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Manual of Practical Electrotherapy



Jagmohan Singh

SECOND EDITION

JAYPEE

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CHAPTER 4

High-frequency Currents

DIATHERMY

Diathermy is a Greek word meaning *through heating.*
Diathermies are of the following types:

- Shortwave diathermy
- Pulsed shortwave diathermy
- Microwave diathermy.

SHORTWAVE DIATHERMY

Shortwave diathermy **(Fig. 4.1)** is the use of high-frequency electromagnetic waves of the frequency between 10^7 and 10^8 Hz and a wavelength between 30 and 3 m to generate heat in the body tissues. It provides the deepest form of heat available to the physiotherapist.



Fig. 4.1: Shortwave diathermy

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The therapeutically used frequencies and wavelengths are 27.12 MHz and 11 m (commonly).

The less common frequencies and wavelengths are 40.68 MHz and 7.5 m and 13.56 MHz and 22 m.

Principles

It is not possible to produce high-frequency currents by some mechanical device which produces sufficient rapid movements. This type of current can only be produced by discharging a condenser through an inductance of low ohmic resistance. If a current of very high-frequency is required, the capacitance and inductance should be small and if a current of low frequency is required, the capacitance and inductance should be large. This is the mechanism of production of high-frequency current.

Construction

The system consists of two circuits:

1. The machine circuit
2. The patient circuit.

Machine Circuit

It consists of two transformers, whose primary coils are connected to source of AC. One is a step-down transformer and its secondary coil supplies current to the filament heating circuit of triode valve. The other is step-up transformer and connected to anode circuit. Anode circuit carries the current produced by valve. Here it consists of triode valve and oscillator circuit **(Fig. 4.2)**. Oscillator circuit consists of condenser XY and inductor or oscillator coil CD. Current

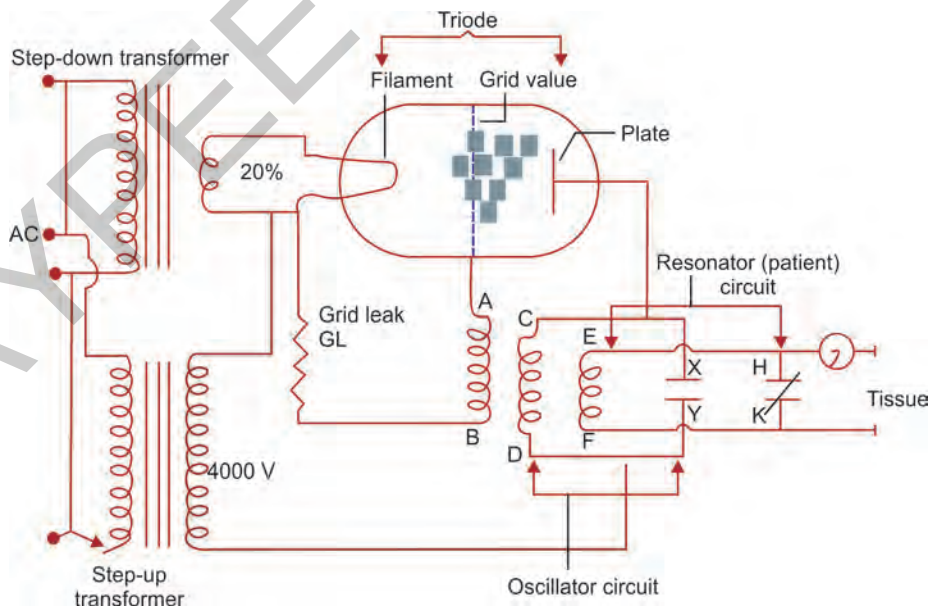

Fig. 4.2: Circuit for shortwave diathermy

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of different frequencies are obtained by selecting suitable condensers and inductances. To produce a current of high-frequency, the capacitance and inductance used must be small and are made to charge and discharge repeatedly and for obtaining this an oscillator is incorporated into machine circuit along with valve circuit.

