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Your Vision, Our Future

Energy Training Manual

PRINCIPLES OF ELECTROSURGERY

(Basic)

CONTENTS

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INTRODUCTION 1

Electrosurgical units (ESU)[1] were first introduced during the early twentieth century and have become an increasingly important component of most of today's surgical and also endoscopic procedures where cutting of tissue or haemostasis is required. The physician has a wide portfolio of electrosurgical equipment to choose from and more and more sophisticated technologies contribute to more safety for users and patients. Nevertheless, an understanding of the basic principles of electrosurgery is essential in order to achieve the best possible clinical result for each individual case. This guide aims to give the medical personnel a better understanding for the principles of electrosurgery. ■

1 Our general term nowadays for a generator or ESU is "HF unit". You will find that term in the following.

BASICS 2

2.1 HISTORICAL BACKGROUND

There have been many reports of using hot oils and hot irons as crude methods of haemostasis, often with devastating results. Egyptian pioneers recognized as early as 3000 B.C. that a bleeding can be stopped by applying heat. The history of the development of radiofrequency surgery even reaches back to Hippocrates, a Greek physician of antiquity, who used a red-hot iron to arrest the flow of blood (haemostasis) during amputations around 400 BC. In the middle of the 19th century, the so-called ‘Paquelin burner’ was developed as a thermocauter (instrument for thermocautery) and the so-called ‘galvanic cauter’ as an electrocauter: The first of these consisted of a metal pin heated to over 1000 °C by a fuel/air mixture and used for the destruction of tumourous tissue. The electrocauter, on the other hand, made it possible to separate or slough off biological tissue by means of a knife or platinum sling raised to red heat by direct current. Prior to the introduction of high frequency technology at the beginning of the 20th century, such ‘cauterization’ was the method usually applied in the field of surgery. In 1891, the French physicist and biologist d’Arsonval reported on thermal effects induced in biological tissue by using alternating current at high frequencies without the stimulation of muscles or nerves (so-called ‘Faradic effect’). In the year 1908, Nernst could verify that nerve and muscle stimulation decreases with increasing frequency. Gildemeister stated in 1912 that above 200 kHz stimulation ceases to exist. In the years 1911 and 1912, Czerny, Werner and Caan published detailed descriptions of methods for the application of RF current to cut and coagulate tissue that are still used today. Between 1907 and 1910, ‘deep coagulation’ with RF current was developed as a method for tissue destruction, particularly against cancer, by Doyen, Czerny and Nagelschmidt. Doyen even used bipolar applicators. Lee DeForest patented the first electrosurgical device – a high frequency spark-gap generator – in 1907. Harvey Cushing and William Bovie collaborated in the 1920s, resulting in an update of these spark-gap generators with sophisticated technology to increase the safety of electrosurgery. Advances in radiofrequency and computer technology have continued to increase the safety of these devices and enabled the development of versatile bipolar devices.

Electrocautery is defined as the use of direct electric current to heat an instrument that is used to coagulate and seal tissue. It should not be confused with **electrosurgery** which uses alternating current at radiofrequency levels to directly heat the tissue instead.

2.2 PRINCIPLES OF ELECTRICITY

For a better understanding of electrosurgical effects on biological tissue, this chapter will provide an overview on elementary aspects of electricity.

Electricity is based on electrons, protons and neutrons, which together create atoms. Atoms which have the same number of protons as electrons are neutrally charged (see fig. 1a). Atoms with more protons than electrons have a positive charge and are called positive ions. Atoms with more electrons than protons have a negative charge and are called negative ions (see fig. 1b).

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Electric current

When charged particles (electrons, ions) flow through a conductor (e. g. metal, air gaps, tissue) an **electric current** (in formula referred to as: I) is formed.
In other words: Electric current is the rate at which electrons or ions flow along a conductive pathway and is measured in **Ampère [A]**. The value describes the number of electric charges (electrons or ions) per time (1 A = 6.24 · 10^{18} electrons per second).

Examples:

Electronics/ integrated circuits:	1 nA–10 mA (0.000000001–0.01 A)
Electrosurgery:	10 mA–10 A (0.01–10 A)
Power transmission:	100 A–100 kA (100–100,000 A)
Lightning:	200 kA (200,000 A)

Note: Current through metal is a flow of electrons. Current through liquids is a flow of ions. Biological tissue consists of a greater or lesser extent of electrolytic liquid (ions) and can conduct electrical current. The effects of electric current on biological tissue are described in chapter 1.3.

There are two types of electric current:

- **Direct Current (DC)**, where the electricity flows in one direction only (see fig. 2a). Batteries for example supply direct current.
- **Alternating Current (AC)**, where the flow direction of the electrons (or polarity) changes continuously (see fig. 2b). A wall socket supplies alternating current. Alternating current flows in cycles and is bidirectional. The usual waveform of AC is a **sine wave**. For electrosurgery, only alternating current is used (see chapter 1.3).

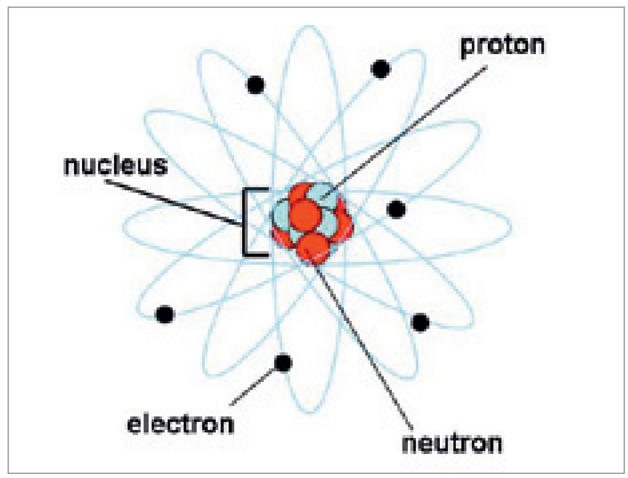

Fig. 1a: Structure of an atom

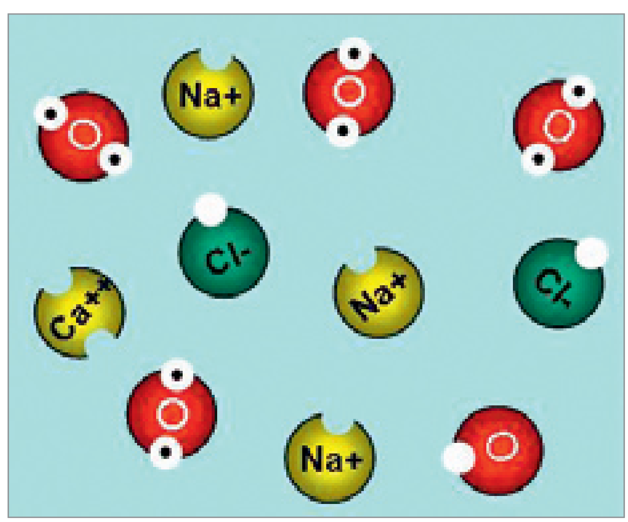

Fig. 1b: Positive and negative ions

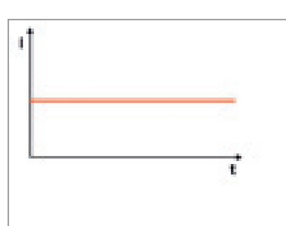

Fig. 2a: Direct current (DC)

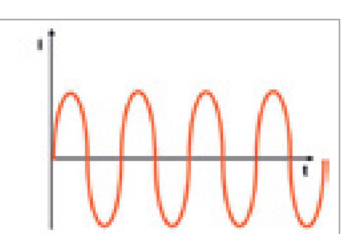

Fig. 2b: Alternating current (AC)

Voltage

The Voltage (in formula referred to as: U) is the force which is needed to push the electrons or ions through an electric conductor such as tissue and is measured in **Volts [V]**. One volt moves 1 ampere of current through 1 ohm of resistance (see below). A voltage between two poles is generated by the separation of positive and negative charges.

Examples:

Electronics/ integrated circuits:	0.1 µV–10 mV (0.0000001–0.01 V)
Electrosurgery:	10 V–7 kV (10–7,000 V)
Power transmission:	230 V–400 kV (230–400,000 V)
Lightning:	several MV (several million V)

Power

The energy converted per second by a current which flows through a resistance is called power (in formula referred to as: P) and is measured in **Watts [W]**.

Power is a product of voltage and current:

$$P = U \cdot I$$

Power dissipated by resistance produces heat.

Note: The higher the power level, the more heat is created in the tissue.

Energy

Energy (in formula referred to as: E, Q) is a physical quantity and a property of objects and systems which is conserved by nature. Energy is often defined as the “capacity to do work”. Several different forms of energy, such as kinetic (movement), thermal (heat), electromagnetic, chemical and nuclear energy have been defined to explain all known natural phenomena.
The energy is measured in **Joule [J]**. Energy can be converted from one type to the other (e.g. chemical energy such as coal can be transformed into electrical energy by a power plant; tissue can be heated by electrosurgical energy):

The electrical energy can be calculated by multiplying power by time:

$$E = P \cdot t$$

Impedance/Resistance

Impedance (in formula referred to as: Z) and resistance (in formula referred to as: R) both represent oppositions to the flow of current, but they are not the same.

Impedance (Z) is the sum of two quantities called resistance (R) and reactance (X):

$$Z = R + X$$

The resistance (resistive part/real part) of **impedance** can dissipate power and hence produce heat. The resistance for electrons as they attempt to move through tissue is measured in **Ohm [Ω]**. Not all kinds of materials convert electrical energy into heat the same way. Conductors have a low impedance to the flow of electrons and include for example copper, saline, blood and muscle. This is why the neutral electrode (or patient plate, return electrode etc.) should be placed over a large muscle mass during monopolar electrosurgical applications. Insulators have a high resistance to the flow of electrons and include air, rubber, plastic, fat, water and glycine.

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Reactance is determined by the inductive and capacitive behavior of the electrical set-up such as condition and position of cables.

Note: The higher the water content of biological tissue, the lower is its resistance.

Frequency

Frequency is the number of times an alternating current reverses (from minus to plus) in one second and is measured in **Hertz [Hz]** (see fig. 3). In Europe frequencies with 50 Hz and in the USA 60 Hz are used in household power supplies and may cause cardiac defibrillation due to electric shock. To give an example: Batteries are powered by direct current supply only, that means that the polarity does not change at all and the frequency is 0.

Low frequency is defined as less than 100,000 cycles (= 100 kHz) in one second. The physical effects of low frequency electricity can vary and may include pain, muscle and nerve stimulations and even cardiac arrest. As the human body is less sensitive to current with high frequencies, electrosurgical generators use frequencies between 300 kHz (= 300,000 cycles/sec) and 4 MHz (= 4,000,000 cycles/sec) and they are called High Frequency (HF) units.

