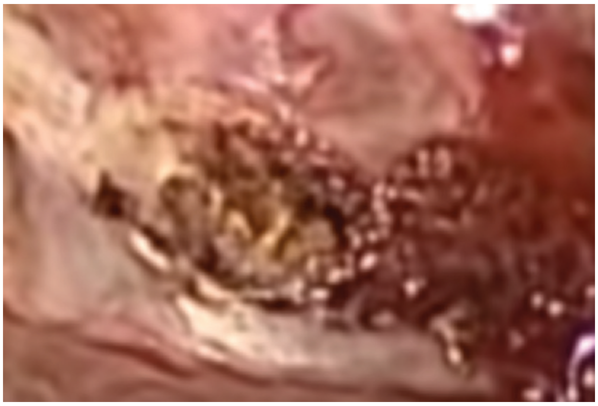

Fig. 1.8: Tissue charring

Factors Affecting Temperature Rise

Temperature rise depends on many factors. Generally, it is a function of:

- **Power setting:** More power setting leads to faster heating of the tissue.
- **Waveform:** This term is defined in the next section. We will see effect of waveform on the tissue in that section.
- **Area of electrode:** Smaller contact area leads to higher concentration of energy and thus higher temperature elevation and *vice versa*.
- **Time duration:** Longer duration of energy delivery leads to higher temperature elevation.
- **Tissue impedence:** Tissue impedance is characteristic of the tissue which opposes flow of current through it. It is function of, among many factors, type of tissue (e.g. fatty tissues have higher impedance compared to regular tissue), water content in tissue (e.g. coagulated tissue has higher impedance).

Understanding Waveforms

Each mode (like Pure Cut, Fulgurate, Precise Bipolar) has a different waveform. Waveform is nature of the current output, which is defined by two characteristics viz. *crest factor* and *impedence response graph*. To understand a mode, it is necessary to understand its underlying charasteristics. Different manufacturers may have different waveforms even though the mode name is the same. Each machine is different and it is useful to understand your electrosurgical unit like your baby. The charasteristics are defined in the following paragraphs.

Crest Factor

Technically, crest factor is defined as ratio of peak voltage to 'average' voltage. Crest factor varies for different modes because not all modes deliver continuous energy. In fact, except pure cut, desiccate and bipolar coagulation modes, all other modes are made up of delivery of energy followed by pause and this pattern is repeated. We do not feel the pauses while using electrosurgical unit because this pattern is repeated at a very fast pace, normally at more than 100 times per second.

To elaborate this, let's take two extreme example viz. one with the lowest crest factor (pure cut) as seen in Fig. 1.9A and one with the highest crest factor (spray coagulation) as seen in Fig. 1.9B. Intuitively, you already know that spray coagulation causes more spark compared to pure cut at the same power setting.

Crest factor has the following implications:

- Higher crest factor leads to more depth of effect. Subsequently, modes with higher crest factors cause more coagulation

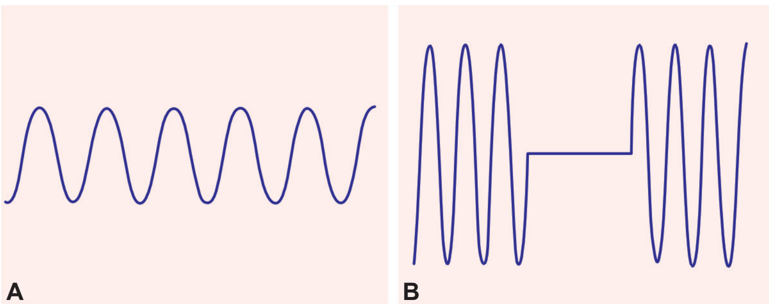

Fig. 1.9: Crest factors for two modes in monopolar (A) Pure cut; (B) Spray coagulation

because they work on larger area, their energy is spread and thus causes lower temperature elevation.

- High crest factor modes can cause spark. Used in the right manner, they can be useful in superficial coagulation.
- While working on vascular tissues, it is better to use modes with moderate crest factor even for cutting. This causes some amount of cutting on the side walls.