Another coil AB lies close to oscillator coil CD and has one end connected to the grid of the valve and other through grid leak (GL) resistance to the filament.

Patient Circuit

The patient or resonator circuit is coupled to machine circuit by an inductor coil (EF) lying close to oscillator coil (CD) and also consists of variable condenser HK which is usually in parallel to patient terminal. A matching high-frequency current is produced in the resonator circuit by electromagnetic induction. For this to happen, the oscillator and resonator circuits must be in resonance with each other, which requires that the product of inductance and capacitance must be the same for both circuits.

Working

The AC from main passes through primary coils of the transformers and EMF is induced in secondary coils. An EMF of 20–25 volt is set-up in secondary coil of step-down transformer and produces current through filament of the valve.

The filament is heated and thermionic emission takes place and current flows through valve.

The EMF of about 4000 volts is induced in the secondary coil of step-up transformer and provided that anode of valve is positive and filament is negative, current flows in anode circuit. The electrons flow from filament to anode through valve, through oscillator coil in direction C to D and to transformer back to filament.

The electrons form in CD will induce EMF in coil AB in direction that electrons will move to grid of valve making it negative thus blocking the flow of electrons from filament. This will lead to dying of current in anode circuit. This reduction in current will lead to self-induced EMF. According to Lenz law, this EMF will try to prevent fall in current by offering resistance to flow of current. This will charge condenser X (positive) and Y (negative) polarity opposite to earlier one. Now when self-induced EMF totally dies away, condensers again discharge through oscillator coil, but in opposite direction (D to C).

Flow of current from D to C induces an EMF in AB such that electrons move from A to B and grid loses its negative charge and anode current flows again. This sequence continues and each time condenser charges and discharges through oscillator circuit leading to production of high-frequency current (SWD).

Grid leak: When the current flows across the valve, some electrons are caught on the grid and grid leak is provided to enable these electrons to escape back to the filament.

The resonator coil EF lies within the varying magnetic field set up around the oscillatory coil, so provided that two circuits are in resonance, high-frequency current is induced in it. The current is similar to that in the oscillator circuit and is supplied to the patient.

Methods of Applications

The transfer of electrical energy to the patient tissues occurs either by electrostatic field or by electromagnetic field.

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Therefore, two methods of applications are used:
1. Condenser/capacitor field method
2. Cable method.

When shortwave diathermy is applied by the condenser field method, the electrodes and the patient's tissues form a capacitor. The capacitance of such a capacitor depends upon:
1. The size of the electrodes
2. The distance between the electrodes
3. The tissue between the electrodes.

When shortwave diathermy is applied by the cable method, the cable and the patient's tissue forms an inductance, the value of which varies according to its arrangement.

Consequently, either the capacitance or inductance of the patient's circuit is varied at each treatment, and so a variable condenser is incorporated in the patient's circuit to compensate for this.

Tuning of the circuit: When the electrodes are arranged in position with the patient's body, the capacitance of the variable capacity is adjusted until the product of inductance and capacitance of the resonator circuit is equal to that of the oscillator circuit. Thus, when the oscillator and the resonator circuits are in tune with each other, there is transfer of maximum energy into the patient's body parts.

Indications of tuning are:
- Indicator light on the equipment either comes 'on' or changes its color, and attains a specific color on tuning, generally blue.
- An ammeter is used in the circuit to register the resonance between oscillator circuit and resonator circuit by showing maximum deflection on turning the tuning knob.
- A tube containing neon gas placed within the electric field between the electrodes or the ends of the cable glows at maximum intensity when the circuits are in resonance.

Nowadays modern machines have automatic resonator or tuners in it which automatically search and select for the adjustment of the variable capacitor to ensure maximum energy transfer to the patient's body.

Capacitor Field Method

Electrodes are placed on each side of the part being treated. The electrodes are separated by the skin by means of an insulating material. The electrodes act as the plates of the capacitor, while the patient's tissues together with the insulating material which separates them from the electrodes form the dielectric.

