BM-3252 MEDICAL PHYSICS

UNIT-1

1.4 OVERVIEW OF NON-IONIZING RADIATION EFFECTS

Low frequency effects

- Biological tissue contains free charge carriers so that it is meaningful to consider it as an electrical conductor and to describe it in terms of conductivity.
- Bound charges are also present in tissue so that dielectric properties also exist and can be expected to give rise to displacement currents when an electric field is applied.
- Biological tissue also contains mechanisms for the active transport of ions.
- This is an important mechanism in neural function and also in membrane absorption processes, such as those which occur in the gastro-intestinal tract.
- Conductivity is the dominant factor when relatively low-frequency (less than 100 kHz) electric fields are applied to tissue.

Frequency–dependent effects

- The electrical properties of a material can be characterized by an electrical conductivity σ and permittivity ε.
- If a potential V is applied between the opposite faces of a unit cube of the

$$I_c = V\sigma \qquad I_d = \frac{dV}{dt}\varepsilon\varepsilon_0$$

material then a conduction current Ic and displacement current Id will flow, where

and where ε_0 is the dielectric permittivity of free space with the value 8.854×10^{-12} Fm^{-1}. If V is sinusoidally varying then Id is given by

$$I_d = V\,2\pi f\,\varepsilon\varepsilon_0$$

where f is the frequency of the sinusoidal potential Ic increases only slowly with increasing frequency and indeed at frequencies up to 100 kHz conductivity is almost constant.

- Id increases much more rapidly with increasing frequency and above about 10^7 Hz the displacement current exceeds the conduction current.

- The region around 10 Hz is generally considered to arise from dielectric dispersion associated with tissue interfaces such as membranes; the region around 1 MHz is associated with the capacitance of cell membranes; the region around 10^{10} Hz represents the dielectric dispersion associated with polarizability of water molecules in tissue

Neural Effects

- If low-frequency currents are passed between a pair of electrodes placed on the skin then a current can be found at which sensation occurs. In general, this threshold of sensation rises with increasing frequency of applied current. Three fairly distinct types of sensation occur as frequency increases.

➢ At very low frequencies (below 0.1 Hz) individual cycles can be discerned and a 'stinging sensation' occurs underneath the electrodes. The major effect is thought to be electrolysis at the electrode/tissue interface where small ulcers can form with currents as low as 100 μA. The application of low-frequency currents can certainly cause ion migration and this is the mechanism of iontophoresis. Current densities within the range 0–10 A m^{-2} have been used to administer local anaesthetics through the skin, and also therapeutic drugs for some skin disorders. The applied potential acts as a forcing function that can cause lipid soluble drugs to penetrate the stratum corneum. Sweat ducts are the principal paths for ion movement.

➢ At frequencies above 10 Hz, electrolysis effects appear to be reversible and the dominant biological effect is that of neural stimulation. If the electrodes are placed over a large nerve trunk such as the ulnar or median, then the first sensation arises from the most rapidly conducting sensory fibres. If the amplitude of the current is increased, then more slowly conducting fibres are stimulated and motor contractions occur. Stimulation over a nerve trunk arises as a result of depolarization at a node of Ranvier. The capacitance of a single node is of the order 10 pF such that a charge of 10^{-12} C is required to remove the normally occurring polarization potential of about 0.1 V. 10^{-12} C can be delivered as a current of 10^{-9} A for 1 ms. However, when the current is delivered through relatively distant surface electrodes only a very small fraction of the current will pass into a particular node of Ranvier.

➢ At frequencies above about 10 kHz the current necessary to cause neural stimulation is such that heating of the tissue is the more important biological effect. Displacement currents are usually negligible within the range 10–100 kHz and therefore the I2R losses are dominant.

- The major biological effects within our frequency range of interest are therefore electrolysis, neural stimulation and heating.
- The threshold will depend upon the electrode area as there is ample evidence to show that current density rather than current is the important parameter.
- However, the relative magnitude of the three effects we have considered is not changed when current density rather than current is used. A typical value of current density at threshold and 50 Hz is 2 A m^{-2}.

<u>Cardiac Stimulation: Fibrillation</u>

- In many cases the patient is directly connected to the equipment so that in cases of a fault electrical current may flow through the patient.
- The response of the body to low-frequency alternating current depends on the frequency and the current density.
- Low-frequency current (up to 1 kHz) which includes the main commercial supply frequencies (50 Hz and 60 Hz) can cause:
  - prolonged tetanic contraction of skeletal and respiratory muscles;
  - Arrest of respiration by interference with the muscles that control breathing;
  - Heart failure due to ventricular fibrillation (VF).
- The skin can have a resistance as high as 1 MΩ (dry skin) falling to 1 kΩ (damp skin). Internally, the body resistance is about 50Ω.

· Internal conduction occurs mainly through muscular pathways. Ohm's law can be used to calculate the current. For example, for a person with damp skin touching both terminals of a

constant voltage 240 V source (or one terminal and ground in the case of mains supply), the current would be given by I = V/R = 240/2050 = 117 mA, which is enough to cause ventricular fibrillation (VF)

Indirect Cardiac Stimulation

- The threshold of current perception is about 1 mA, when a tingling sensation is felt. At 5 mA, sensory nerves are stimulated. Above 10 mA, it becomes increasingly difficult to let go of the conductor due to muscle contraction. At high levels the sustained muscle contraction prevents the victim from releasing their grip. When the surface current reaches about 70– 100 mA the co-ordinated electrical control of the heart may be affected, causing ventricular fibrillation (VF).
- The fibrillation may continue after the current is removed and will result in death after a few minutes if it persists.
- Larger currents of several amperes may cause respiratory paralysis and burns due to heating effects. The whole of the myocardium contracts at once producing cardiac arrest. However, when the current stops the heart will not fibrillate, but will return to normal co-ordinated pumping.
- This is due to the cells in the heart all being in an identical state of contraction.
- This is the principle behind the defibrillator where the application of a large current for a very short time will stop ventricular fibrillation.