In the Anglo-Saxon world, high frequency (HF) is often called radiofrequency (RF) because radio transmitters also operate in this frequency range.
The frequency (f) can be calculated according to the formula:

$$f = \frac{1}{T}$$

Example: What is the frequency when one period T takes 10 ms?

$$f = \frac{1}{0{,}01s} = 100\ Hz$$

Circuit

All electrical current has to complete a circuit. The current is extracted from ground at the power plant and distributed to outlets. The current is then delivered to the patient at the

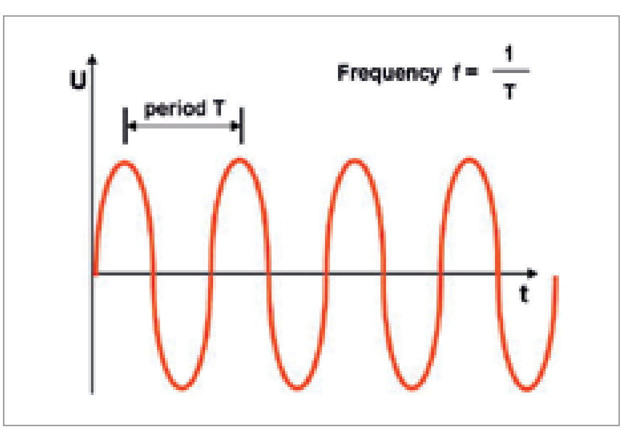

Fig. 3: Frequency of alternating current

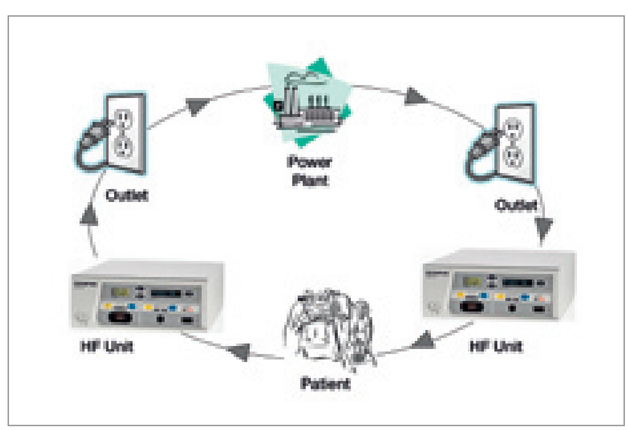

Fig. 4: Circuit of electricity

surgical site and then returns to the HF unit and back to ground and power plant (see fig. 4).

Ohm's Law

In order to perform electrosurgery, a **voltage (U)** source is applied across the tissue, which causes an electric **current (I)** to flow. The **voltage** source and tissue form a simple **electrical circuit**, with the tissue acting as a **resistor (R)**.

The formula simply demonstrates that the resistance of the tissue determines the current flow:

$$I = \frac{U}{R} \quad \text{or} \quad R = \frac{U}{I} \quad \text{or} \quad U = R \times I$$

This relationship is known as Ohm's Law. It is **one of the most fundamental laws** in the field of electronic and electric engineering and demonstrates the relation between voltage, current and resistance.

Joule's Law

Current flowing through a resistor causes the conversion of electrical energy into **heat (Q)**. The converted energy is measured in **Joule (J)**. In electrosurgery, this heat is generated in the tissue itself. In other words, the resistance of the tissue converts the electrical **energy** of the voltage source into **heat (thermal energy)** which causes the **temperature (T)** of the tissue to rise.

Joule's law: generated heat = converted electrical energy

$$Q = E$$

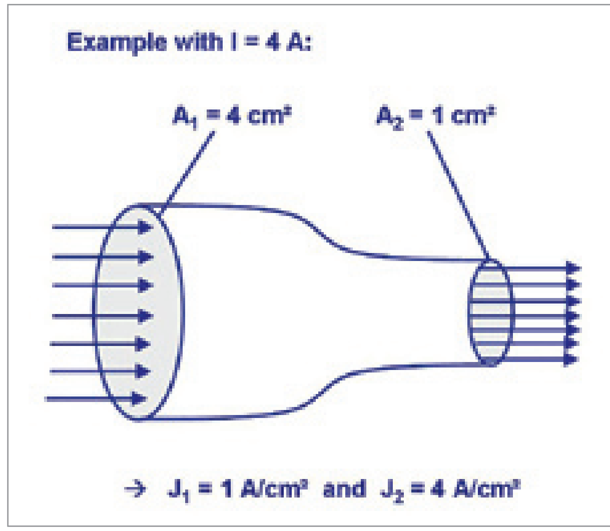

Fig. 5: Low vs. high current density

Current Density

Current density (in formula referred to as: j) is the concentration of electrical current in the cross section of a conductor and is measured in **A/m²**. The current density depends on the size and shape of the electrode. The active electrode of the EndoTherapy instrument has a very small surface compared to the neutral electrode (see chapter 2.4) with a large surface. A small area results in high current densities and produces the tissue effect at the surgical site. Bigger areas such as the neutral electrode correspond with a low current density. Figure 5 gives an example for high and low current density respectively.

$$j = \frac{I}{A} \qquad A = \text{cross-sectional area}$$

The following table summarizes the most important parameters in electrosurgery:

Parameter (Symbol)	Unit (Symbol)	Equitation	Explanation
Voltage (U)	Volt [V]		A voltage between two poles is generated by the separation of pos. and neg. charges.
Current (I)	Ampère [A]		number of electric charges (electrons or ions) per time 1 A = 6.24 x 1018 electrons per sec.
Resistance (R)	Ohm [Ω]	$I = \frac{U}{R}$	(Ohm's law) Resistance is the opposition to the flow of current.
Power (P)	Watt [W]	$P = U \times I$	in electrosurgery: product of voltage and current
Energy (E, Q)	Joule [J]	$E = P \times t$	in electrosurgery: product of power and time
Heat (Q)	Joule [J]	$Q = E$	(Joule's law) Heat is thermal energy.
Frequency (f)	Hertz [Hz]	$f = \frac{1}{T}$	number of oscillations per second
Current density (j)	[A/m²]	$j = \frac{I}{R}$	concentration of electrical current in the cross section of a conductor; A = cross-sectional area
Impedance (Z)	Ohm [Ω]	$Z = R + X$	oppositions to the flow of current; x = reactance
Temperature (T)	° Kelvin [°K] ° Celsius [°C] ° Fahrenheit [°F]		

Important rules of electricity

1. Electrical current seeks ground.
2. Electrical current needs a complete circuit to flow.
3. Electrical current is "lazy" and prefers the path of least resistance.

2.3 EFFECTS OF CURRENT ON TISSUE

Depending on the characteristics of electrical current, three different effects can occur:

Electrolytic effect

Direct current (DC) generates in addition to the desired thermal effect also an undesirable electrolytic effect due to spatial separation of positive and negative ions (see fig.7), producing acids and bases at the electrode poles and resulting in corrosive/acid burns. Therefore direct current is not suitable for electrosurgical procedures.

Faradic effect

Alternating current with low frequencies, which are normally used in every household (50–60 Hz), is not suitable for electrosurgical procedures because in addition to the desired thermal effect, these frequencies can produce undesirable physical effects such as pain, muscle and nerve stimulations and even cardiac arrest. The stimulation of muscles and nerves is also called *faradic effect or neuromuscular stimulation (NMS)*. As the human body is less sensitive to current with high frequencies, electrosurgical HF units usually use frequencies above 300,000 cycles/sec (= 300 kHz).

Figure 8 shows the current strengths that are necessary to cause neuromuscular stimulation in dependence on frequency.

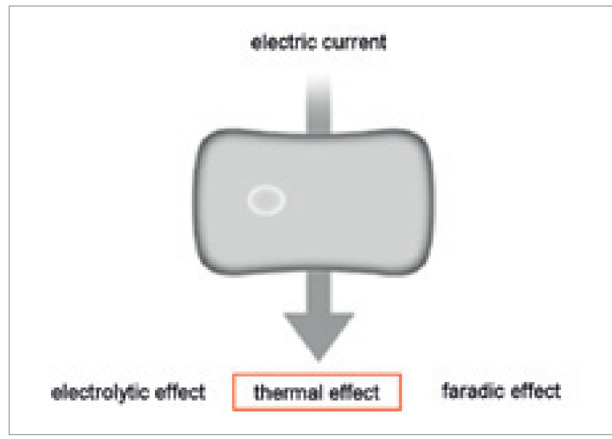

Fig. 6: Three tissue effects caused by current flow. The desired tissue effect is the thermal effect.

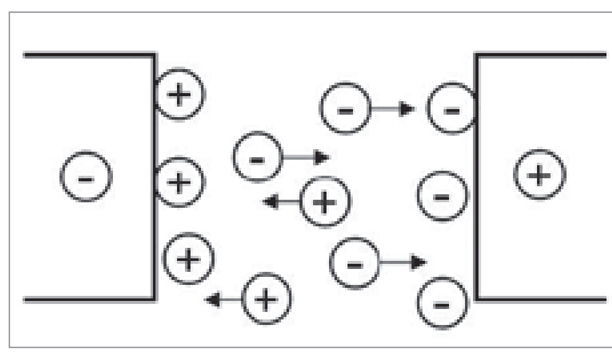

Fig.7: Spatial separation of positive and negative ions causes corrosive/acid burns.

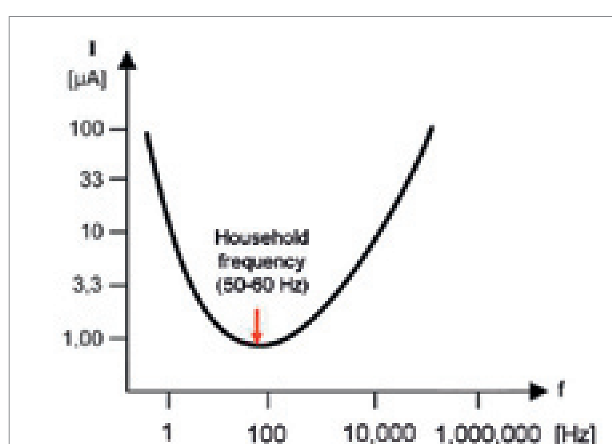

Fig. 8: Relationship of current, frequency and neuromuscular stimulation

Example: A low current level can already cause a faradic effect at the household frequency of 50–60 Hz.
The amount of current (I) that is necessary to cause a faradic effect increases with increasing frequency (f) when starting at 100 Hz.

Note: In some cases all HF units can cause neuromuscular stimulations even at high frequencies due to high current densities applied.

Thermal effect

The electrolytic and the faradic effect can be significantly reduced by using alternating current with high frequencies of above approximately 100–200 kHz.

The ions move very rapidly, but only short distances and therefore do not move across cell barriers. Therefore, there is almost no stimulation and no acid or corrosive burns (see fig. 9). The basic principle of electrosurgery is that heat is generated within the tissue when the current is flowing through the tissue resistance. In other words, it is not the metal electrode that heats up and determines the desired effect but it is the heat generation within the tissue caused by the current flow that results in the cutting or coagulation effect. Every tissue type corresponds with a certain resistance which is higher than metal. The tissue resistance is mainly determined by the water content of the cells. In fat tissue the water content is very low. Fat itself cannot conduct electrical current very well since it contains little electrolytic liquid needed for conduction.

The resistance of fat is approximately 10 times higher than that of blood (see table below).