When the current is applied, rapidly alternating charges are set-up on the electrodes and give rise to a rapidly alternating electric field between them. The electric field also influences the material which lies within it.

Effects of Electric Field on Conductors, Insulators and Electrolytes

As we know, conductors are the substances in which electrons can easily be displaced from their atoms. When such a material lies within a varying electric field, there is rapid oscillation of electrons and heat is produced.

An insulator is a substance in which the electrons are so firmly held by the central nuclei that they cannot be easily displaced and result in the distortion of molecules when varying electric field is applied.

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An electrolyte is a substance which contains ions and when a varying electric field is applied, the ions tend to move from one direction to the other. Electrolytes also contain diploes which contain two oppositely charged ions, when a varying electric field is applied, they rotate their direction. These dipoles are electrically neutral, but one end bears positive and the other a negative charge. As a result of electric field, they rotate themselves and come in an alignment with the electrodes **(Fig. 4.3)**.

Thus, the electric field influences the material that lies between the plates; this causes the oscillation of the ions, distortion of molecules and rotation of dipoles. This causes production of heat in the tissues by the electric field of shortwave diathermy, which is the primary function of shortwave diathermy. The heat production is in accordance with Joule's law, i.e. $Q = I^2RT$, but depends upon the distribution of the electric field.

Effects of Electric Field on Dielectric Constants of the Body Tissues

The dielectric constants of the various tissues differ considerably. The tissues of low impedance such as blood and muscles have higher dielectric constants. The tissues of high impedance such as fibrous tissues and fat have low dielectric constant.

The relative arrangement of the tissues in the body coming in the pathway of electric field affects the distribution of the lines of forces and the heat production. If the different body tissues lie parallel to the electric field, the density of the field and thus the heat production is greatest in the tissues of low impedance. Thus, when the field is passed longitudinally through the limb, blood is heated most because of low impedance.

If the different body tissues lie transversely to the electric field, the density of the field and thus the heat production is greatest in the tissues of high impedance. Thus, when the field is passed transversely through the limb, fat is heated most because of its high impedance.

Actually, the arrangement of the tissues in the body is such that they do not offer a true parallel or series (longitudinal or transverse) arrangement but in fact the mixture of the two. As the deep tissues generally lie parallel to the field, heating is less in deep tissues. Also, the heating is more in the tissues of low impedance such as blood. Tissues in contact with those in which heat is produced, transferred by means of conduction. For example, when muscles surrounding a deeply placed joint are heated some heat is transmitted to the joint. Also, when blood is heated in the part being treated, it provides the heat to other tissues like muscles, etc. and thus the heat is carried away. This helps in prevention of overheating in the part being treated. Also it helps in heating other tissues which are not in direct contact with the electric

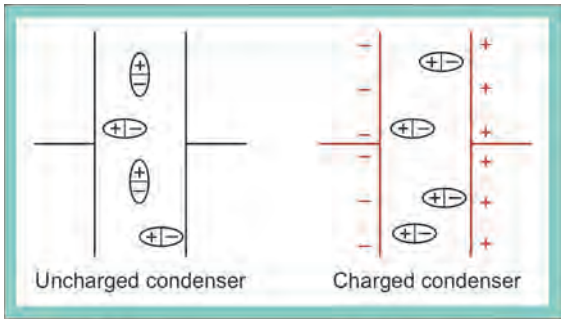

Fig. 4.3: Rotation of dipoles

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field. Therefore, intensity of electric field or any other form of heat needs to be gradually increased so as to allow vasodilatation of the vessels and to avoid overheating.

When shortwave diathermy is applied by the capacitor field method, the production of heat is determined by the distribution of electric field and it tends to be greatest in the superficial tissues and the tissues of low impedance.

The aim is to achieve an even electric field as far as possible throughout the superficial and deep tissues so as to obtain even heating in the tissues. To obtain desirable therapeutic effects the selection and placement of electrodes should be proper. The selection or placement of electrodes should be based on:

- Type of electrodes
- Size of electrodes
- Spacing of electrodes
- Positioning of electrodes.