Impedance Response Graph

Impedance response graph is the graph that plots actual power delivery by an electrosurgical unit against tissue impedance.

Different manufacturers follow different impedance response graph even though they may use the same name for a mode. Also, within a machine, different modes may have different impedance response graph.

The actual delivery of power is almost always not the same as the set power. The delivered power is typically less than the set power and it is function of tissue impedance and the mode used.

For example, in Fig. 1.10, the impedance response of a machine without tissue sensing is shown, which is 'natural' for

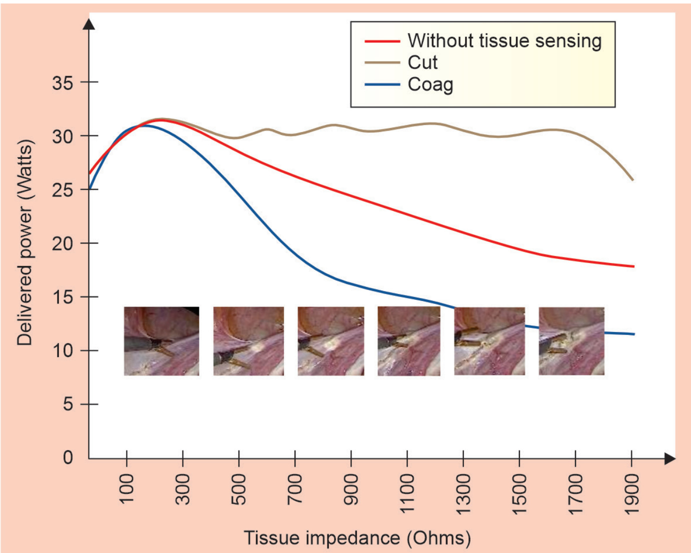

Fig. 1.10: Impedance response graph

a typical circuit. It is beyond the scope of this book to explain the "natural" behaviour of the machine.

Machines with tissue sensing technology can deliver power based on the tissue impedance in such a way that desired tissue effect is achieved. For example, cut current should continue to deliver output at high level (close to set power) even though tissue impedance keeps on increasing as a result of heating of the tissue. That's why the cut impedance response graph stays at higher power even though tissue impedance keeps increasing. Conversely, coagulation impedance response graph reduces the power delivery as a result of increase in tissue impedance. This ensures that the tissue after coagulation, i.e. after reaching 60–80 degrees of temperature and with higher impedance, the power delivery reduces so that the temperature does not rise much beyond that. This ensures a good coagulation, without causing cutting effect or charring.

Thus, machines with tissue sensing technology can deliver smoother cuts and better coagulations.

With the above fundamental concepts, now you are equiped to understand your electrosurgical unit and use it effectively and safely.

The following section describes various tips, which are based on practical experience and understanding of the above concepts.

Safety Hazards and Precautions

The next section on tips covers some of the safety precautions in details. These hazards and the precautions are summarised in the Table 1.2.

Table 1.2: Safety hazards while using electrosurgical units, their causes and preventive measures

Safety hazard	*Cause*	*Precautions*
Patient plate burns Fig. 1.11A	+ Insufficient contact area + Non-suitable area	+ Use disposable plates because they come with adhesives + Use split patient plates and electrosurgical unit that can detect insufficient contact

Contd.

Table 1.2: Safety hazards while using electrosurgical units, their causes and preventive measures *(Contd.)*

Safety hazard	*Cause*	*Precautions*
		+ Avoid areas such as hairy, having scars + Do not wrap wet cloth around the patient plate
Alternate site burns Fig. 1.11B	HF leakage + Current finds alternate path to reach ground Examples + Patient hand touching saline stand that is grounded + Surgeon sitting on a stool that is grounded	+ Insulate the operating area from the ground + Use electrosurgical unit that can detect HF leakage
Remote Tissue Damage Fig. 1.11D	+ Capacitive coupling Example: During gall-bladder surgery, cannula touches bowel + Instrument insulation failures	+ Regular visual inspection of instruments + Be aware of risk of capacitive coupling and ensure instruments do not touch other parts during surgery
Surgery Site Fire Fig. 1.11C	+ Inflammables Example: Spirit used for cleaning. The surgery site is still wet and power delivery is activated	+ Dry the surgery area well before power activation
Adjacent tissue damage	+ Direct coupling Example: + Unintended coupling like retractor touches the artery forcep, which is energised by monopolar electrode + Excessive high power/ high voltage + Two electrosurgical units on one patient	+ Be mindful of the risks of direct coupling + Start with lower settings and then increase, if required + Use only electrosurgical unit on one patient

