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Practical UROLOGY

(Instruments, Pathology, Radiology)

A Comprehensive Guide









Editors

Ravindra B Sabnis
Arvind P Ganpule
Sujata K Patwardhan

Assistant Editors

Abhishek G Singh
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SECOND EDITION

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CHAPTER 10

Energy Sources in Open, Laparoscopic, and Robotic Surgery

"Heat cures when everything else fails"

—Hippocrates

INTRODUCTION

Surgery can be defined as the art of tissue dissection and tissue reapproximation. A variety of energy sources have been used in tissue dissection to provide energy for cutting and hemostasis. Unfortunately, many surgeons poorly understand the biophysics of these sources. For most of us, pressing the cautery pedal is like taking a leap of faith without knowing the science behind it.

Let us in the coming few pages try to understand the energy sources available in market today for different kinds of procedure.

DEFINITIONS[1]

Electrosurgery

It is the use of radiofrequency (RF) alternating current to raise the cellular temperature to vaporize or coagulate tissue.

Electrocautery is not same as electrosurgery. Electrocautery uses direct current, whereas electrosurgery uses alternating current and in electrosurgery patient is a part electrical circuit.[1]

Cautery (Kauterion = Hot Iron)

Destruction or denaturation of tissue by passive transfer of heat or application of caustic substance.

- Current = Flow of electrons during a period of time, measured in amperes
- Circuit = Pathway for the uninterrupted flow of electrons
- Voltage = Force pushing current through the resistance, measured in volts
- Impedance/resistance = Obstacle to the flow of current, measured in ohms (impedance = resistance)

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CLASSIFICATION

- Based on the type of generator used:
  - Electrosurgical
  - Further subclassified into:
    - *Simple generator*: Monopolar/bipolar cautery
    - *Advanced bipolar systems*:
      - LigaSure
      - PK system
      - EnSeal
    - Ultrasonic
    - Integrated ultrasound and advance bipolar generators
    - Argon beam coagulator (ABC)
    - Lasers
    - *Others*: RF, microwave, cryo
    - Based on their use in urologic surgeries:
      - *Open surgery*: Monopolar, bipolar, vessel sealing (LigaSure and EnSeal), ultrasonic, and ABC
      - *Laparoscopic surgery*: Monopolar, bipolar, vessel sealing (LigaSure, EnSeal, and PK), ultrasonic, ABC, laser
      - *Robotic surgery*: Monopolar, bipolar, ultrasonic, and PK

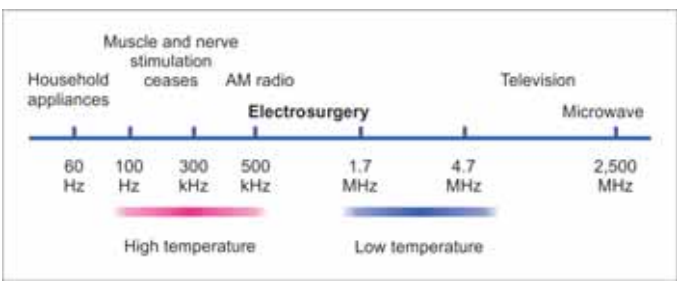
Electrosurgical Generator

Frequency Spectrum (Fig. 1)

A typical electrosurgical generator takes our household current of 60 cycles/s and raises the frequency to 200,000 cycles/s. Such high frequencies are radiofrequencies, when current passes at such high frequency through the human body no neuromuscular stimulation occurs and patient does not get an electric shock.

Monopolar Generator[1]

They are the most commonly available electrosurgical units in all operating rooms (**Fig. 2**).



(AM: amplitude modulation)

Figure 1: Frequency spectrum.