Specific resistance of biological tissue (unit: Ω/cm):

Muscle	160–250
Blood	160–300
Liver	200–380
Brain	670–700
Fat	1,600–3,300
Skin	11,000

Specific resistance of metal (unit: Ω/cm):

Copper	0.0000017
Silver	0.0000016 ■

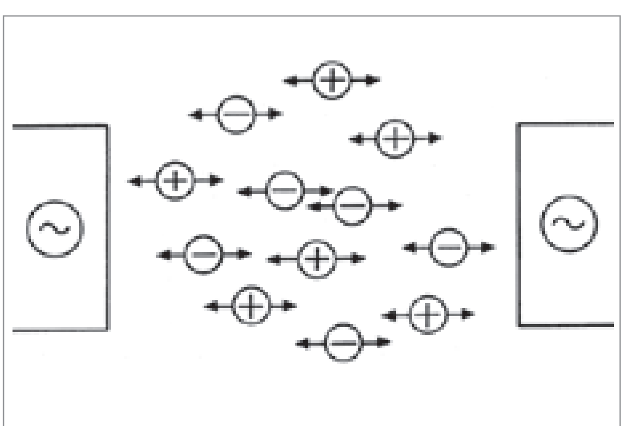

Fig. 9: No separation of positive and negative ions and therefore no electrolytic effect

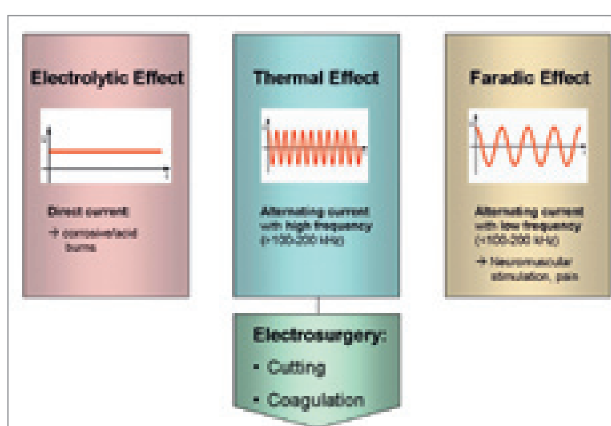

Fig. 10: Summary of the effects of current to the tissue

PRINCIPLES OF ELECTROSURGERY 3

Electrosurgery is defined as the application of HF-current to modify or destroy tissue cells or to dissect or remove tissue in combination with mechanical surgical techniques.

How does radiofrequency current affect tissue? Electrosurgery uses radiofrequency current to cut tissue and seal bleeding vessels by producing heat. The heat produced either vaporizes the intracellular fluid and denatures proteins or explodes the cell membrane at the site of the active electrode. The effect of the radiofrequency current on tissue also depends on the current density in a particular area.

The effectiveness varies based upon four tissue characteristics:

- thickness
- vascularity
- fat content
- liquid content

In any type of electrosurgery, eschar formation and build-up may decrease the tissue effect due to poor heat diffusion.

The following chapters describe the three main effects caused by electrosurgery:

- coagulation
- vaporization (cutting)
- carbonization

3.1 COAGULATION

Temperatures of 60–70 °C in the area around the active electrode heat the cells gradually up until their intracellular fluid can escape through holes in the cellular membrane (which are a result of protein denaturation) and thereby result in the shrinkage of the cell (see fig. 11). Thus the haemostatic effect is attained by the denaturation of proteins that leads to the shrinkage of the vessels' diameter and the clotting of blood. This efficient form of haemostasis is commonly used to stop bleedings in both open and endoscopic surgery and represents an effective alternative to clipping or forms of ligations for smaller vessels.

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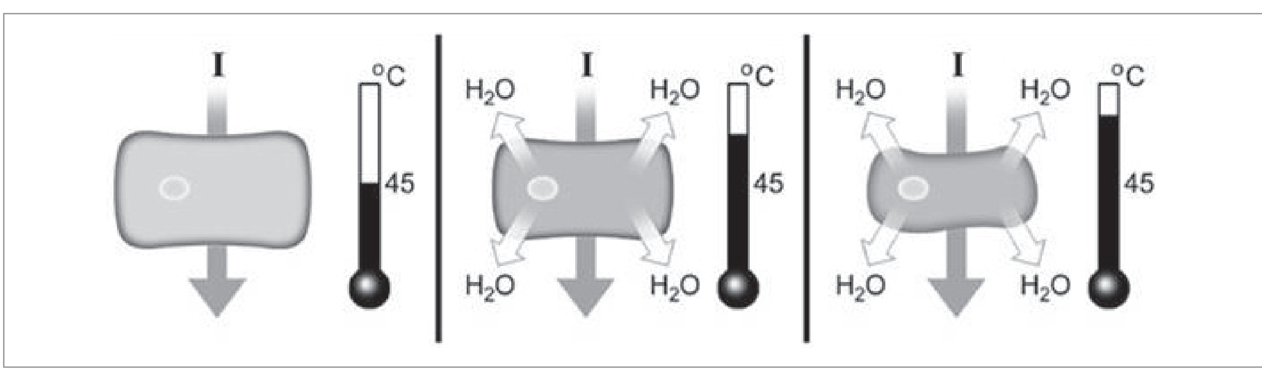

Fig. 11: Mechanism of the coagulation effect on a cell

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3.2 VAPORIZATION (CUTTING)

When the voltage between the cutting electrode and the tissue to be cut is sufficiently high (approx. 200 V_p), sparks (electric arcs) are generated between the cutting electrode and the tissue. These sparks are essential to perform the cutting procedure and they effectively concentrate the high frequency electric current onto specific points of the tissue. The very high temperatures produced at those points at which the sparks contact the tissue result in a rapid conversion of the intracellular fluid into vapour. That vapour produces a high pressure within the cell membrane resulting in the explosive burst of the cell (see fig. 12). The repetition of this effect around the electrode finally determines the incision.

Note: Electrical current, not surgical instruments make electrosurgical cuts.

It is important to distinguish the mechanical cutting from the electrosurgical cutting with HF current where the instrument is not in direct contact to the tissue. The spark can not ignite if the tissue has direct contact to the electrode. There is always a small distance between the electrode and the tissue and in between there is a layer of vapor allowing the spark to move along the electrode. One important advantage of electrosurgery is the fact that every cut generates at the same time a certain extent of haemostasis as the produced heat is transported to the neighbouring cells which then coagulate.

As the electrode passes through the tissue, sparks are produced wherever the distance between the electrode and the tissue is sufficiently small, producing a cut (see fig. 13a/b).

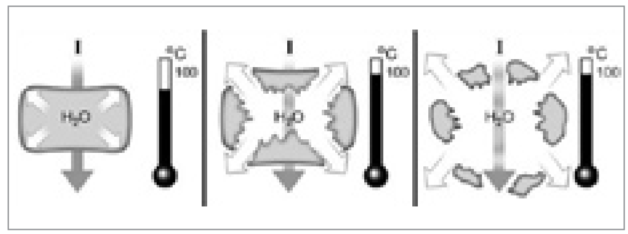

Fig. 12: Mechanism of the cutting effect on a cell

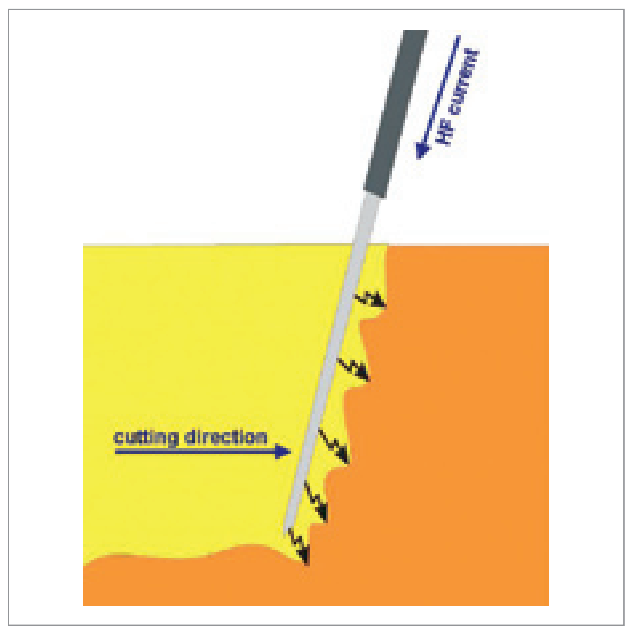

Fig. 13a: Illustration of the cutting mechanism by spark generation

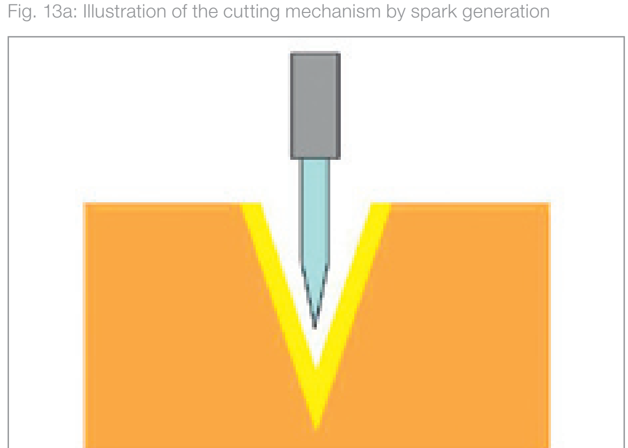

Fig. 13b: Cross section of an electrosurgical cut

3.3 CARBONIZATION

Carbonization is the result of further heating of dehydrated (desiccated) tissue. The solid contents of the tissue are reduced to carbon. Figure 14 illustrates the relation between the temperatures and the tissue effects.

This effect is undesired, because a significant charring of the tissue surface corresponds with reduced wound healing.

Summary of **thermal tissue effects** in dependence on temperature:

up to approx. 40 °C:	no significant cell damage
above approx. 40 °C:	reversible and irreversible cell damage, depending on the duration of exposure
above approx. 50 °C:	irreversible cell damage (start of protein denaturation)
above approx. 60–70 °C:	**coagulation:** Smaller bleedings can be stopped.
above approx. 100 °C:	**vaporization (cutting):** phase transition from liquid to vapor of the intra- and extra-cellular fluid: The complete dehydration of tissue is sometimes also called desiccation.
above approx. 200 °C:	**carbonization (latin: carbo = coal):** reduced wound healing due to significant charring of the tissue surface

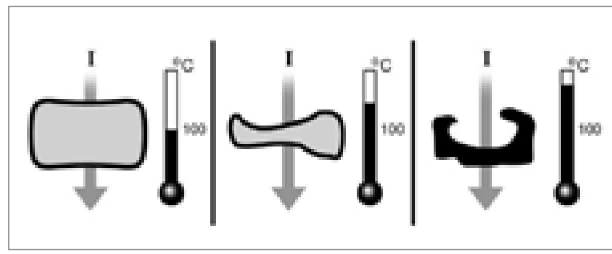

Fig. 14: Undesired carbonization effect

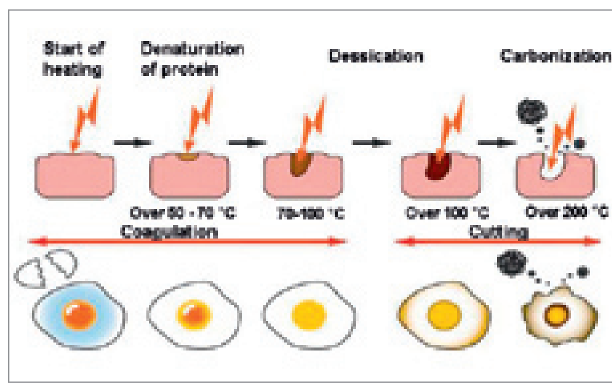

Fig. 15: Mechanism of thermal effect to biological tissue using HF current

3.4 ELECTROSURGICAL MODALITIES

The **electrosurgical circuit** consists of:

- HF unit
- active electrode
- patient/tissue
- neutral electrode
- cables between HF unit and electrodes

Basically, there are two types of electrosurgical circuits. The basic differences between monopolar and bipolar technology are the size and location of the return electrode.