Tips for Safe and Effective Use of Electrosurgical Unit

This section lists and elaborates useful tips for safe and effective use of electrosurgical unit. Given vastness of the subject, this list should not be considered as an exhaustive resource.

Tips for Buying Electrosurgical Unit

Go for electrosurgical unit that does not compromise on safety features. Ideally, it should have the following safety features:

- **Patient plate contact quality monitoring:** This safety feature is a must, given that patient plate burns are the most common thermal damage. This feature is also known by return electrode monitoring and similar names. If there is no sufficient contact between patient plate and the patient, the electrosurgical unit would indicate it and will not allow delivery of output. For this feature to work, the patient plate should be a split one.

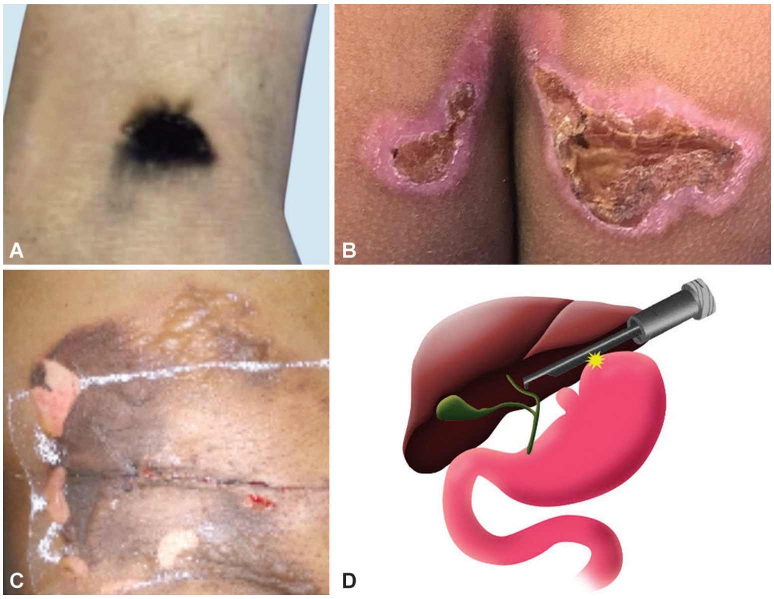

Fig. 1.11: Safety hazards (A) Burns at the site of patient plate; (B) Alternate site burns; (C) Burns due to fire; (D) Remote tissue damage

- **HF leakage monitoring:** During surgery, current may find alternate paths to the ground. There may be burns due to this alternate flow of currents if there is concentration of current at any place in the path. An intelligent electrosurgical unit will detect HF leakage, give alarm and stop delivery of monopolar output.
- **Time-out function:** Electrosurgical unit that has this feature will stop delivery of current if output is activated for a duration more than threshold and also give alarm. This is required to avoid any unintended activation.

The general functionality of electrosurgical unit is also important.

The following are the special cases that are challenging and prove worth of an electrosurgical unit. It is better to evaluate an electrosurgical unit under these conditions (whichever applicable), which clearly differentiate between a good machine and an average machine.

1. **Underwater surgeries:** Underwater surgeries like TUR or surgical hysterescopy are special condition because of very low impdence of the tissue. The ability to provide smooth cut and quick coag in these conditions test performance in low impedance conditions.
2. **Cutting fatty tissues:** Fatty tissues offer high impedance. The ability to provide smooth cut of fatty tissues test performance in high impedance conditions.
3. **Ability to coag in bloody field:** When a bleeder is punctured, a good electrosurgical unit will be able to provide quick control on bleeding.