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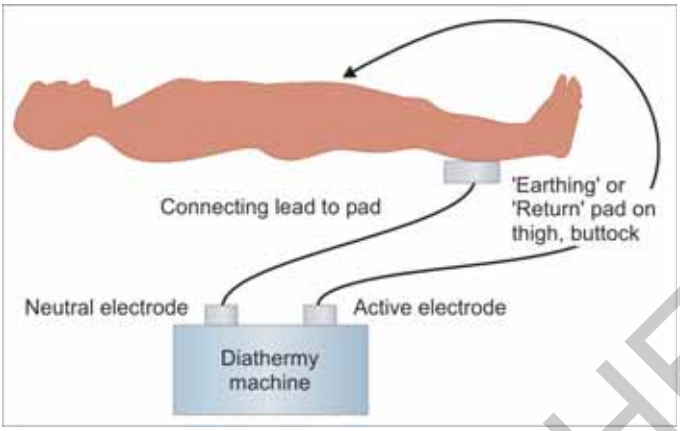

Figure 2: Monopolar circuit.

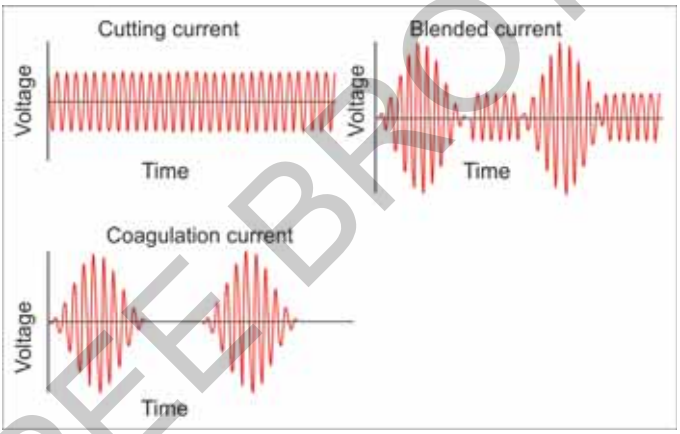

Figure 3: Waveform.

Monopolar circuit: Generator—active electrode—patient—patient return electrode.

Various waveforms generated by electrosurgical generators (**Fig. 3**) are:[1]

- *Cut*: Waveform is constant, heat is generated rapidly leading to tissue vaporization or cutting.
- *Coagulation*: Waveform is interrupted, less heat is produced, and no tissue vaporization occurs instead coagulation occurs.
- *Blend current*: It is modification of duty cycle. Using a lower duty cycle, less heat is produced and less heat produces coagulation. Conversely, higher duty cycle produces lot of heat that vaporizes tissue.

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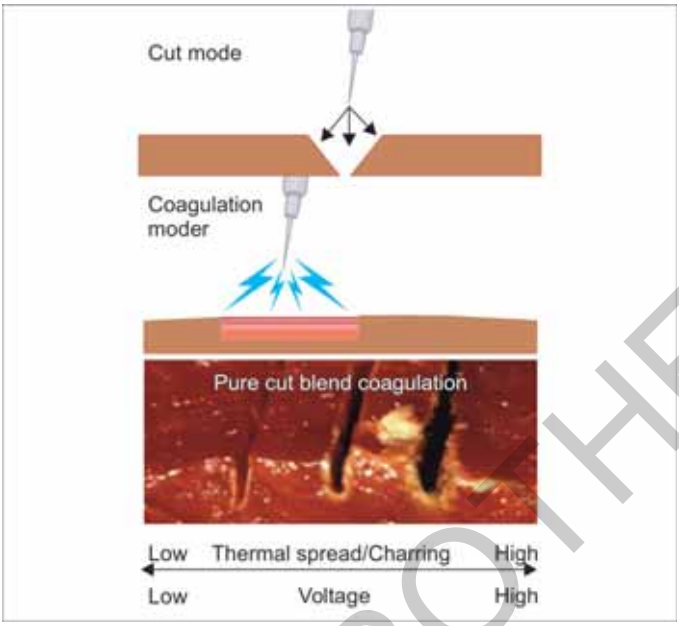

Figure 4: Electrosurgical tissue effect.

ELECTROSURGICAL TISSUE EFFECTS (FIG. 4)

Electrosurgical Cutting

By using this mode, surgeon can cut like a knife, as the intense heat produced vaporizes tissue. When the electrode is held slightly away from the tissue maximum current concentration and maximum cutting can be achieved.

