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Basics of Electrotherapy



3rd Edition

Subhash M Khatri

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4 Muscle and Nerve Stimulating Currents

CHAPTER

Clinical Pearls



- Direct current is used for iontophoresis.
- Faradic current is used for innervated muscles.
- Interrupted direct current is used for denervated muscles.
- TENS is used for pain relief.
- IFT can be used for stimulation of deeply situated muscles as well as pain relief.

As mentioned in the second chapter, muscle nerve stimulating currents are used primarily for muscle re-education, pain relief, to delay atrophy and wasting of muscles. This chapter includes direct current, Faradic current, interrupted direct current, transcutaneous electrical nerve stimulation (TENS), interferential current, sinusoidal current, diadynamic current, high-voltage pulsed Galvanic current (HVPG) and micro amperage electrical nerve stimulation.

DIRECT CURRENT

Direct current (DC) electrotherapy is a form of electrical stimulation therapy used in physiotherapy to deliver continuous unidirectional electrical current. Direct current is a unidirectional as well as continuous current. This current is mostly useful for various therapeutic purposes, including pain relief, tissue healing, and iontophoresis. It is also termed as Galvanic current or plain Galvanic current, as an honor to Luigi Galvani, professor of anatomy who stimulated muscles and nerves of a frog with direct current, in 1786. It is also called *constant current*, as the current passes continuously in the same direction. A schematic representation of direct current is given in **Figure 4.1**.

The key characteristics of direct current include a continuous steady flow of current in one direction, distinct effects at the cathode

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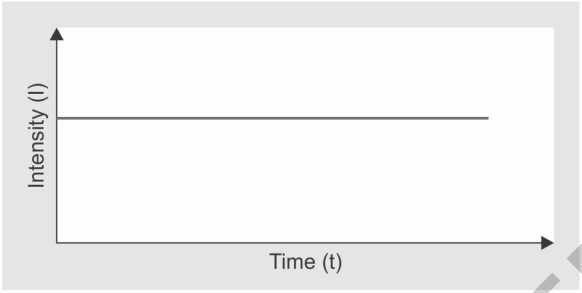

Fig. 4.1: Schematic representation of direct current.

and anode, influencing tissue healing and ion movement and electrochemical reactions that can cause chemical changes under the electrodes, making electrode care and placement crucial. Direct current is mainly used for iontophoresis, anodal galvanism, cathodal galvanism, and for acceleration of healing.

Production

Direct current can be obtained from dry batteries as well as from household alternating current. Direct current can be obtained from dry batteries by connecting the cells in series. This setup ensures a steady and continuous flow of DC. A variable resistance is incorporated into the circuit to control the output current and voltage. Additionally, instruments like a voltmeter or ammeter can be included to measure the intensity of the output. An alternative source of direct current is household alternating current (AC). To achieve this, the AC voltage is first reduced using a step-down transformer. This lowers the voltage to a safer and manageable level for further processing. Once the AC voltage is reduced, it undergoes rectification, a process that converts AC into DC. The rectified current is then smoothened to remove any residual fluctuations, ensuring a stable direct current output. The final DC output is controlled using variable resistance, allowing precise adjustments to the current or voltage as needed. A voltmeter is commonly used to measure and monitor the output, ensuring it meets the required specifications.

Polarity

Polarity is generally marked with direct current source by color codes, for example, red for positive and black for negative. It may be tested with two simple experiments such as, saltwater experiment and phenolphthalein experiment. The saltwater experiment is

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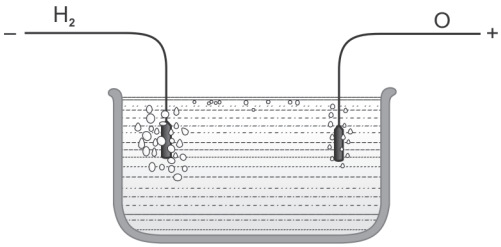

Fig. 4.2: Saltwater experiment.

shown in **Figure 4.2**. In saltwater experiment, little salt is added to water in a glass container, then electrodes attached to direct current terminals are inserted. After this, when the intensity is increased, you can see many more bubbles getting evolved at negative electrode or cathode and few bubbles at anode. It is because, water is split into hydrogen and oxygen ions. Hydrogen being positive ion, gets liberated at cathode and oxygen gets liberated at anode. Considering the water molecule, it is obvious that the number of hydrogen atoms will be double than oxygen and hence, many more bubbles at cathode are evolved as compared to anode. In case of phenolphthalein experiment, add a few drops of phenolphthalein over tissue paper and place the electrodes connected to the direct current source over it, then pass the current for some time and you will see pink color under negative electrode or cathode.