Monopolar electrosurgery is the most common type. Electric current passes from the small active electrode into the tissue, through the patient and then exits the tissue at a large neutral electrode. The amount of high frequency current which flows out of the HF unit through the active electrode is equivalent to the current flow from the neutral electrode back to the HF unit (see fig. 16).

> Electrical current travels in circuit and always prefers the way of lowest resistance. The neutral electrode ensures that the current travelling to the tissue returns back to the HF unit without causing damage to tissues outside the surgical side.

Let's take a look at current density in monopolar applications. The active electrode has a small surface. This results in a high current density and high thermal effect. The current flows through the body to the neutral electrode where the current is spread over a larger area, thereby reducing the current density and allowing the electrical current to return to the HF unit without causing tissue damage at the site of the neutral electrode. The configuration of the active electrode and the application technique will determine the actual tissue result (see fig. 17).

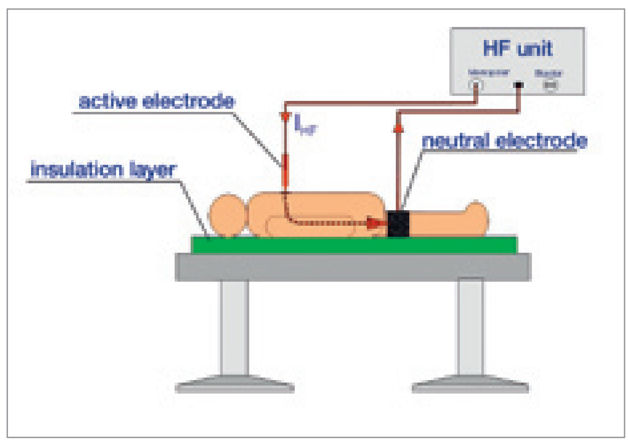

Fig. 16: Monopolar electrosurgery

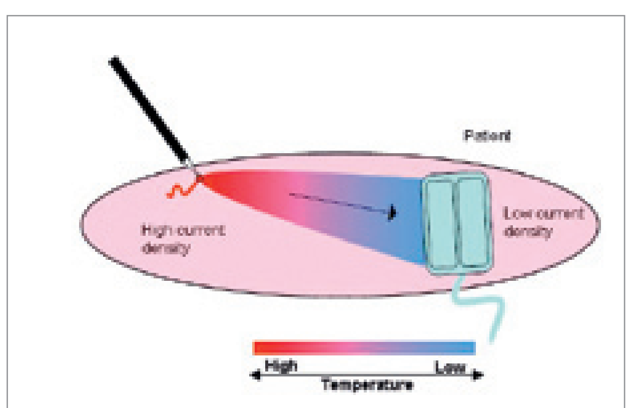

Fig. 17: The current density at the surgical site around the active electrode is much higher than with the neutral electrode.

Bipolar electrosurgery differs from monopolar surgery in that the tissue effect takes place between two electrodes that are part of the same device (see fig. 18).

Electric current passes directly from one electrode, through the tissue, and then returns via the opposing electrode and back to the electrosurgical HF unit. Current does not pass large parts of the patient's body, only through the tissue between both electrodes and therefore no neutral electrode is required (see fig. 19, 20).

The bipolar technique is safer than the monopolar because:

- The current exposition to the patient is limited.
- The risk of burns caused by the neutral electrode is non existent.
- The risk of leakage currents is reduced (see chapter 4.2.3). ■

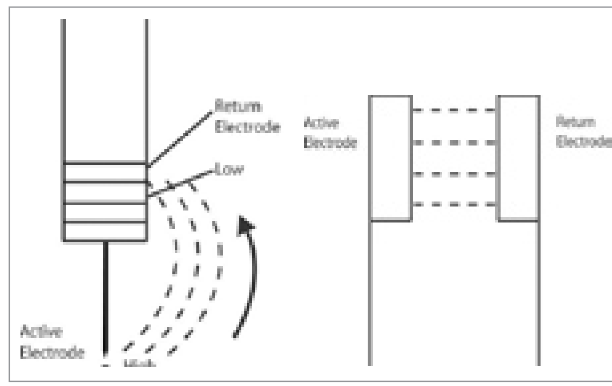

Fig. 18: Examples for the current flow of bipolar instruments

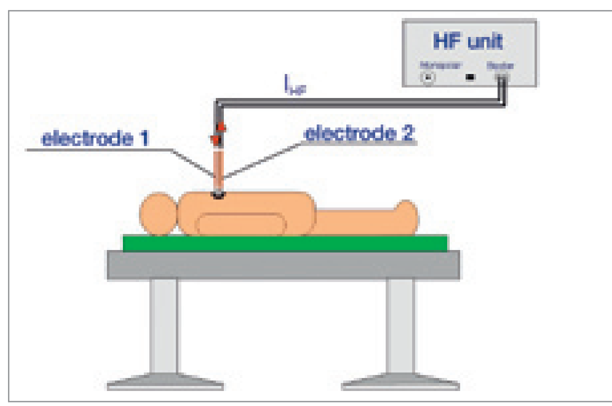

Fig. 19: Bipolar circuit; No neutral electrode is required as the return electrode is part of the surgical device.

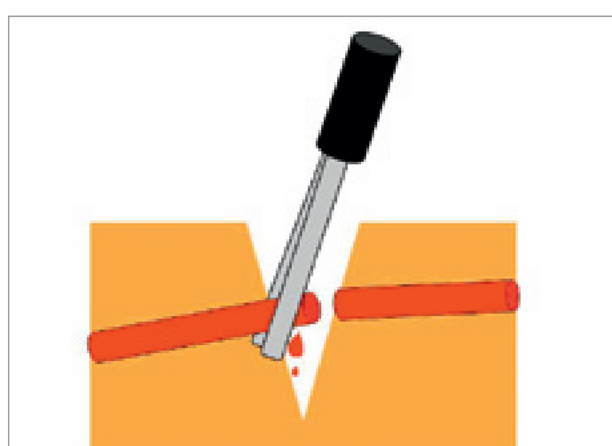

Fig. 20: A common bipolar instrument is a bipolar forceps which is used for the closure of blood vessels.

ELECTROSURGICAL MODES AND TECHNOLOGIES 4

4.1 COAGULATION MODES

The selection of the optimal coagulation mode is dependent on several external parameters such as the location and size of the bleeding, the tissue properties and the design of the electrode. While the focus during cutting procedures is on reproducible tissue effects by implementing automatic regulation measurements, the focus for coagulation modes is to effectively stop the bleeding source with reproducible coagulation effects. The physician can therefore select from different types of coagulation modes in combination with the optimal power level according to the requirements of the individual clinical case.

Suitable electrodes for contact coagulation are e. g. ball electrodes, plate electrodes or the side faces of cutting electrodes. The coagulation electrode should have a bigger surface than a cutting instrument.

Basically it can be differentiated between **contact and non-contact coagulation**. The most important coagulation modes with their characteristics will be described in the following:

Soft coagulation

A soft coagulation mode represents a contact coagulation which means the electrode needs direct contact to the tissue. It is recommended for EndoTherapy instruments with a relatively large surface of the electrode such as the Coagrasper by Olympus (please refer to respective treatment recommendations for more detailed information). A soft coagulation mode is required for **larger and deeper tissue coagulation** and is available in monopolar or bipolar technique. A benefit of the soft coagulation is the low sticking of instruments and low risk of carbonization.

In order to localize the bleeding source an irrigation pump such as the Olympus AFU-100 can be very helpful. By slowly heating up the tissue, the bleeding can be stopped by shrinkage and clotting. In order to avoid unintended cutting or carbonization, this mode has a voltage limitation ($U_p < 200\,V$) accordingly adapting to the tissue properties.

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What impact do different output power limits have to the effect on the tissue?
A higher output power level provides in general more energy to the tissue than a lower output level. In figure 21 the area E1 represents the amount of energy applied to the tissue after a certain period of time (t1) with at a higher power level and E2 represents the amount of energy at a lower power level. E1 is larger than E2 after the same period of time.
However, a higher output power level corresponds also with the **risk of an early dehydration** of the tissue surrounding the electrode. Early dehydration means also a significant increase in the resistance of the superficial tissue layer with the result that no electric current can be transported to deeper layers. When deeper tissue coagulation is required, it is essential to avoid an early dehydration by using lower output power settings (see fig. 21, lower). Although the coagulation will take longer, the total amount of energy provided to the tissue is higher with lower power settings than with higher settings after t2 (E3 > E1).

Forced coagulation

Compared to a soft coagulation the forced coagulation is employed when a quick and superficial desiccation of the tissue is required using electrodes with a relatively small surface. Voltages with peak values up to 2 kV create sparks with a high intensity and high thermal effect in order to achieve **a quick coagulation result**. Due to the spark ignition the possibility of undesired carbonization remains.