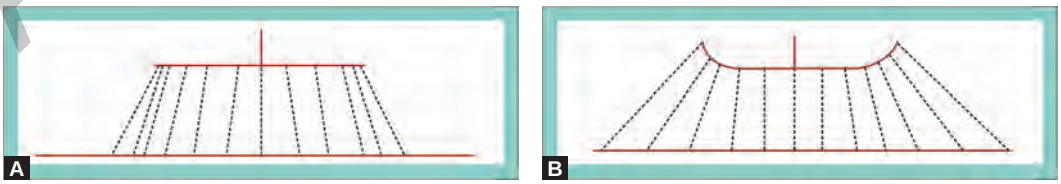
Type of Electrodes

There are various types of electrodes. Electrodes could be pad electrodes, plate electrodes and disk electrodes. Each electrode consists of a metal plate surrounded by some form of insulating material.

One type of electrode consists of a thin malleable metal plate covered with a rubber pad. This has an advantage to get moulded according to the body part. Electrodes of this type are separated from the skin by perforated felt pad and their position is maintained by the weight of the body. Undue pressure of the body part should be avoided as this may crack the plate inside and may hamper the blood supply. The insulating felt pad is perforated so that it contains a small quantity of air inside, which is preferably the best spacing material. Thus it has a disadvantage of not having completely air spacing between the pad and the body.

Another type of electrode consists of a thick rigid metal plate coated with a thin layer of insulating material made up of rubber or plastic. The property of an electric charge is that it concentrates at the edges of a conductor than at anywhere else. Thus these plates are frequently convex at the edges which provide a more even electric field than a flat disk. These plate electrodes are held at a distance from the skin by an adjusting device, thus provides air as an insulating material which is most preferable one (**Figs 4.4A and B)**.

The third type of electrode is a disk type electrode. These are having a transparent plastic cover within which a metal plate is present. These electrodes are commonly circular in shape, but special shapes can be used for irregular areas. The position of metal plate inside the disk can be adjusted. It is advisable to leave small gap between the cover and the skin to allow for the better circulation of the air.



Figs 4.4A and B: Electric fields produced by (A) Flat; (B) Convex electrodes

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Size of Electrodes

- If the two electrodes are of different sizes, they will behave as a capacitor of different sized plates. The different quantities of electricity are required to charge them to the same potential. This puts an uneven load to the machine. The charge will concentrate on the part of larger electrode which lies opposite to the smaller electrode **(Fig. 4.5)**.
- If the electrodes are little larger than the area treated, the outer part where the spread is greatest is deliberately not utilized. The part of the body to be heated lies in the central part of the field, which is more even. For treatment of the limbs, the electrodes should be larger than the diameter of the limbs, and for trunk and back electrodes should be as large as possible **(Fig. 4.6)**.
- If the diameter of the electrodes is smaller than that of the limbs, the lines of forces spread in the tissues, causing more heating of the superficial than of deep structures **(Fig. 4.7)**.
- If the diameter of the electrodes is far larger than that of the diameter of the limb, some of the lines of force bypass it completely and thus results in wastage of energy **(Fig. 4.8)**.

Thus, as a general rule, the electrodes should be equal in size and slightly larger than the area to be treated.