Physiological Effects

The various physiological effects of direct current are stimulation of sensory nerves, stimulation of motor nerves, accommodation and chemical production.

Stimulation of Sensory Nerves

When direct current is applied to the body tissue, it stimulates sensory nerves and produces burning sensation. This sensory irritation is felt under both the electrodes, but if the current flows for sufficient length of time, then more irritation is felt under the negative electrode. Hence, the intensity of current during the treatment is adjusted in such a way that it avoids overstimulation or unpleasant sensation.

Stimulation of Motor Nerves

Direct current can produce stimulation of motor nerves during its "on" and "off". Immediately after direct current is switched on, accommodation in motor nerves takes place and hence there is no

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further response. Direct current is almost ineffective for motor nerve stimulation due to continuous flow since direct current provides a steady, nonpulsed current, which causes polarization of the nerve membrane. Continuous polarization prevents the repeated depolarization necessary to generate a train of action potentials required for motor nerve stimulation. Accommodation or adaptation occurs since motor nerves quickly adapt to a constant stimulus, reducing their response to direct current and there is a polarity effect. The cathode (negative electrode) is more effective in lowering the membrane potential (depolarization). Still, the steady nature of direct current does not provide the required periodic changes for motor nerve activation.

Accommodation

Accommodation is physiological adaptation by nerves. Motor nerves get quickly accommodated to direct current and hence it is not possible to stimulate the innervated as well as denervated muscles by direct current. Analogy of accommodation can be done with our feeling of clothes on the body. We feel that we have put on the clothes after bath, but afterwards we get adapted and do not get the same feel throughout the day. Similarly, if one's house is by the main road, then he gets used to the night traffic and can have sound sleep as a result of adaptation. Accommodation due to direct current (DC) is a phenomenon where nerves, especially motor and sensory nerves, adapt to a constant stimulus and stop responding despite the continued application of the stimulus. This is a critical concept in electrotherapy and impacts the clinical applications of DC. Mechanism of accommodation includes constant stimulus, gradual polarization, threshold increase and ionic redistribution. Direct current provides a steady, unidirectional flow of electrons, causing a continuous and unchanging stimulus at the nerve membrane. Under the cathode, the nerve membrane depolarizes, while under the anode, it hyperpolarizes. Initially, the depolarization may reach the threshold, causing an action potential. However, with continuous stimulation, the nerve membrane adapts to the steady-state polarization. During accommodation, the nerve becomes less responsive as the threshold for action potential generation rises. This occurs due to the inactivation of sodium ion channels and stabilization of the nerve membrane potential and continuous ionic movement caused by DC alters the local ionic balance, reducing the excitability of the nerve over time. Consequences of accommodation includes reduced effective stimulation, inefficiency in exciting motor

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or sensory nerves and higher current requirement. Nerve fibers no longer respond to the same level of current intensity after initial stimulation. Accommodation limits the use of DC for repetitive nerve excitation. To overcome accommodation, a gradual increase in current intensity (ramp-up technique) or the use of interrupted or pulsed currents is needed. Factors Influencing accommodation includes nerve fiber type, intensity and duration and polarity effects. Sensory nerves (e.g., A-beta fibers) accommodate more rapidly than motor nerves. Denervated muscles and non-nervous tissues like muscle fibers respond to DC because they do not accommodate in the same way. Higher intensity and longer duration of DC increase the rate of accommodation. Accommodation occurs faster under the anode due to hyperpolarization compared to the cathode.

Chemical Production

When direct current is applied to the body tissue it produces chemicals in the form of acid and base. Base or alkali is produced at the cathode and acid at the anode (remember A for acid and A for anode). The application of direct current (DC) to the human body, particularly in electrotherapy, leads to chemical reactions under the electrodes due to the movement of ions. This phenomenon, often referred to as electrolysis, results in specific chemical production near the cathode (negative electrode) and the anode (positive electrode). These reactions are essential for understanding the therapeutic effects and precautions of DC application. The cathode attracts positive ions (cations) such as sodium (Na^+) and hydrogen (H^+) and reduction reaction occurs at the cathode and hence water dissociates into hydroxide ions (OH^-) and hydrogen gas. Alkaline reaction due to the accumulation of hydroxide ions (OH^-) and the pH under the cathode increases, which can soften tissues and enhance excitability of the nerves and muscles. At the anode (+) (positive electrode) the anode attracts negative ions (anions) such as chloride (Cl^-) and hydroxide (OH^-). Oxidation reactions occur at the anode. The pH under the anode decreases, which can harden tissues and decrease nerve excitability.