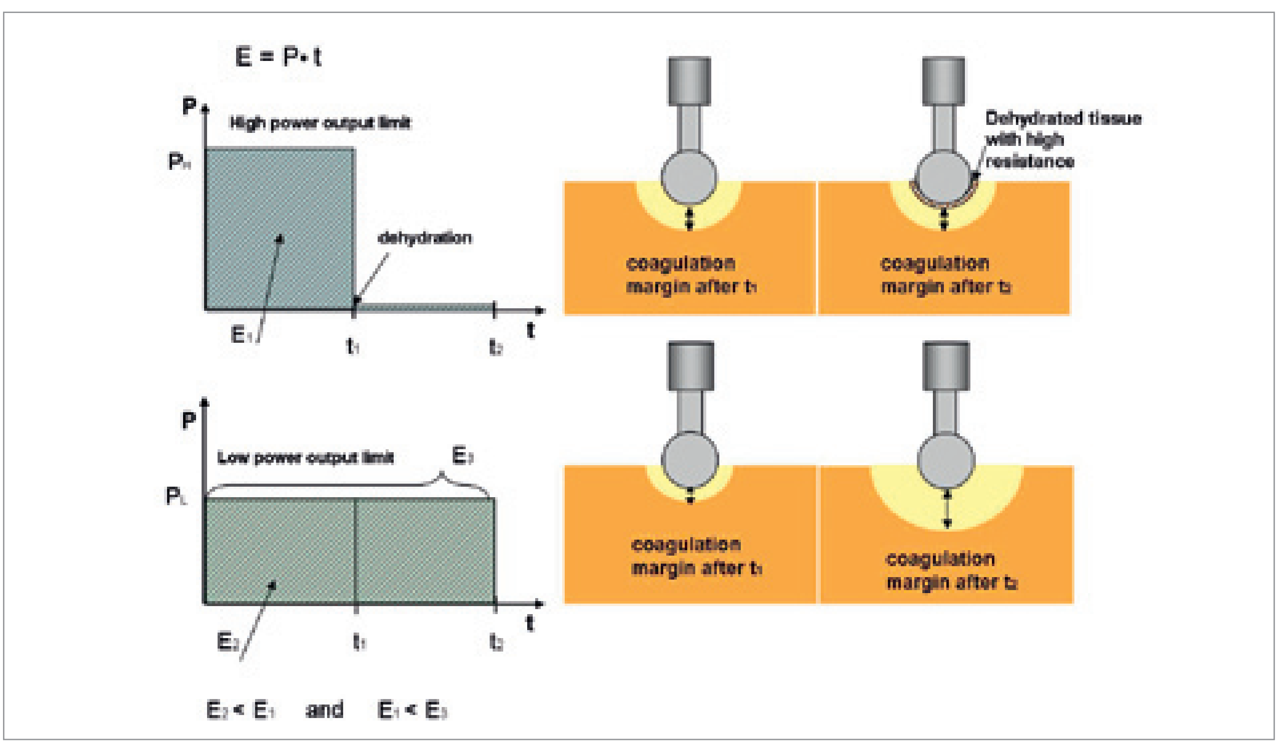

Fig. 21: The total amount of applied energy depends on the power level (P) and duration (t) of the application and are illustrated as blue and green squares (E1–E3). Note: An early dehydration results that no further current can be applied to deeper tissue layers. The yellow coagulation margins demonstrate the clinical results in dependence of the power level and the duration of the application.

Spray coagulation

This coagulation mode represents a technique of **contactless coagulation** and has long been known under the name fulguration. The active electrode is held several millimeters above the surface of the tissue. A very high voltage (several thousand volts) is required to enable a spark ignition even via air gaps of a few millimeters and results in the formation of a “spark rain”. This energy creates a superficial, strongly carbonized coagulation zone. By moving the active electrode, large wound areas of tissue structures can be coagulated. The resulting coagulum is only very superficial and the carbonized area might break open again and result in postoperative bleeding.

Argon Plasma Coagulation

Another method to coagulate tissue without any contact of the electrode is to apply the HF current to the tissue via an **ionized gas**. This technique is beneficial for positions where the EndoTherapy instrument is difficult to handle and it is often used for preventively coagulating residual areas of cancerous tissue after resection, for haemostasis or to prevent post-operative bleedings. Other benefits are the possibility to treat larger tissue areas superficially and coagulate areas that are difficult to reach by a ‘side-fire’ coagulation.

4.2 CUTTING MODES

Depending on the HF unit and the procedure, there are different kinds of cutting modes available. The cutting modes can be divided according to the wave form of the HF voltage into continuous, “blend” and intermittent. The clinical result of the cut is also dependant on external factors which will be described at the end of this chapter.

Continuous cutting modes

A continuous cutting mode is characterized by a **pure sine wave**. The peak voltage (U_p) of a continuous cut mode determines the spark intensity and the coagulation depth achieved during the cut. The spark intensity increases proportional to the peak voltage and determines the thermal effect. The higher the peak voltage U_p the higher the spark intensity and the higher the thermal effect (= deeper coagulation margin).
E. g. in figure 22 the spark intensity increases from the left to the right side, corresponding with a higher voltage level and deeper coagulation.

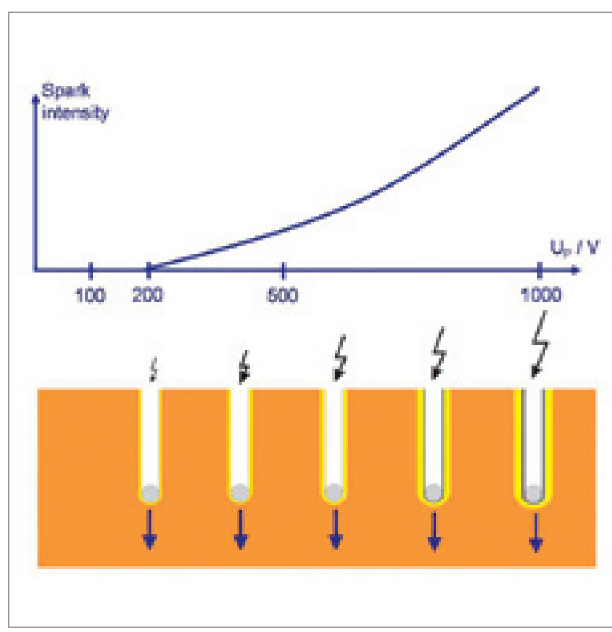

Fig. 22: Voltage level and spark intensity increases from left to right: A spark ignites above approx. 200 V_p.

'Blend' modes

Some HF units offer a so called blend mode. The term blend means that the **voltage signals are modulated**: The sine wave is not regular compared to a continuous mode. A blend mode can consist of sine waves with different phases and amplitudes or even include a pause without any current flow. The modulation happens within microseconds (μs), e. g. 50 μs are the same as 0.00005 seconds.

The crest factor is a value that indicates the coagulation depth of an electrosurgical incision. The higher the crest factor the higher the thermal effect and coagulation depth. The crest factor is defined as peak voltage (U_p) divided by rms voltage (U_{rms}).

$$c = \frac{U_p}{U_{rms}}$$

The general intention of modulation is to increase the thermal effect by increasing the crest factor (c). All three signals in figure 23 represent the same "average" voltage (U_{rms}), but differently distributed. In the third example (3) the crest factor is bigger than in example 1 and 2. The pause without any current flow between the packages of sine waves is bigger than in example 2 or 1, but the peak voltage U_p is higher.

> A higher voltage level corresponds with a higher spark intensity, higher thermal effect and deeper coagulation margin.

The thermal effect increases with increasing crest factor.

Intermittent cutting modes

For some applications an **additional haemostasis period** is beneficial, e. g. during polypectomies or dissection of vascular tissue. For those cases an intermittent cut such as the PulseCut (see fig. 24) of the Olympus ESG-100 offers a good compromise of cutting and coagulation by combining a cut phase (T1) followed by a coagulation phase (T2) within one mode. The intermittent cut offers also the benefit of an **enhanced control** over the cutting procedure as the cutting phase is interrupted and not continuously.

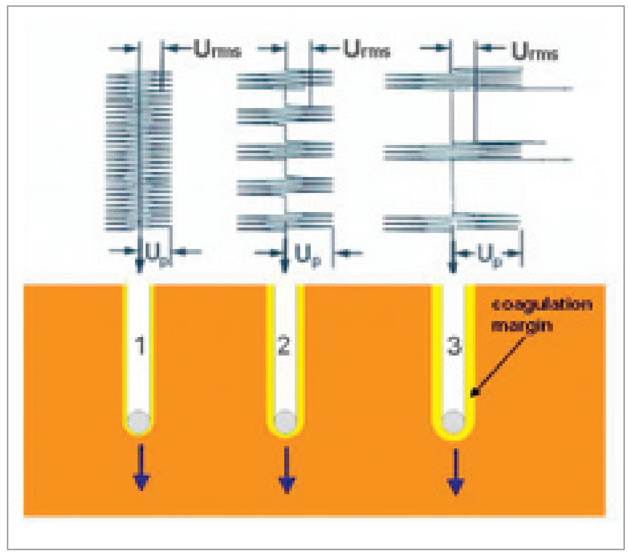

Fig. 23: The left waveform (1) represents a continuous cut mode. The middle (2) and right waveform (3) are modulated. Urms = root means square value of the voltage.

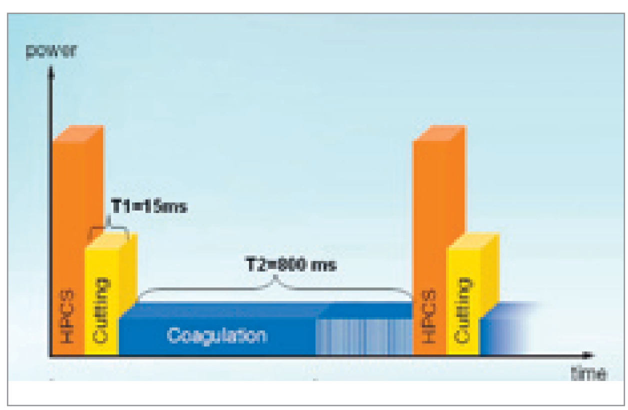

Fig. 24: Example for an intermittent cut (Olympus ESG-100: 'PulseCut; 'HPCS' stands for High Power Cut Support)

Cut support technology

In order to enable an immediate start of the cutting procedure, some HF units offer a cut support – named High Power Cut Support (HPCS) (see fig. 24) – by applying a very high amount of power until a spark is ignited for a very short time (< 50 ms). This high power peak has the effect of rapidly drying out the tissue around the electrode, thereby enabling an immediate spark ignition. The cutting procedure can start right away by reducing the risk of an undesired thermal damage to the tissue. The risk of a mechanical cut can be minimized at the same time.

4.2.1 EXTERNAL PARAMETERS DETERMINING THE CUTTING RESULTS

The thermal effect of the cutting procedure also depends on external parameters which are the duration of electrode contact to the tissue, the design and condition of the electrode and the tissue properties (see below).

In order to deliver a high amount of energy into the tissue, time is needed (remember: Energy (E) = Power (P) · time (t)). The slower the cutting speed is – or the longer the cutting electrode remains on the tissue – the more electrical energy is transformed into heat per unit of length. When a higher thermal effect is required, the electrode should be moved slowly because more energy can be applied to the tissue which results in a deeper heat penetration and denaturated margin (see example 1 of fig. 25). If the electrode is moved more quickly (see fig. 25, example 2/3) then the same amount of energy is spread over a longer incision length than in example 1. The coagulation depth (denaturated margin) of example 3 is smaller than in the examples 1/2.

Note: The thermal effect decreases with increasing cutting speed.

Duration (cutting speed)

The depth of the coagulation margin depends on the cutting speed (bird's eye view, see fig. 25).

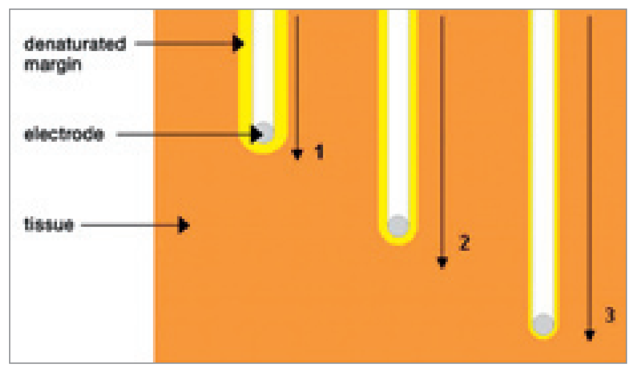

Fig. 25: Three different incision lengths after the same period of time.