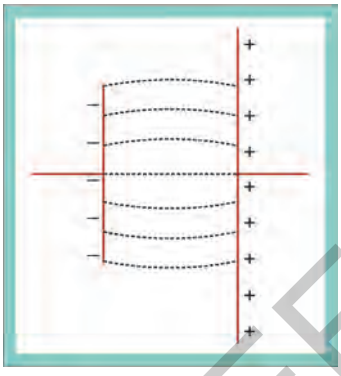

Fig. 4.5: Electrodes of different sizes

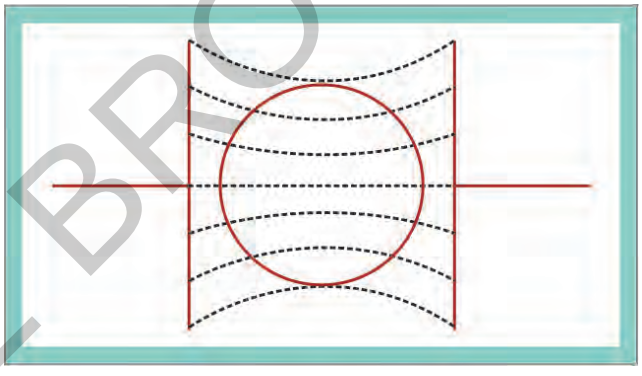

Fig. 4.6: Correct size of electrodes

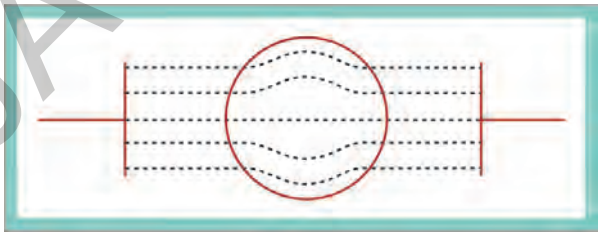

Fig. 4.7: Smaller electrodes

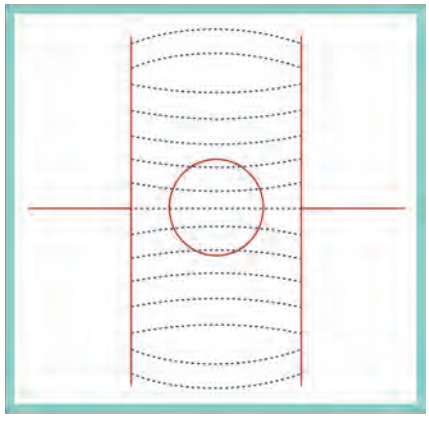

Fig. 4.8: Electrodes too large

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Spacing of Electrodes

- If the distance between the plates is small and the material between them is of high dielectric constant, the lines of forces spread as they pass between the plates of a charged condenser **(Fig. 4.9)**.
- When the distance between the electrodes is large, the spreading out of the electric field is minimal, while the use of spacing material of a low dielectric constant also limits the spread of the field **(Fig. 4.10)**.
- When the electrode spacing is narrow, the superficial tissue lies in the concentrated part of the field close to the electrode is thus heated more than the deep tissues, where density of the field is less **(Fig. 4.11)**.
- If the two electrodes are placed at an unequal distance from the body, the one electrode is placed nearer to the body than the other, then there is a greater heating effect under the closer electrode than under the farther one. The lines of force under the farther electrode have a greater distance in which to spread before reaching the body than those under the nearer one. They therefore cover a greater area of skin and their density is less than under the nearer electrode **(Fig. 4.12)**.

If the distance between two electrodes is less than the width of two pads, then the lines of force will travel through pads only and do not produce heat in the body tissues **(Fig. 4.13)**.

Thus, the spacing between the electrodes and the patient's body tissues should be as wide as possible as the machine allows and the material between the electrodes and skin should be of low dielectric constant, air being the most preferable one.