Fulguration

In this mode, charring occurs involving a wider area. In fulguration mode, the duty cycle (on time) is only 6%, this leads to heating up of tissue and coagulation rather than vaporization.

Desiccation

When an electrode directly touches tissue less heat is generated as a result, the cell do not vaporize and instead dry up and form coagulum.

Surgeons can cut with coagulation current and coagulate with cutting current. Cutting current will penetrate deeper and coagulation current will have lateral spread. When coagulating with the cutting current you require less voltage and cutting with cut current also requires less voltage. The above facts have a bearing when you are using electrosurgery in laparoscopic surgery.

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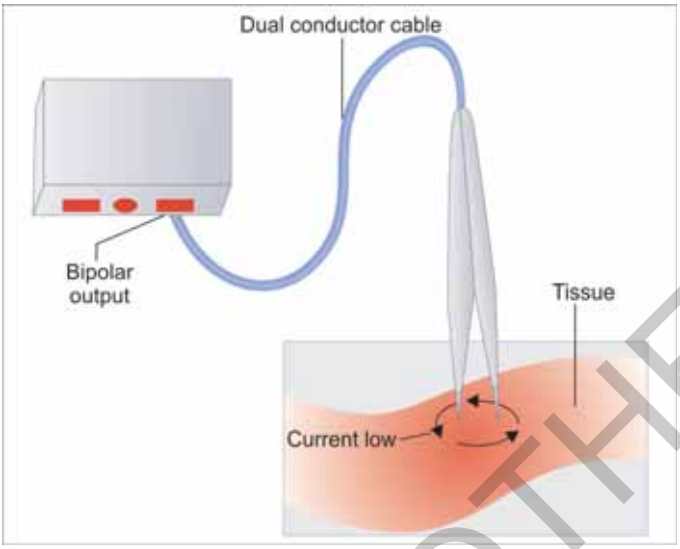

Figure 5: Bipolar circuit.

Bipolar[1]

In this form of electrosurgery, the active and the return electrode are the part of the bipolar device and no patient plate is required. The current passes from one prong of bipolar device to the other through the tissue in between and circuit is completed (**Fig. 5**).

ADVANCE BIPOLAR SYSTEMS

- *LigaSure* (***Fig. 6***): It is advanced bipolar energy source available in surgical armamentarium today. It is combines pressure and energy to create a seal. It consists of a specialized generator system that reliably seals vessels, tissue bundles, and can be used as tool for surgical ligation of tissues in open and laparoscopic surgery.

  LigaSure uses higher current and lower voltage (180 V) along with optimal pressure delivery by the instruments in order to fuse the vessel walls and to create a permanent seal. It has a feedback control mechanism, which gives an alarm once the tissue is adequately sealed. Vessels up to 7 mm can be reliably sealed using this device. It has minimal thermal spread and the seal site is often translucent, this allows the surgeon to look for hemostasis prior to cutting the tissue.

  Sealed blood vessel can withstand a rise in blood pressure equal to three times, the systolic pressure. Sealing tissue and blood vessels with this device is as effective as suture ligation or clip application.

  LigaSure devices are available for open (LigaSure precise) as well as laparoscopic surgery (LigaSure vs. LigaSure lap). LigaSure is as of now not available for robotic platform.

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Figure 6: LigaSure.



Figure 7: PK system.

- Reliable, consistent permanent vessel wall fusion
- Minimal thermal spread
- Reduced sticking and charring
- Seal strength than other energy-based techniques
- Seal strength comparable to existing mechanical-based techniques

- *The Gyrus PK tissue management system (Gyrus Medical, Inc., Minneapolis, Minnesota)* (**Fig. 7**): Gyrus PK system uses bipolar RF energy to seal, transect, coagulate, dissect, vaporize, resect, and mobilize tissue all with the precision and control from one workstation. It is based on principle of vapor pulse coagulation (VPC). On application of the energy, tissue fluid

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Figure 8: EnSeal.

boils producing steam which forms vapor pockets, these vapor pockets coalesce to form vapor zones. This heating of the tissue causes denaturing of vessel wall protein and coagulum formation, which occludes the vessel lumen, pulse-off periods allow tissue for cooling and moisture to return to the targeted area, greatly reducing hot spots and coagulum formation. This system provides enhanced hemostasis, uniform coagulation, minimal sticking, and less thermal spread. The Gyrus PK system has its own generator, which works in tandem with its own instruments. It has application in open surgery, laparoscopy, and robotic surgery. Separated instruments are developed for all types of surgeries but the generator can remain the same.