In other words, the chemical effects of DC application in the human body are primarily due to the electrolysis of water and the movement of ions under the electrodes. These reactions result in alkaline and acidic environments at the cathode and anode, respectively, with significant therapeutic applications but also risks such as chemical burns. Proper techniques and precautions ensure safe and effective use of DC in physiotherapy.

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Effect on Body Proteins

It is believed that the direct current causes coagulation of proteins under the positive electrode and liquefaction under the negative electrode. The application of direct current (DC) to the human body can have notable effects on proteins, primarily due to the movement of ions and changes in the pH environment near the electrodes. These effects are clinically significant in certain therapies, but they can also pose risks if not managed appropriately. The effects include protein denaturation, protein precipitation, electrophoretic movement, effect on enzyme activity, and impact on collagen and elastin.

Under the cathode: The increase in alkalinity (due to hydroxide ion accumulation) can cause local protein denaturation. Alkaline conditions can break hydrogen bonds and alter the tertiary and quaternary structures of proteins, affecting their function.

Under the anode: The acidic environment (due to hydrogen ion accumulation) can also denature proteins. Acidic conditions can disrupt ionic bonds and promote the aggregation of proteins, leading to coagulation. At the anode, the acidic environment may lead to the precipitation of certain proteins, which can be observed in wound care applications where DC is used.

Proteins, being charged molecules, can migrate under the influence of DC: Positively charged proteins move toward the cathode. Negatively charged proteins move toward the anode. This movement can influence cellular processes and tissue healing. Enzymes, which are proteins, can have their activity altered by the pH changes induced by DC. Alkaline or acidic conditions may inhibit enzyme function or denature the enzymes, disrupting metabolic processes in the immediate area. Collagen, a structural protein in connective tissue, may be softened under the cathode due to increased alkalinity, which can aid in scar tissue remodeling. At the anode, the acidic environment can harden collagen fibers, potentially useful in certain therapeutic contexts. Clinical implications includes wound healing since DC can promote tissue repair by influencing protein dynamics: Alkaline conditions under the cathode can help dissolve necrotic proteins. Acidic conditions under the anode may reduce bacterial protein activity, promoting a sterile environment.

Electrolysis and protein effects: The chemical changes induced by DC can impact cellular proteins and extracellular matrix components, facilitating tissue regeneration.

Iontophoresis: DC can aid in the delivery of protein-based drugs or biologics by facilitating their transdermal migration. Risks and

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precautions include protein damage, burns, and tissue necrosis since prolonged DC application or high intensities can denature proteins excessively, leading to tissue damage. Burns and tissue necrosis since protein denaturation under the cathode or anode contributes to the risk of chemical burns if DC is improperly applied.

Therapeutic Indications

Therapeutically direct current is used for medical galvanism, anodal galvanism, cathodal galvanism, surgical galvanism and iontophoresis.

Galvanism

The use of direct current without any drug for the treatment of various diseases and disorders is known as galvanism. **Therapeutic galvanism** refers to the application of direct current (DC) for therapeutic purposes in physiotherapy. This technique utilizes a steady, unidirectional electric current to achieve physiological and therapeutic effects. It is commonly employed in electrotherapy for pain management and tissue repair. Therapeutic effects of galvanism include tissue healing, stimulation of physiological repair mechanism, improve blood circulation, reduces pain. Dosages can be adjusted with current intensity (mA) based on patient tolerance and desired effect.