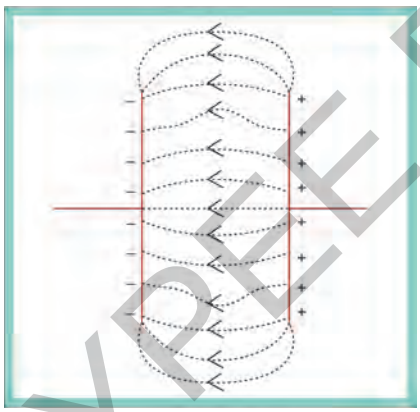

Fig. 4.9: Distance too small

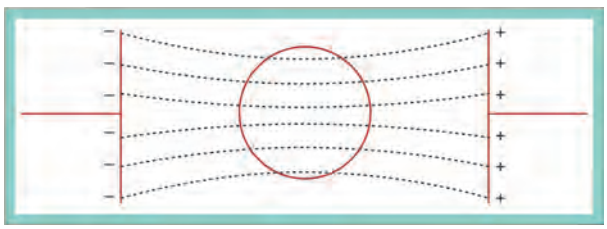

Fig. 4.10: Adequate distance

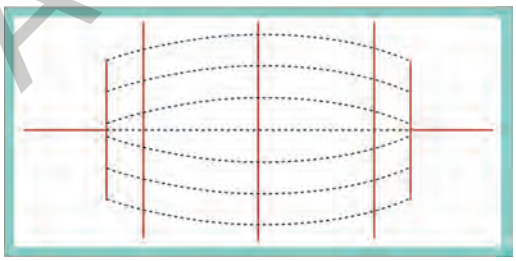

Fig. 4.11: Electrodes closer to the body

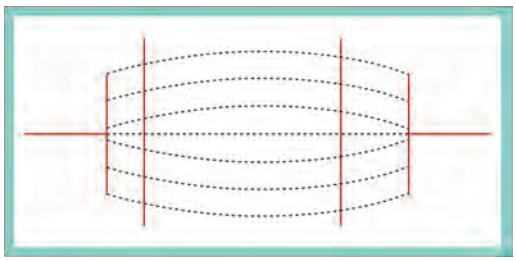

Fig. 4.12: Electrodes at uneven distance

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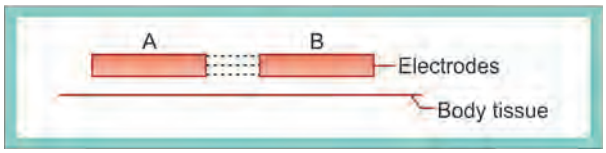
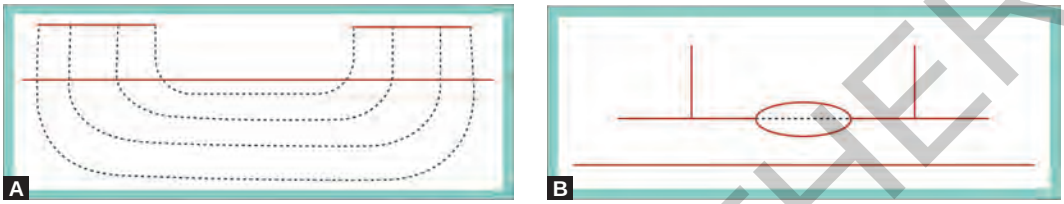


Fig. 4.13: Spacing between two electrodes



Figs 4.14A and B: Coplanar arrangement of electrodes: (A) Correct spacing; (B) Incorrect spacing

Positioning of the Electrodes

The positioning of electrodes is different for different structures to be treated. It depends upon the impedance of the structures and line of electric field. If the structures are of high impedance (fat and white fibrous tissue), the electrodes should be arranged in such a way that different tissues lie in series with each other, i.e. at right angles to electric field. If the structures are of low impedance (blood and muscles), the electrodes should be arranged in such a way that different tissues lie in parallel with each other and with the electric field.

When treatment is to be given to the ankle joint, the electrodes should be placed on the medial and lateral sides, so that tissues lie in series with each other and heating the joint is obtained. If the electrodes are placed longitudinally, tissues lie parallel to the field and heating of blood vessels and muscles is obtained. In injuries of soft tissues, longitudinal method may be used, where soft tissues need heating. Common positioning of electrodes used is:

- *Coplanar positioning of electrodes:* This method is used over larger area of the body, e.g. spine and is also called parallel method of placement. It is important that the distance between the electrodes should be more than the total width of spacing otherwise electric field will not pass through the tissues at all and will pass directly between the electrodes **(Figs 4.14A and B)**.
  This method is particularly suitable for the superficial structures.
- *Contraplanar positioning of electrodes:* This method is used for those structures where through and through heating is required, e.g. hip, shoulder joint. The electrodes are placed over the opposite aspects of the limb or joint, i.e. medial and lateral aspect or anterior or posterior aspect.
  This method is particularly suitable for the deeper structures or tissues.
- *Monopolar method:* Only one electrode is placed over the treatment area and other electrode is placed at a distance site or is not used at all. The electrode used produces a radial electric field **(Fig. 4.15)**.
  The density of electric field becomes less as the distance from the electrode increases and thus the heating is superficial.
- *Crossfire technique:* In this technique, half of the treatment is given with the placement of electrodes in one direction, i.e. medial or lateral aspect and another half is used with the