Direct Cardiac Stimulation

- Currents of less than 1 mA, although below the level of perception for surface currents, are very dangerous if they pass internally in the body in the region of the heart.
- They can result in ventricular fibrillation and loss of pumping action of the heart.
- Currents can enter the heart via pacemaker leads or via fluid-filled catheters used for pressure monitoring.
- The smallest current that can produce VF, when applied directly to the ventricles, is about 50 μA. 0.5 mA limit for leakage currents from normal equipment is below the threshold of perception, but above the VF threshold for currents applied to the heart.

Ventricular Fibrillation

- VF occurs when heart muscle cells coming out of their refractory period are electrically stimulated by the fibrillating current and depolarize, while at the same instant other cells, still being in the refractory period, are unaffected
- The cells depolarizing at the wrong time propagate an impulse causing other cells to depolarize at the wrong time.

- Thus, the timing is upset and the heart muscles contract in an uncoordinated fashion.
- The heart is unable to pump blood and the blood pressure drops. Death will occur in a few minutes due to lack of oxygen supply to the brain.
- To stop fibrillation, the heart cells must be electrically co-ordinated by use of a defibrillator.
- The threshold at which VF occurs is dependent on the current density through the heart, regardless of the actual current.
- As the cross-sectional area of a catheter decreases, a given current will produce increasing current densities, and so the VF threshold will decrease.

Higher Frequency Effects

Surgical Diathermy / electrosurgery

- The technique uses an electric arc struck between a needle and tissue in order to cut the tissue. The arc, which has a temperature in excess of 1000 ˚C, disrupts the cells in front of the needle so that the tissue parts as if cut by a knife; with suitable conditions of electric power the cut surfaces do not bleed at all.
- If blood vessels are cut these may continue to bleed and current has to be applied specifically to the cut ends of the vessel by applying a blunt electrode and passing the diathermy current for a second, or two or by gripping the end of the bleeding vessel with artery forceps and passing diathermy current from the forceps into the tissue until the blood has coagulated sufficiently to stop any further bleeding.
- Diathermy can therefore be used both for **cutting and coagulation.**
- The current from the 'live' or 'active' electrode spreads out in the patient's body to travel to the 'indifferent', 'plate' or 'patient' electrode which is a large electrode in intimate contact with the patient's body.
- Only at points of high current density, i.e. in the immediate vicinity of the active electrode, will coagulation take place; further away the current density is too small to have any effect.

· Although electricity from the mains supply would be capable of stopping bleeding, the amount of current needed (a few hundred milliamperes) would cause such intense muscle activation that it would be impossible for the surgeon to work and would be likely to cause the patient's heart to stop.

- The current used must therefore be at a sufficiently high frequency that it can pass through tissue without activating the muscles.

Diathermy Equipment

- Diathermy machines operate in the radio-frequency (RF) range of the spectrum, typically 0.4–3 MHz. Diathermy works by heating body tissues to very high temperatures. The current densities at the active electrode can be 10 A cm^{-2}.
- The total power input can be about 200 W. The power density in the vicinity of the cutting edge can be thousands of W cm^{-3}, falling to a small fraction of a W cm^{-3} a few centimetres from the cutting edge.
- The massive temperature rises at the edge (theoretically thousands of ˚C) cause the tissue fluids to boil in a fraction of a second. The cutting is a result of rupture of the cells.
- An RF current follows the path of least resistance to ground. This would normally be via the plate (also called dispersive) electrode.
- However, if the patient is connected to the ground via the table or any attached leads from monitoring equipment, the current will flow out through these.
- The current density will be high at these points of contact, and will result in surface burns (50 mA cm^{-2} will cause reddening of the skin; 150 mA cm^{-2} will cause burns).
- Even if the operating table is insulated from earth, it can form a capacitor with the surrounding metal of the operating theatre due to its size, allowing current to flow.
- Inductive or capacitive coupling can also be formed between electrical leads, providing other routes to ground.

<u>Heating effects</u>

- If the whole body or even a major part of the body is exposed to an intense electromagnetic field then the heating produced might be significant.
- The body normally maintains a stable deep-body temperature within relatively narrow limits (37.4±1 ˚C) even though the environmental temperature may fluctuate widely.
- The normal minimal metabolic rate for a resting human is about 45Wm^{-2} (4.5 mW cm^{-2}), which for an average surface area of 1.8 m^2 gives a rate of 81 W for a human

body.

- Blood perfusion has an important role in maintaining deep-body temperature.
- The rate of blood flow in the skin is an important factor influencing the internal thermal conductance of the body: the higher the blood flow and hence, the thermal conductance, the greater is the rate of transfer of metabolic heat from the tissues to the skin for a given temperature difference.
- Blood flowing through veins just below the skin plays an important part in controlling heat transfer surface temperatures will be affected by vessels carrying blood at a temperature higher or lower than the surrounding tissue provided the vessels are within a few millimetres of the skin surface.