Electrode design

With most HF units the thermal effect to the tissue is bigger with a larger diameter of the electrode. Larger electrodes correspond with a higher current flow and result therefore in a higher energy penetration and coagulation depth than smaller electrodes (for constant cutting speed).

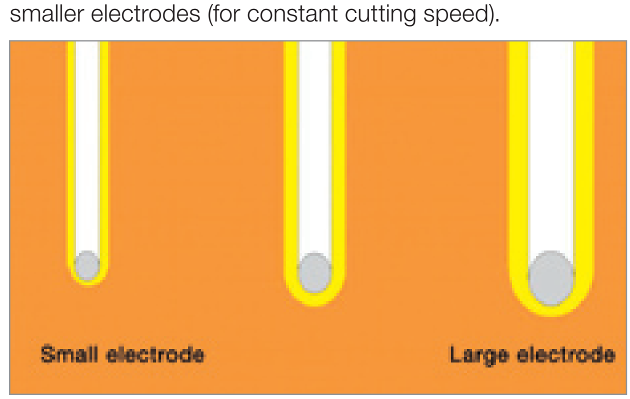

Fig. 26: The depth of the coagulation margin depends on the design and condition of the electrode.

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Note: The thermal effect increases with increasing surface of the electrode.

Tissue properties

The thermal effect is also dependant on the tissue properties. For example, fatty tissue has a relatively high resistance compared to muscle tissue that is very vascular. Thus a higher voltage is required for fatty tissue in order to achieve the same effect as for muscle layers. More sophisticated HF units can regulate their output according to the tissue properties (see chapter 3.3).

4.3 OUTPUT CONTROL TECHNOLOGIES

In order to cut tissue, the voltage has to be high enough to ignite a spark between the tissue and the electrode. A minimum voltage of approximately 200 V_p is needed.

The spark intensity increases in proportion to the peak voltage. Conventional HF units face the issue that the tissue results are not reproducible due to fluctuations of the output peak voltage (U_p). These fluctuations happen due to external parameters such as the distinct resistance of tissue structures, the design of the electrode, the cutting speed and the internal resistance level of the HF unit. This can lead to irregular cutting and coagulation results including carbonized or not sufficiently coagulated areas even during one single cutting process. As mentioned above a minimum of approximately 200 Volt peak (U_p) is necessary to start the cutting procedure by spark generation. If the output voltage is lower than approx. 200 V_p cutting is not possible. If the output voltage is much higher than 200 V_p, the spark intensity and therefore the thermal effect is very high and might result in an undesired carbonization.

In order to enable reproducible tissue effects independently from tissue characteristics, today's HF units offer automatic output control measurements. These sophisticated technologies are comparable to cars incorporating a cruise control. This cruise control maintains the driving speed (analogue: tissue effect) on a constant level (analogue: reproducible) independently from external parameters such as incline of the street (analogue: increase of tissue resistance).

Voltage control

Since the 80s, an automatic voltage control has been implemented in order to allow the physician to achieve improved cutting results. The voltage level is kept constant while the output current varies depending on the tissue resistance. When, for example, the resistance of the tissue increases due to dehydration and the voltage is maintained on a constant level, the electrical current also decreases and in total the level of output power is lower than without this feature.

Power and current control

In order to optimize the clinical results and contribute to more safety for the user and the patient, Olympus has implemented for its ESG HF unit portfolio – additionally to the voltage control – the control of power and current output. By combining the limitations of these three parameters, Olympus optimizes the control of the power output (see black line in fig. 27) during electrosurgical procedures.

Spark control

A highly sophisticated and effective way of automatic output control is the constant monitoring and control of the spark intensity. The Olympus HF units (ESG – line) incorporate a Fast Spark Monitor (FSM) which represents an advanced technology that constantly monitors and reacts to changes of the tissue resistance and keeps the power output as low as possible and as much as necessary in order to keep the spark intensity on a constant level. This makes the effect on the tissue reproducible. Each mode has a preset spark intensity that is kept constant during the cutting procedure independently from the tissue characteristics and electrode design. Another benefit of the FSM is a lower risk of carbonization due to the spark control. By combining the spark control with the voltage, power and current, control Olympus effectively contributes to the safety for users and patients. ■

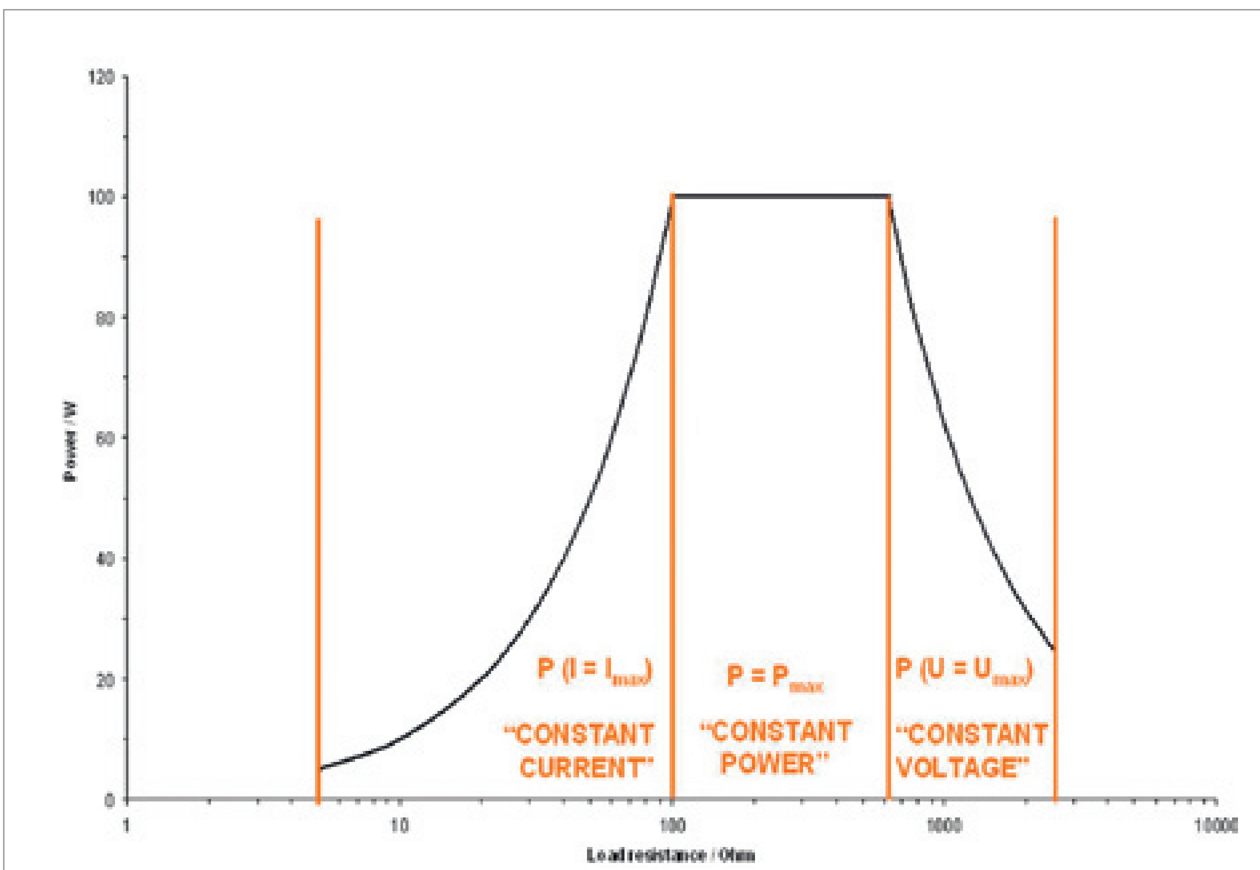

Fig. 27: Example of a voltage, power and current control of a cutting mode

SAFETY AND HAZARDS 5

5.1 SAFETY

There are five areas of concern for safety when using electrosurgical devices. These are the **HF unit**, the **power settings**, the **cords**, the **electrodes** and the **environment**.

5.1.1 HF UNIT

The HF unit should be checked for any signs of damage. If there is any question about the integrity of the HF unit, it should be checked by a technician prior to use. HF units should be plugged directly into a wall outlet and not into a portable multiple outlet or extension cord. The power cord should be checked to make sure it is not frayed or damaged. Any other accessories that are attached to the HF unit should also be checked. The instructions for use will provide specific information on what to check and how frequently. Never put heavy objects or containers on top of a HF unit. Fluids and electricity are a dangerous combination.

5.1.2 POWER SETTING

The power setting of the electrosurgical unit should be determined by the physician. There are some devices that are pre-programmed and will automatically set to the default values when a particular instrument is recognized by the HF unit. The power settings (if not already automatically set) should be adjusted to the tissue type and the size and shape of the active electrode. If the surgeon repeatedly requests that the power output of the HF unit (e.g. Gyrus ACMI G400) should be increased, check the following items in both bipolar and monopolar electrosurgery:

- Ensure that all cords are connected properly to allow the circuit to be completed.
- In monopolar electrosurgery check the adequacy of contact between the dispersive return electrode and the patient.
- Evaluate the power setting and increase the power in small increments.
- Clean the active electrode to remove eschar. If problems persist, consider replacing the accessories and/or the HF unit.
- In bipolar electrosurgery, check the alignment of the electrodes.
- If electrosurgery is being used in a liquid environment such as urologic procedures or hysteroscopy, it is important to use the correct kind of solution. Monopolar applications require the use of non-conductive fluids such as water, sorbitol, glycine or mannitol. Bipolar applications require the use of conductive fluids such as saline.

5.1.3 ACTIVE ELECTRODES

Safety measures regarding **monopolar and bipolar active electrode**s include:

- Inspect the active electrode for damage before use. Including the insulation, cord and hand piece functionality.
- Plug the active electrode into the appropriate receptacle on the HF unit. Never force a connector into a HF unit. This is a clue that the instrument is not meant to be used with that HF unit.
- Activate the electrode only when ready to use.
- Always place the active electrode into an insulated holster when not in use. If the active electrode tip is removable, be sure it is securely attached to the hand piece.
- If the active electrode should fall off the sterile field and down the side of the OR table, disconnect it immediately to prevent accidental activation or related risks.

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- Frequently clean the active electrode to prevent eschar build up on the active electrode tip and accessories.
- Do not activate the electrode if flammable vapours such as those from disinfection solution are present.
- Do not reuse single-use electrodes.

Additional safety measures

- Do not attempt to connect a bipolar instrument to a monopolar HF unit.
- As with all electrosurgical instruments, turn off the power when not in use, do not place them on flammable materials such as drapes or gauze.

The monopolar electrosurgical HF unit may start alarming after repositioning the patient. Switch the HF unit into the standby mode and check the following items:

- Are all cables secured?
- In monopolar electrosurgery: check that the neutral electrode has good contact with the skin.