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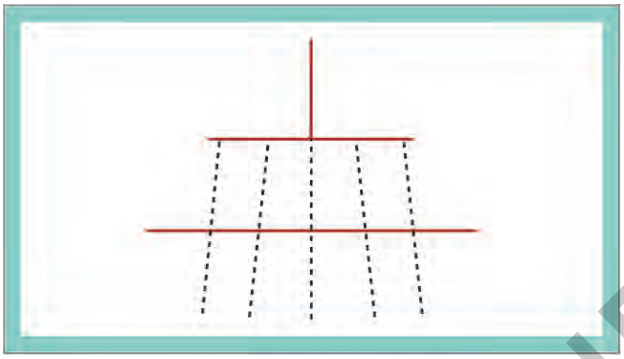

Fig. 4.15: Monopolar electrode with radial effect

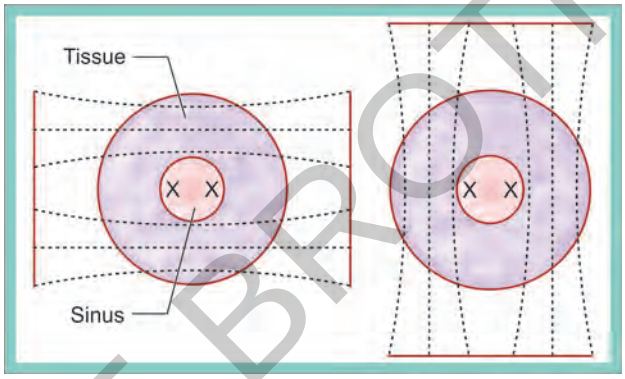

Fig. 4.16: Crossfire technique for sinus

placement of electrodes in other direction, i.e. anterior or posterior aspect. This method is commonly used for the treatment of the knee joint, sinuses (frontal, maxillary and ethmoidal) and for pelvic organs **(Fig. 4.16)**.

Cable Method/Inductothermy

In this method a thick, insulated cable is used for treatment purposes. Electric field or magnetic field or both are achieved by the use of cable method. When the high-frequency current oscillates in the cable, a varying electrostatic field is set up between its ends and a varying magnetic field around its center. The cable is coiled around the patient's body and is separated from the patient's body by a layer of insulating material.

- *The electrostatic field:* Electrostatic field is produced at the end of the cable and the effects are similar when the current is applied by a condenser method. The heating is more in superficial tissues and those of low impedance, also some heating is obtained in deeply placed structures of high impedance if suitable placing is done.
- *The magnetic field:* The magnetic field varies as the current oscillates and an EMF is produced by electromagnetic induction. If the conductor is a solid piece of conducting

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material, the EMF gives rise to eddy currents. Such currents are produced especially in the tissues which lie close to the center of the cable. The eddy currents produce heat and their effect confines only to the tissues of low impedance, thus heating of fat and white fibrous tissue is avoided. The currents are produced primarily near the surface of the conductor where the magnetic field is strongest and the superficial tissues are heated most. Some heat is transferred to adjacent tissues by conduction and by the circulation of blood, but the heating effect is primarily on superficial tissues of low impedance.

- *Effect of relative fields:* If the cable is coiled around the material of high impedance the electric field predominates, while the current produced by the electromagnetic induction is strongest when the material around which the cable is of low impedance. Thus when treating an area of high impedance, particularly if deep heating is required, the electric field between the ends of the cable is utilized in preference to the magnetic field at its center. When treating an area of low impedance, particularly if superficial heating is required, the eddy currents set up by the magnetic field at the center of the cable are utilized in preference to the electric field. Alternatively, both the effects can be utilized at the same time; if the whole cable is arranged in relationship to the patient's tissues, an electric field is set up between its ends and eddy currents near its center.