Other than the above points, it is important to check the following:

1. **General current quality:** Current quality is the ability to cut smoothly, coagulate or seal quickly to avoid much blood loss or smoke, charring.
2. **Multiple cut modes:** A good ESU will have various cut modes in monopolar viz. low, high, pure, blend and endo. These modes are required in specific situations.
3. **Multiple coag modes:** A good electrosurgical unit will have various coag modes (e.g. in monopolar: desiccate, fulgurate, spray and in bipolar: precise, standard and macro).

4. **Intuitive interface:** If the user can start using the machine without demonstration or withour reading user guide, it is a good sign that it is easy to use.[1]
5. **Reliability and service support:** While these factors can be assessed only after purchase, it is a good idea to evaluate the manufacturer on these factors by taking feedback from the existing users.

A Note on Twin Coagulation

There are specific cases, e.g. cardiothoracic surgery or multiple injuries, where two surgeon might be operating on a patient. It is convenient if two surgeons have their respective monopolar pencils.

To support this requirement, ESU manufacturers have developed twin coagulation feature where two monopolar outputs are available from a single ESU. Some manufacturers have implemented it as two simultenous outputs while some manufacturers have implemented it as two alternate outputs (i.e. at a time only one monopolar can be active).

Most of the manufacturers have only one generator inside and the output is split between the two monopolar outputs. As explained in Fig. 1.12, when one of the monopolar outputs is activated, power delivery is as per the settings. However, when both the monopolar outputs are activated, power is divided between them. Existence of two independent generators is proven only if two separate settings for the two monopolars and simultaneous outputs are possible.

Hence, it is recommended that even if you buy an ESU with twin coagulation, the output is used alternatively. There is still a case for buying twin coagulation ESU because having two pencils for two surgeons is a great convenience.

Before Surgery

Understand functionality of the electrosurgical unit: If you are using a particular model for the first time, familiarise yourself with the functionality and safety features of it.

[1]Please note that I am not recommending that user guide should not be read. For getting the best out of the machine, the user guide should be read.

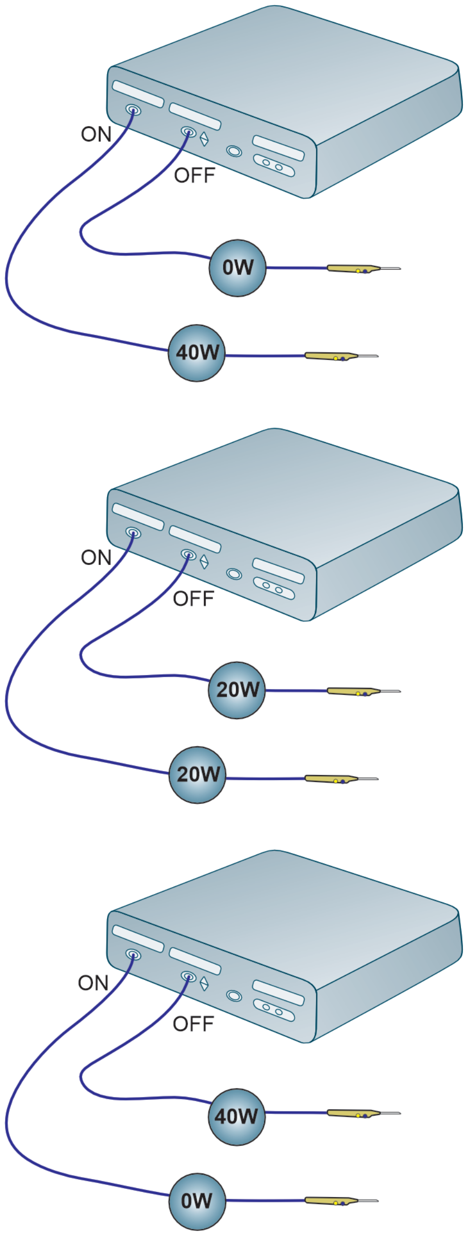

Fig. 1.12: Power delivery in twin output ESUs

Instruments, connectors and cables

- Check for any insulation failures in instruments or cables. If any found, they should be immediately replaced.
- Check that the instruments, cables and the main unit are compatible with each other.
- All cables should be untangled.

