Electrosurgery In Laparoscopy

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'Electrosurgery' is the generation and delivery of radiofrequency current between an active and dispersive electrode to elevate the tissue temperature for the purpose of cutting, fulguration, and desiccation. 'Electrocautery' is not the correct synonym for electrosurgical units, although they are commonly used. Cautery refers to a direct heating process whereby the electricity does not flow through the tissue while in electrosurgery, the electric current actually passes through the tissues. Electrosurgical unit (ESU) is the correct term for modern units that utilize either monopolar or bipolar elements. The first modern, high-frequency electrosurgical generator was developed by William Bovie, a Harvard physicist, in 1926. This unit causes flow of electrons through the instruments and tissue, concentrated to small contact areas. This induces heat generation by creating molecular motion, rather like heating water in microwave. The transfer of heat from one object to another occurs through one or more of three basic mechanisms: conduction, convection and radiation. Electrosurgery when used properly, relies only on radiation which involves the transfer of thermal energy by electromagnetic waves.

Biological effects of electricity

Three biological effects can arise when electric currents flow through human tissue: electrolyte, faradic and thermal effects. The electrolytic effect is predominant with low-frequency alternating currents in which electrolysis induces flow of positively charged ions to the negative pole and the negatively charged ions to the positive pole. It is undesirable effect in electrosurgery as it can lead to chemical cauterisation and tissue damage. Currents with frequency range <20 KHz cause stimulation of nerves and muscle cells (faradic effect). This property is used in diagnosis of neuromuscular disorders, identification of the nerve trunks during surgery or used by anaesthetists to assess the neuromuscular blockade but is undesirable during electrosurgery as it could be dangerous especially when electrocuting is done near nerve trunk. The thermal effect is obtained with high-frequency currents and has its clinical application for cutting or coagulation. Above 40 0C, reversible cell damage occurs while irreversible cell changes occur above 50 0C. While coagulation and haemostasis (conversion of glucose to collagen and shrinkage of collagenous tissue) occur above 70 0C, desiccation (cellular fluid vaporization and shrinkage of coagulum) occurs above 100 0C and carbonization occur from 200 0C. The frequency of alternating current used for electrosurgery is between 500 and 4000 KHz so both the electrolyte and faradic effects are largely eliminated and allows utilization of only the thermal effect.

Therapeutic effects of electrosurgery

There are three distinct therapeutic effects that electrosurgical energy has been reduced to in practice; cutting, fulguration and desiccation. Electrosurgical cutting is non-contact mean of dissection that requires a high current (continuous uninterrupted flow) low voltage (small peak to peak difference) waveform to elevate rapidly the tissue temperature producing vaporization of the fluid contents and division. During pure electrosurgical cutting there is minimal effect on haemostasis on the walls of the incision. This pure cutting waveform is referred to as undampened or non-modulated current (Voyles and Tucker 1992). Advantages of this cutting technique over the traditional mechanical incision include reducing bleeding, preclusion of germ implantation, avoidance of mechanical damage to the tissue and being applicable endoscopically.

Electrosurgical fulguration (stray coagulation) is a non-contact modality of coagulation. It utilizes high voltage low current non-continuous waveform designed to coagulate by means of spraying long electrical sparks to the tissues. These bursts of increasing voltage are interrupted by intervals without current flow, resulting in cell heating and dehydration, with haemostasis and charring. Using the coagulation current, there is less rapid tissue heating as the pause between bursts of current allows the heat to dissipate with subsequent minimal or no cutting of the tissues. The commonest use of fulguration is to arrest bleeding emanating from capillary or arteriolar bed where a district bleeder cannot be identified. This is achieved by maintained raining effect of sparks until the electrode is withdrawn or the tissue is carbonized to the extent where sparking cease.

Desiccation is another form of coagulation that is achieved by electrode contact to the tissues. The high-voltage waveform of the coagulation mode causes tissue desiccation that is more penetrating and inflicts more damage to the surroundings than the cutting waveform of equal power. The commonest application of desiccation, in open surgery, is occlusion of discrete bleeder caught by a haemostat; when energy is applied to the haemostat body. Coaptation of the vessels occurs by collagen chain reaction resulting in a fibrous bonding of the dehydrated denaturated cells of the endothelium.

With a ratio of modification of the cutting waveform, by interrupting the current and increasing the voltage, 'blend' waveform is established. It becomes non-continuous with a train of pockets of energy consisting of higher voltage and reduced current per-time to increase haemostasis during dissection. The blend waveforms will require a longer period of time to dissect the same length of incision as compared to the cutting waveform due to the interrupted delivery of current at the same power setting and consequently increase the coagulation of the small vessels. These blends are very valuable when needed to control bleeding during dissection but unfortunately, it increases the tissue necrosis and then risks of postoperative infection. The amount of smoke plume will be increased in laparoscopy on using high blends or coagulation modes.