Medical Galvanism

Here both the electrodes are of the same size **(Fig. 4.3)**. It causes vasomotor stimulation of the skin and increased circulation to the body part where direct current is applied. This method leverages the electrochemical and physiological effects of DC for a variety of applications in medicine and physiotherapy. Unlike alternating current (AC), DC flows steadily in one direction, allowing for precise control over therapeutic effects. Basic principles of medical galvanism include sedative action, softening, and tissue relaxation. Medical galvanism is used for acute and chronic inflammatory conditions such as chilblain, Raynaud's disease,

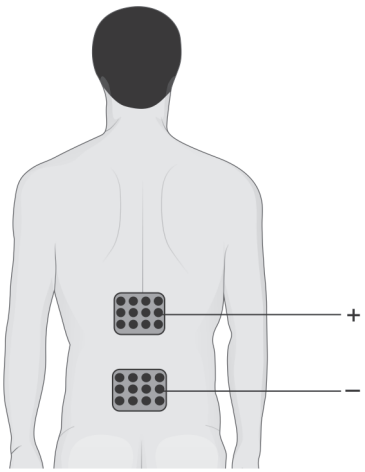

Fig. 4.3: Medical galvanism.

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and Buerger's disease, for pain relief, tissue healing, scar tissue softening, and promoting healing of wounds, pressure sores, and diabetic ulcers.

Anodal Galvanism

Here anode is an active electrode and cathode, which is larger, acts as an indifferent electrode **(Fig. 4.4)**. Anodal galvanism produces acidic reaction, hardens the tissue and reduces nerve irritability (**Mnemonic:** 'HARN' where H: harden, A: acidic reaction and RN: reduce nerve irritability). Anodal galvanism is used for pain relief. *Anodal Galvanism refers to the therapeutic use of direct current with the anode (positive pole) as the active electrode.* This application has the unique physiological and electrochemical effects of the positively charged electrode for targeted therapeutic outcomes. The anode attracts negatively charged ions, produces an acidic environment (formation of hydrochloric acid in tissues), and causes protein coagulation at the site of application. Biological effects produced by anodal galvanism are sedative effect through reduced nerve excitability, vasoconstrictive effects through reduced local blood flow and inflammation. Therapeutic indications or uses are pain relief in conditions like neuralgia, radiculopathy, and tendonitis, wound healing particularly in chronic wounds, ulcers, and burns, hyperhidrosis since it can reduce excessive sweating by altering sweat gland activity and in softening scars by modulating tissue remodeling.

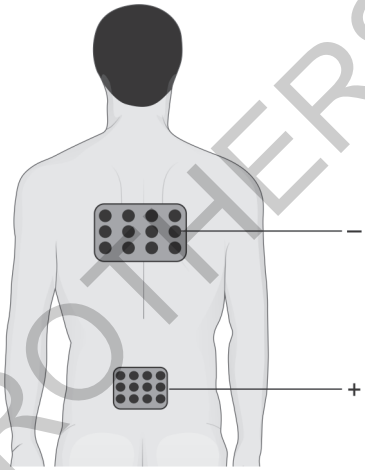

Fig. 4.4: Anodal galvanism.

Cathodal Galvanism

Here cathode is an active electrode, and anode is an indifferent electrode **(Fig. 4.5)**. It produces basic reaction or alkaline reaction, softens the tissues and increases nerve irritability. It is used to soften scar tissue. *Cathodal Galvanism refers to the therapeutic use of direct current (DC) with the cathode (negative pole) as the active electrode.* The cathode exerts unique electrochemical and physiological

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effects, making it suitable for specific therapeutic goals, such as enhancing tissue healing. The cathode attracts positively charged ions, produces an alkaline reaction (formation of sodium hydroxide in tissues) and softens tissues and enhances hydration at the site of application. It increases nerve and muscle excitability, enhances local blood flow, promoting tissue oxygenation and nutrient delivery. It accelerates healing by enhancing circulation and promoting cellular repair, reduces chronic pain by influencing nerve function and aids in resolving localized swelling through improved lymphatic and venous return.

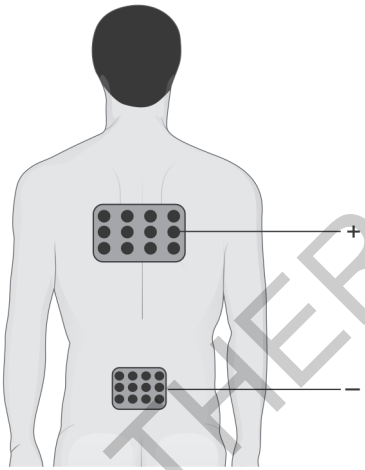

Fig. 4.5: Cathodal galvanism.