Types of patient plates: The safest patient plates are the split disposable types. Split patient plates allow intelligent electrosurgical unit to identify contact quality. Disposable patient plates come with adhesives and hence, contact is maintained even when the patient is moved during surgery. Fig. 1.13 shows a disposable split patient plate.

Split silicon patient plates are the second-best choice and offer cost effective alternative. Fig. 1.14 shows a silicon split patient plate.

Fig. 1.13: Disposable split patient plate

Fig. 1.14: Silicon split patient plate

Disposable and silicon patient plates are available in non-split form as well. Non-split patient plate cannot provide intelligence to the machine about how good the contact is between patient and the patient plate. Hence, they should be avoided. Within these two options, disposable is still a better option due to adhesive which can maintain good contact (Fig. 1.15).

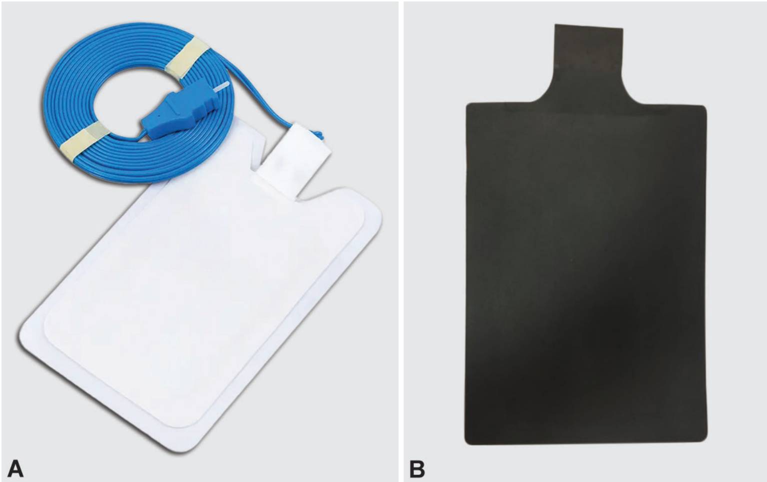

Fig. 1.15: Nonsplit patient plates (A) Disposable; (B) Silicon

Steel patient plates should be avoided because (i) being rigid, provide smaller contact area and (ii) cannot help intelligent electrosurgical unit to assess contact quality.

For silicon patient plates, though not mandatory, applying a conductive jelly will enhance contact quality.

If the patient has pacemaker, consult the pacemaker manufacturer: The older pacemakers may not have filters for the high frequency current generated during electrosurgery. Consult with the pacemaker manufacturer before surgery on the possible impact of high frequency current on the pacemaker.

Just before Surgery

Keep the activation sound volume at audible level: If the sound volume is not audible, any inadvertent activation will not be noticed by you.

Proper placement of patient plate: Patient plate placement plays a key role in safe surgery and also in effective delivery of current while using electrosurgical unit. The patient plate should be placed as per the guidelines below:

- It should be close to the area of surgery but it should not be adjacent as well.

- It should be on muscle area. Avoid fatty, hairy and bony area.
- It should be on a flatter surface for maximising contact area.
- The current path (surgery site to patient plate) should avoid heart, if possible.
- It should be placed in such a way that two parts of (a split) patient plate get roughly same amount of current.

Flammable disinfectants: Flammable disinfectants should be wiped dry and should be allowed to evaporate fully before electrosurgical unit use is started. Otherwise, there is a risk of fire.

Check initial settings: Keep initial power settings to the minimum. Select safe modes.

During Surgery

Start with lower settings, increase if required: The settings should be as low as possible and as high as needed. Power, which is more than required, causes tissue damage and toxic smoke.

Any change in settings should be orally informed by the technician and acknowledged by the surgeon.

Use low voltage waveforms as much as possible: For example, pure cut and desiccate waveforms are lower voltage compared to fulgurate and spray. Higher voltage waveforms cause more spark and may also cause more leakage currents.

Use bipolar than monopolar, wherever possible: Bipolar is a safer mode than monopolar. Thus, wherever possible, bipolar should be preferred.