Many variables determine the electrosurgical cutting and coagulation effects on the tissues. A definite correlation between peak voltage and coagulation zone was determined as the higher the voltage the broader the coagulation zone. The duration of the electrical energy application and the tissue impedance are other influencing factors. When the electrode is moved rapidly there will be little coagulation effect but slowing down the rate of movement increases it. Shape of the electrode is of decisive impact. A hook electrode, besides having a convenient geometry to handle the tissue, has a moderate electrode size to allow haemostatic dissection. Thin-needle electrodes are used in microsurgery as it provides finer and cleaner dissection but on the expense of coagulation. Ball electrodes will be good for electrodesiccation and fulguration of oozing tissue beds as the thicker the electrode the wider the coagulation zone.

Monopolar and bipolar systems

Electrosurgical units (ESU) can be divided into two major types: monopolar and bipolar. Monopolar system refers to current flow from one active electrode through the patient, who is entirely included in the circuit, and exists via dispersive electrode to the generator. Monopolar systems have proved advantages of being quick and effective in dissection. It's effective at haemostasis due to its greater penetrability so, it might be suitable to the deeply seated vessels.

Safety of monopolar system

Safety of the monopolar electrosurgical energy has been proved by 50 years during open laparotomy, however, the potential problems associated with its laparoscopic use need to be fully appreciated. Problems of the monopolar electrosurgery relate to unrecognised energy transfer or 'stray current' outside the view of the laparoscope. Mechanisms of these stray currents are found to be mainly insulation breaks, capacitative coupling or direct coupling. Laparoscopic images viewed on the monitors show about 10% only of the active electrode which is covered with insulating material. Any breakdown in insulation particularly along the shaft, out of the laparoscopic view, may produce severe burns to adjacent structures. Insulation failures can occur either due to normal wear, improper handling, sharp edges of the metal trocar or excessive heating by high voltage frequency. However, hazards of insulation failure depend largely on the location of the point of failure. Failures mostly occur in the distal portion of the instrument which is, fortunately, within view of the surgeon. Defects in the handle insulation usually pose little direct risk unless unexpected shock to the surgeon leads to patient injury. The shaft of the instrument is divided into two parts, intra- and extracannular. Failures in the part outside the cannula are the most dangerous being out of view and the most careful surgeon is unable to predict it. Insulation failure inside the cannula is not detectable if a plastic cannula is used, however, with metal ones the resulting arcing of currents create a lower frequency current which is usually dissipated harmlessly through the broad surface of contact at the abdominal wall. Some authors recommend the use of metal cannulas. Thorough visual examination of the instruments is mandatory preoperatively by the operating room staff to detect any defect in the insulation material. There are several recent commercial solutions to this problem including the use of disposable instruments or electroshields. The electroshield consists of the reusable sheath that surrounds the laparoscopic electrode and the electroshield monitor. It slides over the shaft of standard 5 mm instruments, dynamically monitors insulation failure and deactivates the electrosurgical generator should a fault develop. Although they are effective, two disadvantages are identified to these shields; the additional expenses and wider pore cannulas are mostly required (7-8 mm cannula for 5 mm instrument).

Capacitative coupling occurs when electrical energy is induced from the active electrode to a nearby conductive material despite intact insulation. A capacitor exists wherever an insulating material separates two conductors that have a different potential between them; a situation which may be created during the laparoscopic surgery. A classical example occurs when insulated monopolar electrode is passed through the operating channel of the laparoscope, 50% to 70% of the electrical energy passed through the well-insulated electrode will induce capacitative coupling to the surrounding laparoscope. The acquired energy can be transferred to surrounding skin then to the ground plate without causing injury if the covering sleeve of the scope is conductive. If the laparoscope is inserted through plastic cannula or conductive sleeve with non-conductive collar, the energy will be concentrated on the laparoscope and may cause an unintended injury to adjacent organ as bowel, omentum and blood vessels. This potential hazard can be avoided by using conductive trocar sleeves for the scope. In 1980, the Food and Drug Administration (FDA) advisory panel reported that the non-conductive trocar sleeves of the scope is potentially dangerous and should not be used with the operating laparoscope and recommended the use of all metal cannulas. Again the use of electroshields will collect measure and shunt all the capacitatively coupled currents. Direct coupling occur when an active electrode touches other metal instruments within the abdomen, transferring the energy to the second instrument and possibly injuring tissues with which it comes in contact. The only way to avoid such injuries is not to activate the electrode until the operative field is in full panoramic view and avoid contact of the activated electrode with other instruments or the scope during laparoscopic procedures. Many authors recommend the use of 300 forwards oblique scope instead of the zero degree as better and a more precise field of view is usually obtained. There had been controversy about the possibility of intestinal burns being the result of contact with hot recently cauterized tissues or with recently activated electrodes. DiGiovanni (1990) investigated this possibility in animal study and was unable to produce any histologic evidence of tissue injury.