For open surgery PK, seal open forceps is available, for laparoscopy cutting forceps, dissecting forceps, hook and spatula are available. Recently, the PK dissecting forceps for robotic surgery was launched but not in common use till now.

- EnSeal™ (SurgRx, Inc., Palo Alto, CA) (**Fig. 8**).

Ethicon Endosurgery Generator

The EnSeal tissue sealing system uses an advanced bipolar technology to seal the tissue within the blades of the instrument. It uses the patented I blade technology, which offers strong uniform compression along the tissue sealing line. EnSeal uses a smart electrode technology, which includes numerous conductive particles embedded in a plate, which is temperature-sensitive. Each of these particles acts like a discrete thermostatic switch to regulate the quantity of current that passes into the tissues in contact, thereby generating heat within it. Once the tissue starts heating above a critical level, these nanoparticles interrupt the flow of current and when the temperature dips below, the desired level they again reactivate the current, this cycle is continued till desired temperature is reached (temperature is regulated

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to a set level of 100°C). The procedure continues until the entire tissue segment is uniformly heated and fused without charring or sticking. Less heat is needed to accomplish fusion, since the tissue volume is minimized through compression; energy is focused about the captured segment; and the vessel walls are fused through compression and protein denaturation. It can seal vessels up to 7 mm with a seal strength of seven times the systolic pressure and has one-step actuation for both cutting and sealing. EnSeal was United States (US) Food and Drug Administration (FDA) approved in 2003.

EnSeal has instruments for open surgery (e.g., super jaw tissue sealer)[2] as well as laparoscopic surgery (straight and curved tissue sealer) but not for robotic arm. It has an articulating tissue sealer (G2 articulating tissue sealer)[2] which can have application in single port surgery.

Ultrasonic Generators (Fig. 9)

Physics of Ultrasound

Ultrasound is longitudinal wave, whose frequency is above the audible range. High power ultrasound can be harnessed to produce surgical cutting, coagulation, and dissection of tissues. This involves mechanical propagation of sound (pressure) waves from a power source via a medium to an active blade element.

Ultrasonic dissectors are of two types:

1. *Low power*: These operate at a low frequency and cleaves water-containing tissues by cavitations. The organized structures with low water content are sparse, e.g., arteries, bile ducts, etc. For example, (ultrasonic cavitational aspirators) bring liver surgery and neurosurgery (Cusa, Selector). They do not achieve coagulation.



Figure 9: Ultrasonic generator.

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2. *High power*: These systems operate at high frequency of 55.5 kHz, which cleave loose areolar tissues by frictional heating and, therefore, cut and coagulate the edges simultaneously. In laparoscopic surgery, high power ultrasonic systems are utilized extensively. Ultrasurgical devices consist of a generator, hand piece, and blade. The ultrasonic transducer is housed in the hand piece, a collection of piezoelectric crystals sandwiched under pressure between metal cylinders. The transducer is attached to a mount, which is then connected to the blade extender and blade. The harmonic scalpel cools the hand piece with air. AutoSonix and SonoSurg systems have a large diameter hand piece made of heat-dissipating materials to remove the heat and stop heat buildup.

Once activated, the electrical energy is passed to hand piece, piezoelectric ceramic disks in hand piece become excited, this electrical energy is transferred into mechanical energy. Mechanical energy is amplified at nodes in shaft of the instrument and reaches a maximum amplitude of 55,500 cycle/s at blade tip, when in contact with tissue pressure causes coaptation of vessels, H+ bonds are broken and cell protein is denatured forming sticky coagulum.