Do not activate the power when current delivery is not intended: Some surgeons keep the power activated for a long duration even though actual usage is for shorter duration. When the current is not delivered to the tissue, it will likely find alternate paths and can cause unintended damage. Also, higher duty cycle of usage lowers life and reliability of the electrosurgical unit main unit.

If the patient is moved, check the patient plate again: Any movement of the patient body necessitate checking of the patient plate and its proper contact with the patient body.

The active electrode should be visible all the time: The active electrode should preferably be kept in a holster when not in use. In absence of a holster, it should be visible all the time and should not be touching patient body or other conductive items (like metal instruments).

Be attentive to activation and alarm sounds: Advanced surgical diathermies provide distinct activation sounds for different modes (monopolar cut, monopolar coag, bipolar coag). Ensure that the activation sounds are consistent with the expected activated modes.

Also, be attentive for any alarms (visual and audio). Alarm sounds are, as per the standards, at highest volume levels irrespective of volume level set. An advanced electrosurgical unit will give alarms for:

i. Patient plate contact not sufficient,
ii. HF leakage current more than threshold, and
iii. Other errors like bipolar instrument being open (without any continuity) and time-out.

Clean electrodes regularly: Any carbon deposition on electrodes hinder flow of current through the electrode. Hence, electrodes should be cleaned regularly during the surgery. Fig. 1.16 shows (A) electrode with carbon deposition and (B) cleaned electrode.

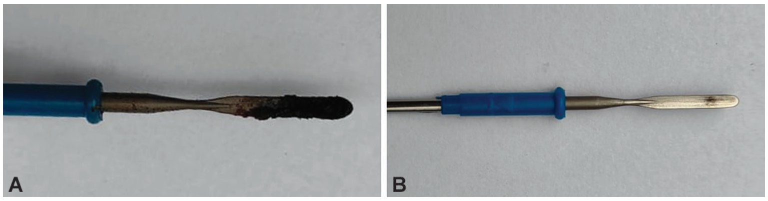

Fig. 1.16: Electrodes (A) Carbon deposition; (B) Cleaned electrode

Avoid tissue sticking to the electrodes: For monopolar open surgery, teflon coated electrodes can be used to reduce tissue sticking. For bipolar, using irrigation by saline can help avoid tissue sticking. Also, in general, clean electrodes cause less tissue sticking.

Keep electrode in your view during activation in a laparoscopic surgery: Activation of power during a laparoscopic surgery should always be done when the camera focuses on the active electrode.

Use all metal or all plastic trocars: Trocars that are combination of plastic and metal for a capacitor and allow for capacitive coupling. This can cause flow of stray current in monopolar mode and cause damage on the abdominal wall.

Ensure the instrument is not touching any other metal parts: Monopolar current may find alternate paths to the patient plate than the surgery site. Such alternate paths should be avoided. The alternate paths are possible due to insulation failures on the instrument or capacitive coupling. Hence, care should be taken that the instruments do not touch any other parts during the surgery.

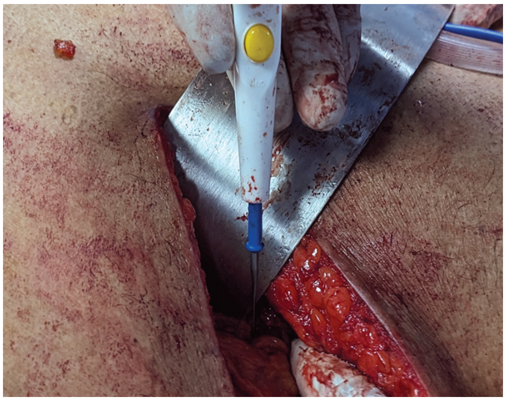

Fig. 1.17: Unintended direct coupling

This is especially important in laparoscopic surgery because the surgeon's vision is limited to the surgery site. In open surgery as well, contact with other metallic instruments (like retractor, as shown in Fig. 1.17) should be avoided.