Surgical Galvanism or Electrolysis

Surgical galvanism or electrolysis is destruction of superfluous hair (hypertrichosis) by the use of galvanic current. Here cathode, which acts as an active electrode is in the form of needle and anode, is an indifferent electrode. Half milliampere of direct current is applied for 1 minute. Bubbles will come out and then hair can be lifted easily with forceps. Aseptic precautions should be taken during this procedure. Skill is required for surgical galvanism. There are 10 to 20% chances of recurrence following this technique. Surgical galvanism is a specialized application of direct current (DC) in medical and surgical procedures. It leverages the electrochemical effects of galvanic current for tissue destruction, coagulation, or other therapeutic purposes. This technique is largely historical but has modern analogs in electrochemical and surgical technologies. Direct current induces localized chemical changes, such as the formation of acidic and alkaline environments at the electrodes. These changes can cause tissue coagulation, destruction, or dissolution. The current creates precise, controlled tissue necrosis without significant damage to surrounding areas. Applications includes electrolysis used to destroy unwanted tissues or lesions, such as tumors, warts, or hair follicles (for permanent hair removal), cauterization that helps to coagulates

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tissues to stop bleeding during surgeries, previously it was also used for destruction of pathological growths used to treat conditions like granulomas, polyps, or certain benign tumors, treatment of infections since it is applied to drain or disinfect infected areas, leveraging its antiseptic properties and historically it was also used in oncology to destroy small malignant tumors by electrochemical decomposition.

Iontophoresis

It is also known as *ion transfer, ionization, or cataphoric medication* (**Mnemonic**: 'ICI'). It is believed that Stéphane Leduc discovered it in 1903. Iontophoresis is the specific transfer of ions into the body tissue by using direct current for therapeutic purposes. (You can recall this definition by asking yourself questions, such as, what is transferred? where is it transferred? how is it transferred? and what for it is transferred?) Transdermal administration of drug is assuming an important place in modern drug therapy. It is used for nonionized drugs required in a small dosage. Transdermal administration can be passive or facilitated. In passive administration, the nonionized drug traverses the skin through the stratum corneum. The skin, being a semi-permeable membrane, allows only a small amount of any drug molecule to passively penetrate the skin. Ionized drugs do not easily penetrate this barrier and are not suitable for routine transdermal delivery unless an external source of energy is provided to drive the drug across the skin. Facilitated diffusion can utilize either ultrasound (phonophoresis) or electrical (iontophoresis) energy. In iontophoresis, this external source of energy is in the form of an applied direct electrical current.

Principle

It is based on the principle that an electrically charged electrode will repel a similarly charged ion. In other words, if a drug is in ionic form, then it can be made to travel through the body tissue through the skin by the use of direct current via repulsive force between similar charges. We can understand this theory or principle with Leduc experiment, as shown in **Figure 4.6**.

Two rabbits are arranged in a series. Over positive electrode of rabbit A, strychnine is applied. Over negative electrode of rabbit B, potassium cyanide is applied. Other electrodes are moistened to allow the passage of current. Pass direct current through this series. Rabbit B will die, and rabbit A will have convulsions. Place new rabbits and reverse the polarity, there will be no effect. This suggests

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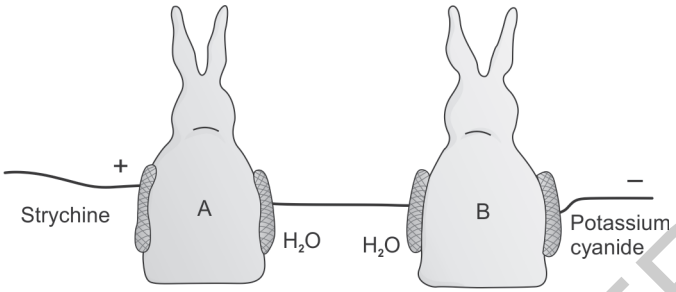

Fig. 4.6: Leduc experiment.

that there is a transfer of ions when placed over similarly charged electrodes.

Iontophoresis enhances transdermal drug delivery by three mechanisms:

1. Ion-electric field interaction provides an additional force that drives ions through the skin.
2. The flow of electric current increases the permeability of the skin, and
3. Electro-osmosis produces bulk motion of solvent that carries ions or neutral species with the solvent stream.