Ultrasonic hook or spatula blade can coagulate blood vessels within the 2 mm diameter range quite easily and also the scissors can coagulate vessels up to 5 mm in diameter. Heat generated using the harmonic is limited to temperature below 80°C. This leads to reduced tissue charring and desiccation and also minimizes the zone of thermal injury. Ultrasonic surgery causes slower coagulation than that observed with either electrosurgery or laser surgery, but is as effective.

Incisions made with the ultrasonically activated scalped or cold steel scalpel heal almost identically and, therefore, are superior to electrosurgically made incisions.

Due to the vibration from the active blade, the coagulated tissue does not stick to the active element, this is a unique feature of ultrasonic coagulator as compared to other sources. Also there is less charring compared to other sources, leading to better visualization of the tissue planes thereby improving the surgical precision. It also has a second cutting mechanism, which is the particular "power cutting" offered by a relatively sharp blade vibrating 55,500 times per second over a distance of 80 μm. Excessive heating of ultrasonic dissectors causing collateral damage is well documented in clinical practice, therefore, one must be careful while using this instrument as a dissector. Ultrasonic surgical dissection allows coagulation and cutting with less instrument exchanges (reduction in operating time), decreased smoke, and no current.

Ultrasonic dissectors are available for both open (harmonic focus) and laparoscopic surgery (harmonic ACE).

Now harmonic ACE™ curved shears is available for da Vinci S/Si system.

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Salient Features

- Mechanical energy at 55,500 vibrations/s
- Disrupts hydrogen bonds and forms a coagulum
- Temperature by harmonic scalpel—80°C
- Temperature through electrocoagulation—200–300°C
- Minimal collateral damage
- Multifunctional instruments
- Less tissue sticking
- Less smoke formation
- No stray energy
- No neuromuscular stimulation
- No electrical energy to or through the patient

Factors Affecting Cutting and Coagulation in Ultrasonic Devices

- Tissue tension
- Blade sharpness
- Time
- Power level
- Grip force

It can be sterilized by autoclaving/ethylene oxide (EtO)/Sterrad.

Integrated Ultrasound and Advanced Bipolar Generators

The Thunderbeat™ (Olympus)[3] was the first device to integrate the ultrasonic and advanced bipolar generator. Both the generators can be used interchangeably. Ethicon has also come up with an integrated generator ETHICON ENDO-SURGERY™ compatible with all harmonic and EnSeal devices. The sealing capabilities of this device is necessarily same as ultrasonic or advanced bipolar depending on the generator used.

Comparison of Various Energy Sources

Device	*Safety: Minimal thermal spread*	*Vessel sealing efficacy on vessels ≤7 mm*	*Efficiency: Treatment time*	*Consistency: Independent of user*	*Utility: Multiple uses*
Harmonic scalpel	1 mm	Poor	Excellent	Poor	Excellent
Gyrus PK	2–6 mm	Poor	Excellent	Fair	Fair
LigaSure V	2–3 mm	Excellent	Good	Excellent	Fair
EnSeal	1 mm	Excellent	Poor	Excellent	Poor

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ARGON BEAM COAGULATOR[1]

The ABC uses RF electrical energy, which is delivered to tissue through a jet of argon gas. It provides noncontact, monopolar, and electrothermal hemostasis. Argon is inert and noncombustible. Easily ionizes, making it more conductive and safe medium for electric current to pass. The depth of penetration is less and less smoke is produced.

It is particularly useful in repair of solid organ injury and finds its utility in cases of partial nephrectomy in urological spectrum of surgeries. Drawback of ABCs in laparoscopy is that it increases the intra-abdominal pressures dangerously and may cause fatal gas embolism (**Fig. 10**).

Properties of Argon

- Inert
- Noncombustible
- Easily ionized by RF energy
- Creates bridge between electrode and the tissue
- Displaces nitrogen and oxygen
- Advantages of ABC
- Decrease smoke and odor
- Decreases blood loss, rebleeding, and tissue damage
- Flexible

Light amplification through stimulated emission of radiation (LASER): All the discussion about lasers in urology revolves around prostatectomies. Lasers have been used in laparoscopy. Lasers described for laparoscopic use have been CO_2, diode, KTP, holmium, thulium. Though the use is still not widespread, there have been many animal studies and few clinical trials. CO_2 laser has been used in open surgeries like wide local excision for carcinoma penis, head, and neck surgeons used it for excision of head and neck malignancies.