High-frequency current leakage is a well known complication of monopolar units that may cause collateral injuries. This occurs when the patient's body comes in contact with another electrically conductive object e.g operating table or infusion stand, while the return electrode improperly placed, then high current density causes thermal necrosis at the point of contact. The burn usually occurs outside the surgeon's view while the patient is under anaesthesia unable to detect or respond to burn. Arcing or sparking to adjacent structures can also occur when high voltage coagulation current is used which may jump the gap between active electrode and unintended tissues. Under atmospheric condition, a driving pressure of 15000 V is required to push electrons more than one cm in the air which is, fortunately, well above the maximum voltage (1200 V) produced by the high-frequency electrogenerators currently recommended by the FDA for laparoscopic use. It has been found that electrons take 30% more power to spark or arc in CO2 than in room air; thus at the same electrosurgical power settings, less arcing occur in laparoscopy than laparotomy. Recent advancements have been introduced to promote the safety of the electrosurgical units such as the generators with return electrode monitoring (REM) that gives alarm and deactivates the unit when contact between the pad and skin is inadequate. A microprocessor-controlled generator is another new advancement. When applied to a tissue, this device automatically initiates and concludes the process when optimal coagulation has been achieved through detection of the vaporization which coincides end-point of coagulation. In case of cutting, the cutting effect and quality become unaffected by the variables of size and shape of the electrodes, type, speed of cutting and varying tissue characteristics.

Safety of bipolar systems

In bipolar units, both the active and return electrodes are housed within the same instrument so the current flows only through the tissue between the two blades of the electrode and return to the generator without passing through the whole body. No remote dispersive electrode is required. Reich first reported bipolar desiccation of large vessel coagulation in 1987. Bipolar forceps can use high frequency, low voltage cutting current to coagulate vessels as large as the cystic, ovarian and uterine arteries. Bipolar electrocoaptive desiccation seals arterial blood vessels immediately so that they can withstand the pulsating arterial pressure until permanent fusion of the collagen and elastic fibres is accomplished through the healing process. Cessation of flow is indicated by an ammeter or current flow monitor. Coagulation current is not preferred in bipolar systems as it may rapidly desiccate the outer layer of the tissue, producing superficial resistance that may prevent deeper penetration. Cessation of tissue bubbling is not a reliable indication of complete desiccation. It is always recommended to use an indicator system for complete haemostasis especially when the bipolar current is used for large vessel coagulation. Recently, microbipolar forceps has been introduced which contain a channel for irrigation. It allows irrigation of the bleeding sites to identify vessels before their coagulation and prevent sticking of the electrode to the eschar created.

Actually, bipolar electrosurgery is intrinsically safer than the monopolar systems as it uses low voltages that limit the depth and breadth of necrosis. It also has a more precise localised tissue effect. The current flows only to the site where coagulation is required and because each jaw of the forceps is the same surface area, the electrons only heat the tissue imposed between them.

This flow process is self-limiting because as the cells are charred, the current ceases to pass avoiding damage to the surrounding tissues. Standard bipolar technology eliminates the possibility of arcing or capacitative coupling as both electrodes are contained in the same instrument and their magnetic fields will cancel each other out. The possibility of inadvertent injury due to insulation failure is reduced in this system. Despite the advantages of the bipolar systems, however, they cannot fully respond to many challenges of using electrosurgery in the minimally invasive surgery due to some technical difficulties. It requires that the tissue being coagulated be surrounded by the forceps, therefore, it is more difficult to use with retracted blood vessels or with thick tissue. Until recently, only bipolar coagulation was possible but continuous developments have led to bipolar cutting and dissection. The power supplies on these cutting instruments adopt the same physical principles underlying the monopolar systems as the sparks occur between the tissue and one of the electrodes. Another characteristic of bipolar systems to be considered is its potential to create a 'mushrooming' coagulation effect inside and outside the actual space between the jaws of the instrument. This is created because of the magnetic field-like nature of the electrical conduction. This means that delicate structures such as the ureters are not immune from injury although the spread can go just for several millimetres around the tip of the device. Many cases of inadvertent ureteric injury have been reported after using bipolar electrosurgery.