Electro-osmotic flow occurs in a variety of membranes and is in the same direction as the flow of counter-ions. It may assist or hinder drug transport. Since human skin is negatively charged above pH 4, counter ions are positive ions, and electro-osmotic flow occurs from anode to cathode. Thus, anodic delivery is assisted by electro-osmosis, but cathodic delivery is retarded. Because of the electro-osmotic flow, transdermal delivery of a large anion (negatively charged protein) from the anode compartment is more effective than that from the cathode compartment. Iontophoretic devices may be powered by electricity, batteries or by rechargeable power sources. An iontophoresis device consists of a microprocessor-controlled battery powered DC current, drug reservoir, and electrodes. The battery is most commonly 9-volt one. The drug reservoir consists of a gauze/cloth or gel pad to which the solution is applied, or the solution is injected through a port into the reservoir electrode combination. Wires are connected between the microprocessor unit and the active and passive electrodes. Iontophoretic drug delivery electrodes are available and are composed of hydrogel material that is hydrated before use to deliver local anesthesia.

Reverse iontophoresis is the application of an electric current across the skin that is used to extract a substance of interest from

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within or beneath the skin to the surface for testing. In vivo and in vitro methods have shown that the approach can be used to monitor the subdermal concentration variation of glucose and provide a non-invasive technique by which a diabetic can monitor the fluctuation of blood sugar.

Advantages of iontophoresis

Iontophoresis provides for controlled delivery rates (through variations of current density, pulsed voltage, drug concentration and ionic strength). It eliminates gastrointestinal incompatibility, erratic absorption, and first pass metabolism. It reduces side effects and avoids the risks of infection, inflammation, and fibrosis associated with continuous injection or infusion since it is noninvasive. It enhances patient compliance with a convenient and noninvasive therapeutic regimen, and decreased dosing frequency. It improves efficacy by continuous release and decreases the total dose and dosing frequency.

Disadvantages of iontophoresis

There is a possibility of burns if the electrodes are improperly used. The formation of undesirable vesicles and bullae in skin being treated can be avoided by periodically interrupting a unidirectional treatment current with a relatively short pulse of current in the opposite direction.

Effectiveness

The effectiveness of iontophoresis depends on a number of ions transferred and the depth of penetration. The number of ions transferred is determined by current density, duration of current flow, and concentration of ions, the physicochemical properties of the drug, formulation factors, biological factors and electro-endo-osmotic flow. Iontophoresis is facilitated by increased vasodilation to the area under electrodes and inhibited by the insoluble nature of ions. Physicochemical variables that include the charge, size, structure and lipophilicity of the drug. The drug should be water soluble, low-dose and ionizable with a high charge density. Smaller molecules are more mobile but large molecules are also iontophoresable.

Formulation factors include the drug concentration, pH, ionic strength, and viscosity.

- **Drug concentration:** Increasing drug concentrations results in greater drug delivery to a certain degree.

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Basics of Electrotherapy

Basics of Electrotherapy, Third Edition by Subhash Khatri continues to be a trusted and comprehensive guide for students and practitioners of physiotherapy. Carefully revised and updated, this edition reflects the latest advancements in electrotherapeutic modalities and clinical applications, ensuring its relevance in today's rapidly evolving healthcare environment.

Covering foundational principles, clinical techniques, safety protocols, and the practical usage of various electrotherapy devices, this book remains an essential resource for undergraduates, postgraduates, and practicing professionals. The language is lucid, the content is evidence-based, and illustrations are thoughtfully included to enhance understanding.

Key Features

- Updated content aligned with current clinical guidelines and therapeutic practices
- Enhanced diagrams and illustrations for improved visual learning
- New insights into recent technological advancements in electrotherapy
- Case examples and practical tips for clinical application
- A student-friendly layout with clear objectives and summaries

This book is a must-have and handy reference for physiotherapy students and clinicians. It offers practical guidelines to help memorize difficult segments in electrotherapy and is written in a simple, straightforward, and comprehensive language.

Subhash M Khatri BPhT MPT (Ortho) PhD (Physiotherapy) FIAP, an eminent teacher of physiotherapy, has been involved in undergraduate and postgraduate teaching of electrotherapy for several years. He serves as an examiner for numerous universities and actively contributes to paper setting, evaluation, and practical examinations. He is a recipient of several prestigious awards, including the *Best Senior Scientific Paper Award* (2000) and the *Fellowship Award* (2008) from the Indian Association of Physiotherapists. He has also participated in the Linnaeus-Palme Teacher Exchange Program and served as a Foreign Adjunct Scholar at the Physiotherapy Division, Department of Neurobiology, Science and Care, Karolinska Institutet, Stockholm, Sweden.

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