Repositioning when using only bipolar devices is usually not a problem since there is no neutral electrode used.

Interference with electronic implants

Electronic implants (like automatic cardioverter & defibrillator, pacemakers, chochlear implants) are being used more and more frequently. The electrical energy of electrosurgical procedures can interfere with some of these devices. It is always best to check the IFU of the implant or contact the manufacturer of the implant prior to using an electrosurgical device.

5.1.4 NEUTRAL ELECTRODES

Neutral electrodes have many safety considerations. Wrong application or malfunction of the neutral electrodes are the main causes for endogenous skin burns (=burns created within the tissue).

- Thoroughly assess the skin integrity before and after the procedure.

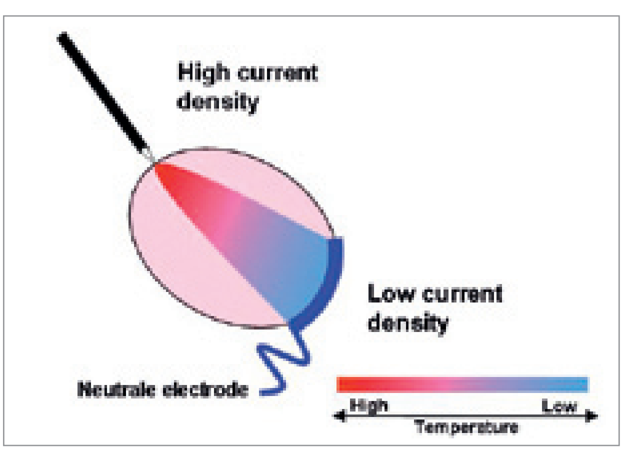

Fig. 28a: Correct application of the neutral electrode with full contact to the skin

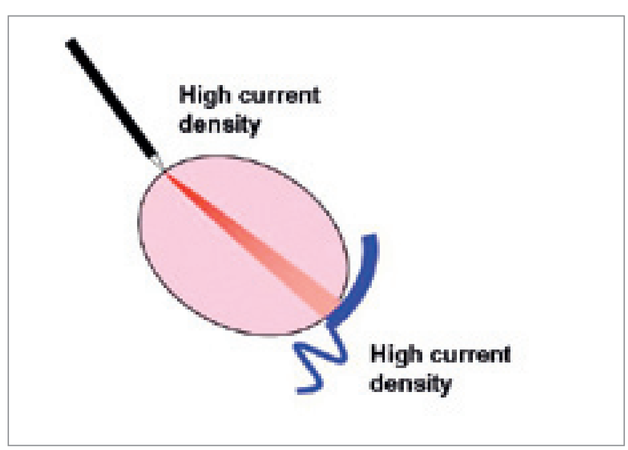

Fig. 28b: Wrong application as the neutral electrode has no full skin contact. The small contact point of the neutral electrode causes a high current density and corresponds with the risk for endogenous burns.

- Make sure that the neutral electrode is in full contact with the skin (see fig. 28). Overlapping of the electrode must be avoided.
- Always select a new and unopened disposable, adhesive neutral electrode, appropriate for the patient's size and weight.
- Never use a neutral electrode that has been left open and never cut it to "custom fit" a patient.
- Pad placement is key to avoid burns. There must be adequate tissue blood perfusion to promote electrical conductivity and to dissipate heat. For traditional adhesive pads, the ideal placement is on a clean, dry, large muscle mass. Other sites may increase resistance to current flow, thereby increasing the risk of burns.
- Place the neutral electrode with the long side to the treatment side (see fig. 29). Otherwise the current density might increase and enhance the risk for endogenous burns.
- Avoid proximity to metal prostheses. Remember that electrical current always follows the way of lowest resistance. Metal implants have a very low resistance and could thereby concentrate the current and increase the risk of endogenous burns (see fig. 30). Do not align the neutral electrode in relation to the treatment site so that the implant is positioned in between.
- Remove excessive hair from the neutral electrode site. It may be necessary to shave the site for optimum contact.
- Place the neutral electrode as close to the surgical site as possible.
- Maintain complete contact with the patient's skin. Gaps in the adhesion of the pad to the patient's skin could result in a burn as the entrapment of air acts as an insulator.
- Plug the neutral electrode into the appropriately labelled receptacle on the HF unit.
- Remove all metal jewellery from the patient.
- Avoid contact between two neutral electrodes when more than one HF unit is used.
- In bipolar electrosurgery, no neutral electrode is needed.

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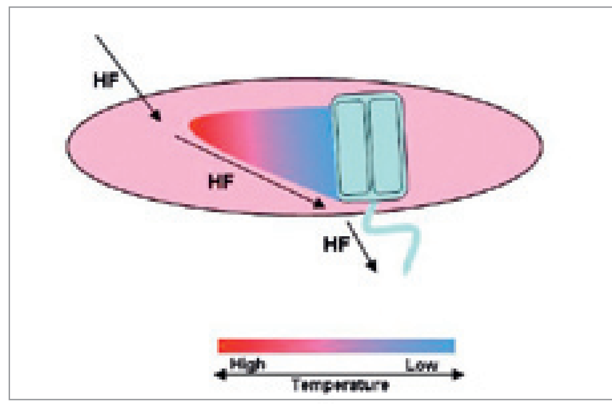

Fig. 29a: Correct application of the neutral elec-trode to the patient with the long site to the treatment site

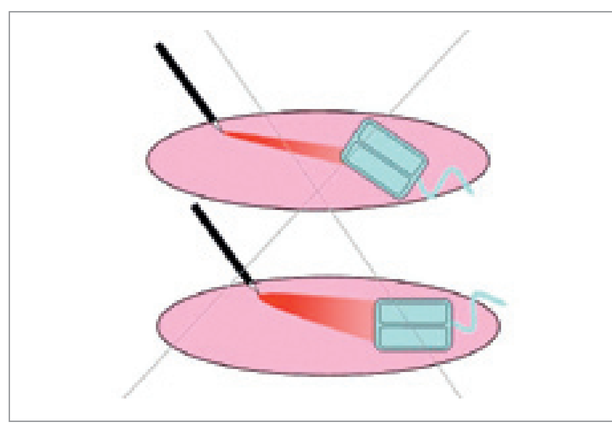

Fig. 29b: Wrong applications

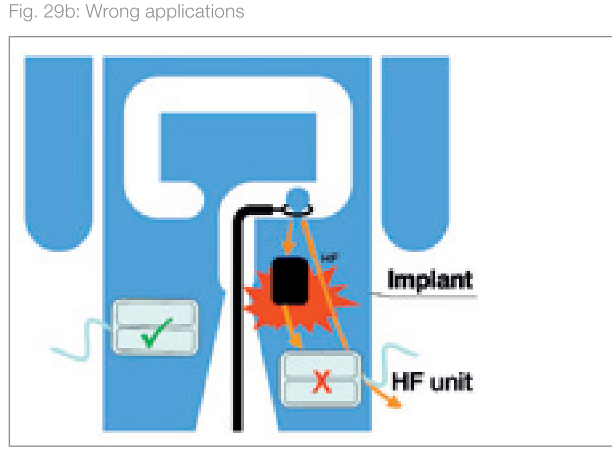

Fig. 30: Endogenous burns might result if a conductive implant is located between the surgical site and the neutral electrode.

Recommendations

Basically, there are two types of neutral electrodes: split or non-split ones (see fig. 31 a/b).

In order to minimize the risk of burns, the use of split neutral electrodes is recommended because most HF units such as the Olympus ESG line incorporate an additional safety feature in combination with split neutral electrodes: The Contact Quality Monitor (CQM) of the ESG-100 constantly monitors the contact quality of the split neutral electrode to the tissue. If the contact quality decreases to a risky level, the HF unit will give an acoustic feedback and disable the activation in order to avoid any burns.

5.2 HAZARDS

5.2.1 SMOKE

The heat produced by an HF unit results in the formation of bioaerosols which are composed of gases and particles matter from patient tissue, both vital and dead. Particles, varying in size from 0.1 to 5.0 µm (microns), may include both viruses and bacteria. The noxious gas produced carries many chemicals, some of which may have either mutagenic or carcinogenic potential. The NiOSH[2] released a study in 1998 regarding the effects of smoke on OR personnel. This included nausea, headache, myalgia, upper respiratory infections and eye and skin irritation.

High filtration pumps for smoke evacuation are commercially available to filter the hazardous chemicals from the plume that is the result of lasers or electrosurgery. In addition, the use of a high filtration mask is recommended to reduce the exposure.

5.2.2 LAPAROSCOPIC CONSIDERATIONS

Laparoscopic surgery requires particular considerations for electrosurgery. Surgery is performed in a moist environment with limited access and visibility. Electrosurgical tools are frequently used due to their versatility, reasonable costs and overall ease of use. An awareness of the hazards and an understanding of the mechanisms of injury can enable the medical personnel to facilitate safe tissue dissection and effective haemostasis. Bipolar devices are becoming more popular due to safety concerns with monopolar devices.

2 National Institute for Occupational Safety and Health

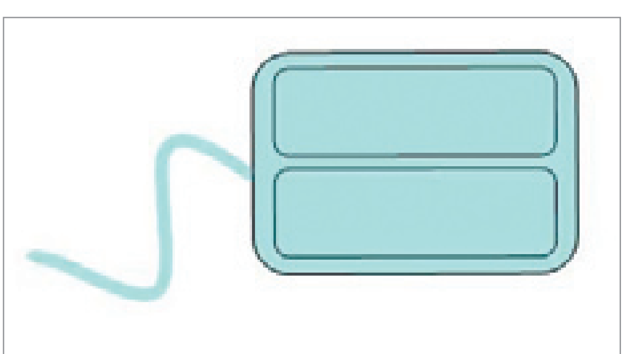

Fig. 31a: Split neutral electrode

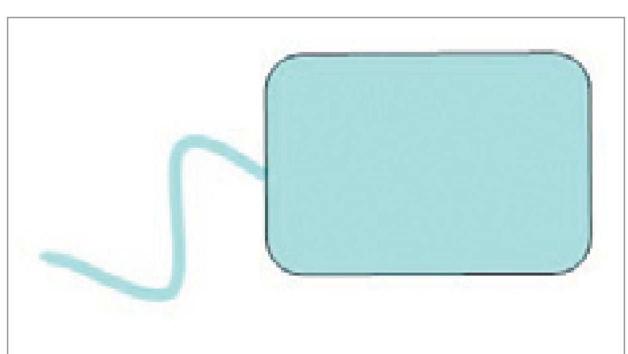

Fig. 31b: Non-split neutral electrode

5.2.3 UNINTENDED CURRENT FLOW

High frequency alternating current always corresponds with a certain level of **leakage currents**. Leakage currents represent current flows which travel another pathway than initially intended. In the ideal case. the current that leaves the HF unit should travel back via the neutral electrode to the HF unit (see fig. 32, 'I1'). But a certain percentage of the current could alternatively travel via the patient and the operating table (see fig. 32, 'I2') or the surgeon (see fig. 32, 'I3') and then via the ground back to the HF unit. These alternative current flows are also called earth leakage currents and correspond with the risk of thermal tissue damages.