In spite of this mushrooming, bipolar instruments provide much more control over the electric current than dose the monopolar devices. The standard bipolar systems have variable tissue effects due to variable tissue impedance. They have maximum efficiency output at impedance of 100 ohms which matches well with impedance encountered with vessels, blood and irrigants but the efficiency of coupled energy into desiccated vessels (impedance of 600-1500 ohms), fat and connective tissue (impedance of > 1000 ohms) is quite low. Another problem associated with a standard bipolar system is tissue carbonization that creates a thin layer of high impedance and subsequently decreases the operating efficiency, being an electrical barrier preventing the completion of circuit. When the temperature increases, tissue sticks to the paddle leading to vascular rebleeding as it peels off.

Procision bipolar electrosurgery system is a new modification introduced to overcome many of the disadvantages of the standard system. It uses Advanced Resonance Technology to deliver consistent power and repeatable tissue effects across a wide range of tissue impedance up to 10000 ohms, which is well in excess of the standard systems. This technology matches the output impedance of the Procision device to the patient's tissue impedance by varying the frequency at which the device operates. This means that the device is operating at optimum efficiency throughout the procedure allowing much lower power settings than conventional diathermy, which operate at fixed frequencies. Another problem that is solved is carbonization, which creates an electrical barrier.

Procision modulates the output waveform to induce carbonization but unlike conventional outputs, the waveform then changes to a high-energy sinusoidal output capable of breaking through the impedance wall and re-establishing electrical continuity with the tissue. It is claimed that Procision allows true electrosurgical cutting owing to the higher proportions of energy delivered to the patient's tissue at higher tissue impedances than the conventional systems. The early clinical experience with this technology is promising.

Prevention of electrosurgical complications

Burn injuries represent an important area of potential trauma during laparoscopy. Good surgeons perform good surgery with whatever tools they choose to use. The best surgeons make the effort to become very knowledgeable about the attributes of every technical tool from which they can choose. Wheeless (1978) has reported the overall incidence of thermal injury associated with laparoscopy at 2.2 per 1000 cases. The Royal College of Obstericians and Gynaecologists (RCOG) Confidential Enquiry into Gynaecological Laparoscopy (1978) reported one per 1000 cases of non-fatal burn complications and showed that sterilization by electrosurgery resulted in less complications than clips or rings. Peterson (1981) have reported two deaths resulting from thermal intestinal injury after monopolar surgery. More recent reports proved the same injury risks to the patients. The majority of injuries, mostly intestinal, go unrecognised at the time of insult and commonly present three to seven days afterwards. Grainger et al. (1990) reported many cases of ureteric injuries; most of them were following both monopolar and bipolar electrosurgical procedures of sterilization or ablation of endometriosis.

On using conventional electrosurgical equipments in laparoscopic surgery, many surgical techniques and guidelines have been suggested to prevent patient complications. It is recommended to avoid high power settings and high-voltage waveforms as spray coagulation and to use the lowest possible power setting that will deliver the desired tissue effect. There are three modes of coagulation: soft, forced and stray coagulation according to power and modulation of used current. Soft coagulation is the safest form of monopolar coagulation that employs relatively low unmodulated voltage (190 V) so; it is the mode preferred during minimal access surgery. It must be noted that coagulation can be accomplished adequately with low-voltage, low-power settings using a cutting waveform, as efficient but safer than coagulation waveform.

All-metal cannulas and no hybrid systems (trocars or cannulas that are comprised of metal and plastic components) are recommended so that stray currents can be dispersed harmlessly through the patient abdominal wall. Avoidance of touching the active electrodes to other metal instruments or open-circuit activation of the electrosurgical units is basic practical directions. Multiple short activations are preferable to prolonged activations to allow the normal surrounding tissues to remain cool. Using bipolar systems is to be recommended when appropriate. Recent technology, when available, as disposable instruments, microprocessor-controlled electrosurgery, Procision technique and active electrode monitor (AEM), undoubtedly, increase the margin of safety. There are suggested interventions for perioperative nurses to follow that can help to minimize electrosurgical complications. These directions include preoperative and postoperative examination of the instruments for insulation failure and discarding sharp edged cannulas, avoiding reuse single-use active electrodes, proper connection of equipments, ensuring that the power settings are in typically employed ranges and avoiding placing active electrodes on the patient drapes.

Further readings

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