For treatment of the limbs, the cable is coiled around the part. If the area is large, e.g. the whole of a limb, all the cable is used and both electrostatic and electromagnetic fields are utilized. When treating the smaller area, the whole of the cable may not be required; either the ends or the center may be used, according to the depth of the heating required and the impedance of the tissues. If the area is of high impedance the electrostatic field between the ends of the cable is most effective, e.g. for the knee joint, two turns may be made with each end of the cable, which lie above and below the joint. When treating two joints of both shoulders, a few turns may be made with one end of the cable round one joint and a similar arrangement of the other end around the other joint. If the area to be treated is of low impedance, e.g. muscles and blood, the eddy currents produce satisfactory heating so the center of the cable is used.

To treat a flat surface like back, the cable can be arranged in a flat helix, two helices can also be made from its ends, or a grid arrangement may be used. With the grid, the magnetic field is complex and does not penetrate deeply into the tissues, so heating is mainly by the electric field, but with the other two methods, the tissues are heated with eddy currents. This flow at right angles to the magnetic lines of forces and the heating produced by a single helix is therefore in the form of a hollow ring in the tissues lying under the coil.

Advantages of Cable Method

The cable method is useful:

- For the treatment of an extensive area which could not be included between the condenser electrodes
- When the area is irregular
- When it is desirable to avoid heating of the subcutaneous fat.

Disadvantage of Cable Method

The impossibility of using air spacing.

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Monode Electrode

The main benefit of using a monode electrode is that it uses air spacing. The monode works on the principle of a cable. It consists of a flat helix of a thick wire mounted on a rigid support, a condenser is lying parallel with the coil making it possible to use shorter length of wire than that required for the cable. Heating is produced by the eddy currents.

Dosage

The treatment dosage should have an intensity that causes sufficient warmth (thermal dosage) of the tissues and the duration of the treatment should be 20–30 minutes. The treatment may be given daily or on an alternate day.

As a general rule, for the treatment of acute inflammation or any recent injury, the intensity of the treatment should be less but it should be carried out more frequently, i.e. twice daily. The current used may be that which produces mild warmth (midthermal) and may be reduced to the point at which no warmth is felt (subthermal or athermal). The duration of treatment is reduced to 5–10 minutes.

Physiological Effects of Heating the Tissues

The principal effect of shortwave diathermy to the body is heating of tissues. This is the modality which provides deepest heating of the tissues. The main physiological effects due to heating of the body tissues are:

- Effects on metabolism of the body
- Effects due to increased blood supply
- Effects of heat on the nervous tissues
- Effects of heat on the muscular tissue
- Effects of heat on the sweat glands.

Effects on Metabolism of the Body

As the Van't Hoff's statement states that 'any chemical change which is capable of being accelerated is done by the rise in temperature'. Therefore, all the chemical changes of the body that can be accelerated are accelerated by heat. The metabolism of the body itself is accelerated. Both the anabolism and catabolism are enhanced. The oxygen supply to the tissues is increased, removal of waste products is enhanced, the nutritional supply to the tissues is increased and thus the healing of damaged tissues is accelerated.

Effects due to Increased Blood Supply

The heat has a direct effect on the blood vessels. It causes vasodilatation of the vessels in the area of heating. Stimulation of the superficial nerve endings can also cause reflex dilatation of the arterioles. As a result of vasodilatation, there is an increased flow of blood through the area, so that the necessary oxygen and nutritive materials are supplied and the waste products are removed. Also, there is increased filtration and diffusion through different membranes and faster transport of some enzymes. Thus, this results in faster healing of the damaged tissues and early recovery from the injury.

When there is generalized vasodilatation, the peripheral resistance is reduced. Heat also reduces viscosity of the blood and thus there is generalized fall in the blood pressure.

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