Figure 10: Argon beam coagulator.

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In laparoscopy, CO_2 laser has been used in gynecological practice to treat endometriosis, etc.

Lot of experimental work in animal models has been done demonstrating utility of laser in laparoscopic partial nephrectomy. Clinical studies have also demonstrated use of thulium and holmium lasers for laparoscopic partial nephrectomy.

A study by KUN Pang et al. demonstrated use for thulium laser for resection of distal ureter with bladder cuff in case of transitional cell carcinoma (TCC) kidney. An Italian study has demonstrated use of thulium laser for partial nephrectomy. On the whole, use of lasers in laparoscopic surgeries is yet to find its distinct place, but as the search for a better cutting and coagulating energy source continues, more studies on lasers in laparoscopy are going to tell us if lasers in laparoscopy are here to stay.

Note: Details about physics of laser can be found elsewhere in the book.

Radiofrequency Ablation

It consists of a probe, which may be a simple needle, or in form of prongs. The probe is mounted on a RF generator. The generator sends RF waves through the needle, RF energy causes atoms in the cells to vibrate that will create friction. This generates heat (as much as 100°C) and leads to coagulative necrosis. The use of RF ablation as energy source is limited.

Gill et al. have studied animal models of laparoscopic and percutaneous RF ablation of part of kidney. The application of RF ablation is more studied in malignancy, e.g., ablation of small renal masses and carcinoma prostate. It is as of now less likely to be used as a hemostatic agent.

Microwave Ablation

Like RF ablation, microwave ablation is also being used for tumor ablation rather than as a hemostatic agent for surgery. It is an alternate way of producing thermal coagulation of tissue, microwaves induce ultrahigh speed (2,450 MHz) alternating field current, resulting in rotation of water molecule. This heats up the tissue causing coagulative necrosis. Majority of experience comes from its use in hepatocellular carcinoma. It is being used in management of small renal masses and carcinoma prostate. It can be used laparoscopically as well as image guided.

Cryotherapy

The cell destruction by rapidly cooling the cell and the thawing is the principle of cryotherapy. It can be used laparoscopically as well as under image guidance. It is being used in management of small renal masses and carcinoma prostate. As of now it cannot be used for cutting and coagulating tissue in open and minimal access surgery.

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SAFETY CONSIDERATION[1]

- *Patient pad placement*: Patient plate should be in contact over a large surface area at least 100 cm^2. One should avoid bony prominences; soft pads are better than metallic plates as they give uniform area of contact. The pads should be placed near the area of interest.
- *Demodulated current*: Modern generators filter demodulated current so that only electrical current of 250–2,000 kHz is delivered. Demodulated currents occur in common practice when an active electrode is activated off metal after which touched toward the metal, like the common practice of "buzzing a hemostat." Demodulated currents produce neuromuscular activity. The flickering movements in laparoscopic surgery may be caused by demodulation of current to diaphragm and adjoining muscles.
- During minimally invasive surgery:[1]
  - *Direct application*: Direct application of active electrode to an unintended area causes tissue injury.
  - *Direct coupling*: When the activated active electrode touches a nearby metallic instrument it energizes it and this stray energy may find its way to the patient plate causing injury. Like if a monopolar hook touches a laparoscopic telescope, if the telescope is in turn in contact with bowel. The energized telescope will cause thermal injury to the bowel (**Fig. 11**).
  - *Insulation failure*: Breaks in the insulation can cause energy to stray and cause tissue injury. For example, if a portion of monopolar hook has an insulation break and this area comes in contact with bowel, it will cause the current to leak and may lead to bowel injury (**Fig. 12**).
  - *Capacitative coupling*: Capacitance is the charge generated when an insulator separates two conductors. This charge has a tendency to