Sophisticated HF units such as the Olympus ESG line constantly monitor earth leakage currents and give an acoustic and visual signal if the value of the earth leakage current exceeds a certain level. The signals make the physician aware that there is an increased risk of burns for the patient.

Note: The Olympus HF units will not disable the activation of the HF unit immediately as the physician might be in the middle of a life saving procedure.

Another phenomenon of electricity is that high frequency alternating current can pass from a conductive material (like an active electrode) through an insulator (e.g. the insulation of the electrode) into another nearby conductive material (e.g. biological tissue) without the aid of wires or cables. This can occur despite intact insulation surrounding the conductors and is called capacitive coupling.

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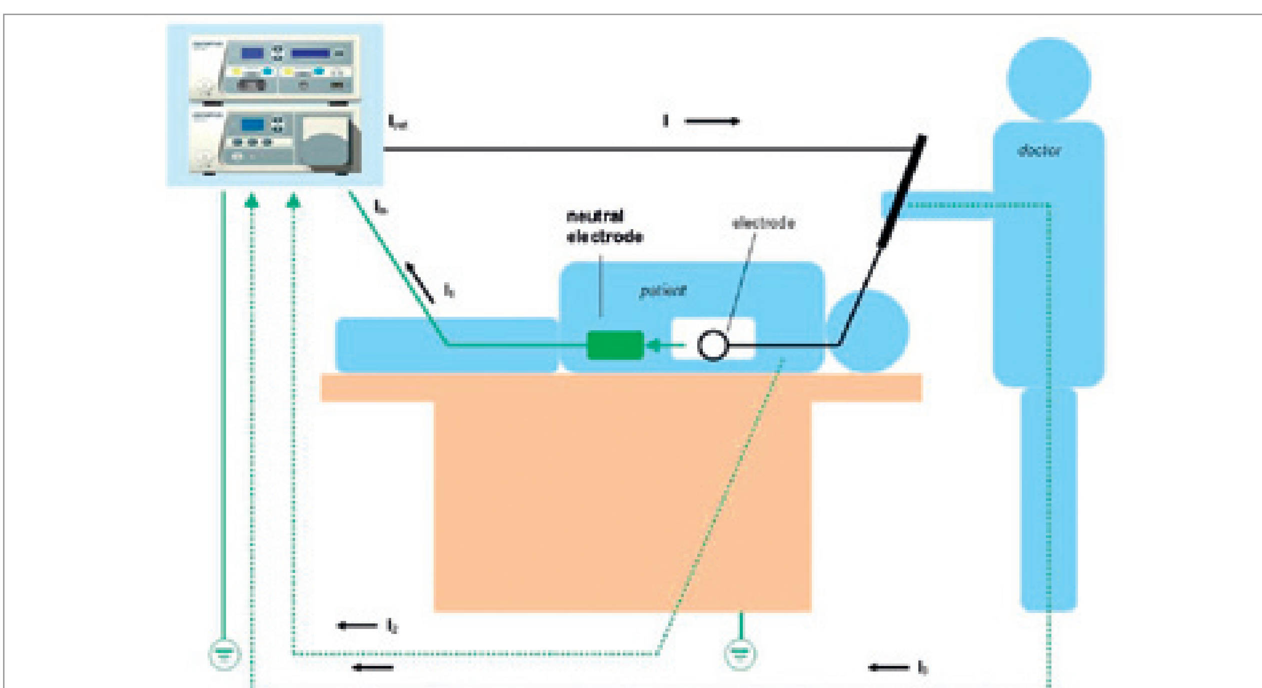

Fig. 32: In the ideal case the current that leaves the HF unit (I1) should travel back to the HF unit via the neutral electrode. I2 and I3 represent earth leakage currents.

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Those **capacitively coupled** currents are often also called leakage or stray currents which occur mainly in monopolar electrosurgery.
Due to capacitive coupling, the current can pass from the active electrode via air or insulating material to the metal tube (e. g. trocar) and onto any tissue in contact with the metal tube. Should the metal tube make contact to a small area of the bowel wall, a burn could result (see fig. 33).

Direct Coupling is the movement of electrons directly from one conductor to another. This occurs when the surgeon touches the active electrode to a metal instrument or object in the field and accidently activates the HF unit. The first electrode can then activate the other instrument and create an unintentional burn on the tissue it is touching (see fig. 34). In laparoscopic surgery, never activate the electrosurgery unit unless the uninsulated part of the active electrode is in full view.

Insulation failures occur in monopolar electrosurgery and describe the breakdown of insulation along the shaft of an active electrode. This failure allows the energy an opportunity to seek another pathway of lesser resistance. In this case the current can either activate another metal instrument or inadvertently directly burn tissue (see fig. 35).

In **summary**, all electrosurgical devices should be handled with respect. The staff using these devices should be thoroughly trained. If there is no automatic regulation of the output power available, the suitable voltage/power setting should be used to achieve the desired tissue effect. Requests to increase the power setting should trigger the nurse to ensure that all cords are properly connected and the neutral electrode is properly applied. Electrosurgical devices are used daily in the surgical suite and assist the perioperative team to deliver safe and efficient patient care. To ensure patient safety, the principles of electrosurgical safety must be understood and all safety measured observed. ■

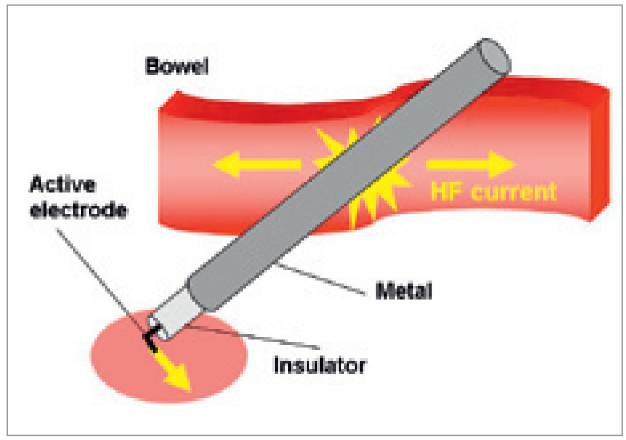

Fig. 33: Capacitive coupling

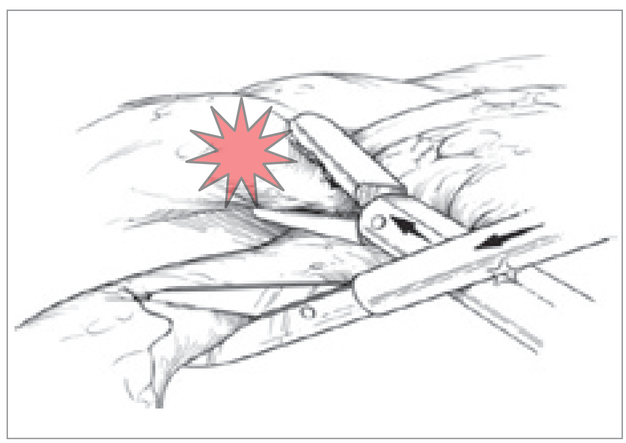

Fig. 34: Direct coupling

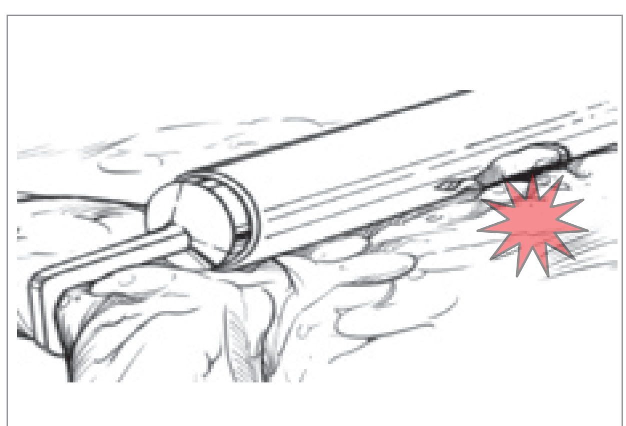

Fig. 35: Insulation failure

FURTHER READING 6

- **AORN guidance statement:** Care of the perioperative patient with an implanted electronic device. Recommended Practices, and Guidelines, 2005
- **Barlow DE:** Endoscopic applications of electrosurgery: a review of basic principles. Gastrointestinal Endoscopic, 28:73-6, 1982
- **Cotton PB, Williams CB:** Colonoscopic Polypectomy. Practical gastrointestinal endoscopy. Blackwell, Victoria, 2008
- **Curtis LE:** High frequency currents in endoscopy: a review of principles and precautions. Gastrointestinal Endoscopic, 20:9-15, 1973
- **Czerny V:** Über Operationen mit dem Lichtbogen und Diathermie. Dtsch Med Wochenschr, Vol. 35, No. 11, 489-493, 1910
- **D'Arsonval A:** Action physiologique des courants alternatifs. C R Soc Biol, Vol. 43: 283–286, 1891
- **Doyen E:** Traitment local des cancers accessibles par l'action de la chaleur au-dessus de 55 °C. Rev Thér Méd Chir, Vol. 77, 551-577, 1910
- **Doyen E:** Bipolaire Voltaisation. Münch Med Wochenschr, Vol. 48, 2516 ff, 1908
- **Gildemeister M:** Über die im tierischen Körper bei elektrischer Durchströmung entstandenen Gegenkräfte. Pflügers Archiv, Vol. 149, 389-400, 1912
- **Heymann E:** Chirurgische Eingriffe mit Hochfrequenzströmen. Med Klin, Vol. 15, 539-545, 1930
- **Huschak G, Steen M, Kaisers UX:** Principles and risks of electrosurgery, Anasthesiol Intensivmed Notfallmed Schmerztherapie, Jan 44(1):10-3, 2009
- **H.-D. Reidenbach:** Hochfrequenztechnik und Laser in der Medizin. Springer-Verlag, Berlin, 1983
- **Laine L:** Bipolar Multipolar electrocoagulation. Gastrointestinal Endoscopic, 36: 538-41, 1990
- **Luciano AA, Soderstrom RM, Martin DC:** Essential principles of electrosurgery in operative laparoscopy. J Am Assoc Gynecol Laparosc, May 1(3):189-95, 1994
- **Massarweh NN, Cosgriff N, Slakey DP:** Electrosurgery: history, principles, and current and future uses. Journal of the American college of Surgeons, Mar 202(3):520-30, 2006
- **Morris ML.:** Electrosurgery in the gastroenterology suite: principles, practice, and safety. Gastroenterology Nursing, Mar-Apr 29 (2):126-32, 2006
- **Nagelschmidt F:** Über Hochfrequenzströme, Fulguration und Transthermie. Z Phys Diat Ther, Vol. 3, 1909
- **Nernst W:** Zur Theorie des elektrischen Reizes. Pflügers Archiv, Vol. 122, 275-315, 1908
- **Swerdlow DB, Salvati EP, Rubin RJ, Labow SB:** Electrosurgery: Principles and use. Diseases Colon Rectum, Jul-Aug;17 (4):482-6, 1974
- **Vilos G:** How to Do Electrosurgery Safely. Outpatient Surgery Magazine, July, 2000

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