Be mindful of current density: The increase in temperature depends on the concentration of current. If the current flows through a narrow path of tissues, it can cause thermal enjury there even though the narrow path is away from the surgery site. For example, while cutting an adhesive band between gallbladder and duodenum, if the band is narrower near the duodenum, the current will get concentrated there. It can cause thermal damage to the duodenum which may not be recognised during surgery.

Insulating surgery area from the ground: The surgery set up should be insulated from the ground to avoid HF leakage. Examples are: patient hand touching saline stand, surgeon sitting on a steel stool that does not have bushings on its legs. In both these cases, part of the current flows to the ground through these alternate paths. Surgeons using wooden platform, using non-conductive material for the flooring are some of the solutions.

Evacuate smoke: To reduce effect of toxic gases, use of smoke evacuator or suction machine is recommended during surgery.

After Surgery

Inspect for any thermal damage: Check skin at the patient plate for any thermal damage. Also, inspect the other patient body parts for any thermal damage that can happen due to HF leakage.

Clean instruments and the patient plate: If any jelly is used for silicon patient plate, clean it without rubbing too much. Rubbing the silicon patient plate reduces its conductivity. After cleaning instruments, use of air spray for drying is recommended.

Inspect instruments and cables for any insulation failure: Check for any insulation failures in instruments or cables. If any found, they should be immediately replaced.

Handling of adverse incidents: If any adverse incident has taken place, it should be documented, in as much details as possible, describing nature of incident, sequence of events.

The medical equipments including their settings and instruments should be kept as they are and clinical engineer should be called. Without this, the clinical engineer may not be able to investigate the root cause of adverse incident.

Once the investigation is completed, the learnings should be shared, proactive actions should be taken so as not to repeat the incident.

Basic Troubleshooting

Manufacturers typically provide troubleshooting guide as part of service manual. Many of the troubleshooting procedures are specific to the particular model and it is advisable that either the surgeon, OT technician or biomedical engineer is aware of the trobleshooting procedures.

Flowcharts given in Figs 1.18 and 1.19 are some of the basic troubleshooting procedures for common problems.

Problem: Patient plate error sound and visual indicator

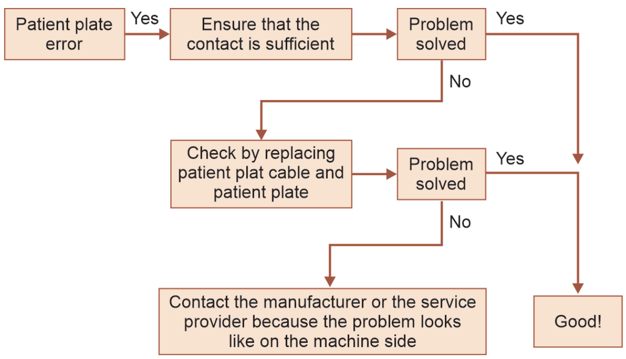

Fig. 1.18: Flowchart for resolving patient plate error and visual indicator

Problem: No power delivery of monopolar even though activation sound beeps

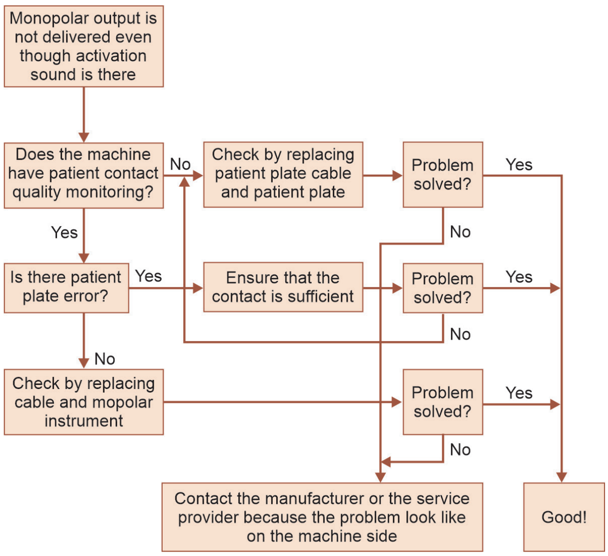

Fig. 1.19: Flowchart for resolving no power delivery of monopolar despite of activation sound