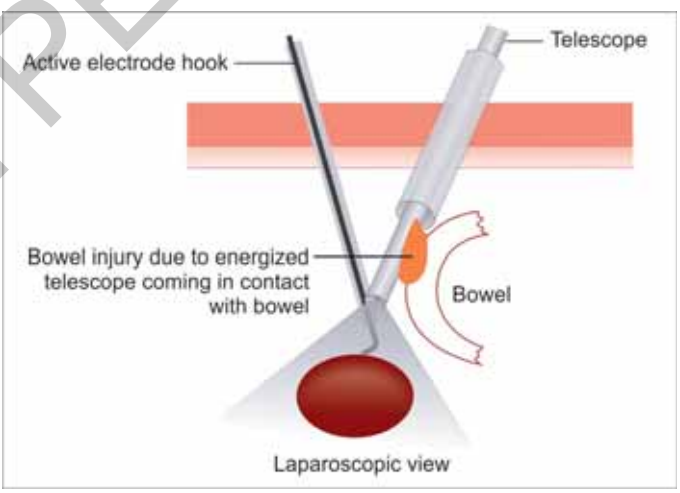

Figure 11: Direct coupling of current.

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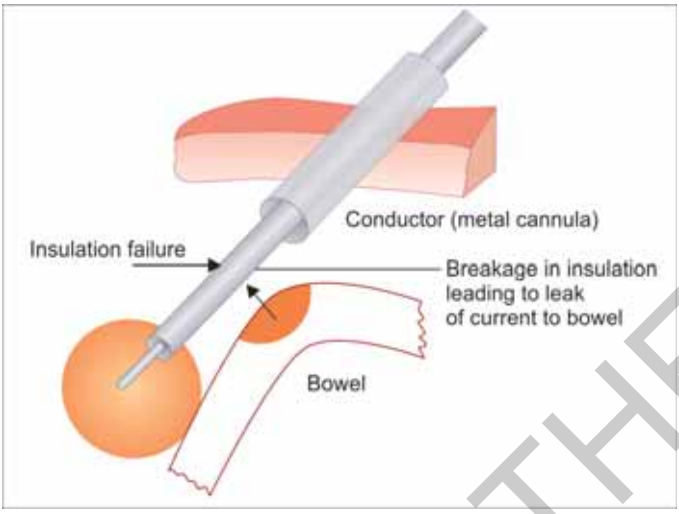

Figure 12: Insulation failure.

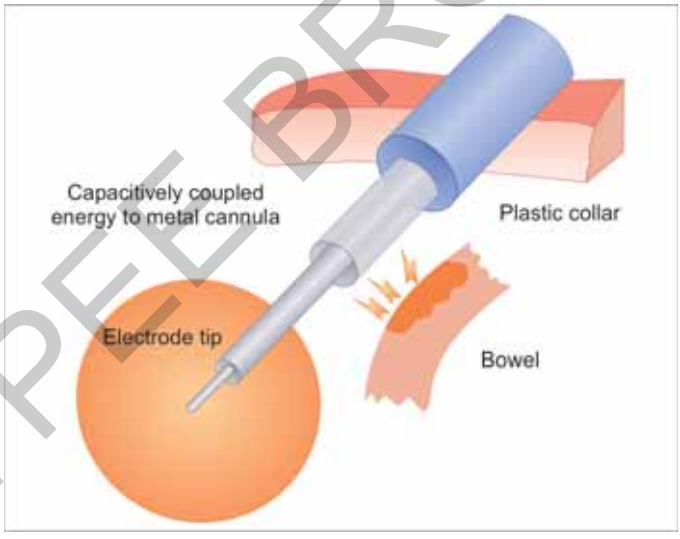

Figure 13: Capacitative coupling.

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complete circuit and cause surrounding organ injury. For example, hybrid cannula with suction and hook have a metallic hook covered by an insulator which is fixed within a metallic suction cannula. The insulator between to metallic conductor acts as a capacitor and when it comes in contact with adjacent bowel the stray energy may be leaked causing a bowel injury (**Fig. 13**).

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