

LECTURE 2 and 3

TOPIC: USEFULNESS OF ELECTRODIAGNOSTICS AND ELECTROTHERAPY IN MEDICINE

TIME: 4 HOURS

Application of electric currents is very useful both in electrodiagnostic and electrotherapeutic branch of medicine.

Electrodiagnostics

Electrodiagnostic testing had its beginning in the mid to late 1800s. An excellent historical review of traditional electrical evaluation techniques may be found in Sidney Licht's "Electrodiagnosis and Electrotherapy". The early recognition of motor point by Duchenne in 1870 and the later mapping of these points by other scientists, were major steps in the development of electrical testing.

motor point - a small area overlying a muscle where a slight visible contraction is most easily elicited with a minimal - amplitude (intensity) electrical stimulus. The normal motor point is usually located near the proximal portion of the muscle belly.

As instrumentation and understanding of electrophysiology developed during these early years, the strength - duration curve procedure and measurement of chronaxie were described and used on laboratory animals. Adrian reported using these electrodiagnostic techniques in human in 1916. Strength - duration curves, chronaxie measurements, and other electrical tests gained importance with their frequent use in evaluating peripheral nerve injuries during the two world wars. The tests are valuable when performed by skilled and experienced professionals. Their clinical use diminished, however, as newer technology provided electromyography and nerve - conduction testing. An understanding of the electrophysiologic rationale of traditional tests is basic to understanding contemporary electrical testing and to intelligent and effective application of electrotherapeutic technique.

CONTRAINDICATIONS AND PRECAUTIONS

All traditional electrical evaluation tests require similar safety precautions and are contraindicated in the same circumstances. Electrical stimulation may interfere with the sensitivity of the demand pacemaker and should not be used with patients depending upon this cardiac - regulating device. Electrical stimulation should not be used over the carotid sinus because the stimulation may induce cardiac arrhythmia. To avoid the possibility of cardiac arrhythmia or fibrillation, electrodes should not be placed so the path of electrical current passes across the heart. The effect of electrical stimulation on the developing fetus and on the pregnant uterus have not been determined; therefore, stimulation should not be applied over the abdominal area during pregnancy.

TRADITIONAL CLINICAL ELECTRICAL EVALUATION TESTS

1. Reaction of Degeneration Test

The reaction of degeneration (RD) test is a useful screening procedure for assessment of problems that may involve lower motor neurons. Normally innervated muscle will respond with a brisk twitch when stimulated with a short - duration pulse lasting less than 1 ms and also when stimulated with longer pulse durations, for example 100 ms. If the pulses are applied in rapid succession, the muscle will respond with a sustained or tetanic contraction. In

contrast, a muscle that has lost its peripheral innervation will not respond to a stimulus of 1 ms or shorter but will contract in a sluggish manner when the longer pulse duration stimulus is applied. When performing RD the electrode is used to search as precisely as possible for the motor point of the muscle of interest. The motor point area is first stimulated with a series of short - duration (less than 1 ms) pulses. The stimulus is applied at a frequency greater than 20 Hz which would be expected to produce a tetanic or sustained contraction, either a monophasic or biphasic waveform may be used. If a monophasic or asymmetrical biphasic waveform is used, the negative (cathode) electrode is used as the active stimulating electrode over the motor point. If a tetanic response occurs, the muscle has intact peripheral innervation. If no response or a sluggish response is seen, peripheral denervation is likely. The second part of the classical RD test is stimulation of involved muscle with a long - duration pulse. This may be done with a make and break key of the pencil - type electrode using a stimulator that will automatically provide a monophasic pulse of at least 100 ms duration and preferably longer. A slow or sluggish response to this part of the test indicates that contractile muscle tissue is present but that the muscle is either partially or completely denervated.

The RD test is usually not done until at least 10 days after onset of the problem, so that the process of neural degeneration can progress to a stage in which electrical changes would appear. An abbreviated form of the test for reaction of degeneration may be used as a quick screening test for differentiating a muscle with normal peripheral innervation from a muscle with peripheral denervation. The RD test is only a gross screening procedure and should not be expected to differentiate or precisely identify the location of pathology. The test may be indicated in conditions of unexplained paralysis.

ELECTRICAL TEST FOR REACTION OF DEGENERATION

STATUS OF MUSCLE INNERVATION	MUSCLE RESPONSE ELICITED WITH SERIES OF SHORT DURATION PULSES: <1 ms, >20-50 Hz	MUSCLE RESPONSE ELICITED WITH INDIVIDUAL 100 ms PULSES
normal peripheral nerve innervation	smooth, continuous isotonic (tetanic) contraction	brisk, individual twitch contraction
partial degeneration of nerve fibers	partial or diminished tetanic contraction	partial or diminished, sluggish individual contraction
degeneration of all nerve fibers, muscle tissue retains contractile elements	no contraction	very slow, sluggish individual contraction
absolute degeneration, muscle tissue severely atrophic, fibrotic	no contraction	no contraction

2. Strength - duration curve and chronaxie test

Strength - duration curves and chronaxie measurements were widely used for electrodiagnosis of peripheral nervous system disorders from 1930s to the 1960s. Their frequency of use sharply declined with the development of nerve conduction testing and electromyography. When performed by the clinician experienced in strength - duration (S - D) curve and chronaxie measurements, these tests provide a reliable means of assessing the location, severity and progress of peripheral motor - nerve degeneration and regeneration.

The S - D curve has the limitation of providing data to evaluate neuromuscular integrity in the local fibers responding to the stimulus. This limitation can only be overcome by testing several muscles in the distribution of the nerve of interest.

The three concepts of intensity, pulse duration and rise time of the electrical stimulus described in the preceding section on neurophysiologic principles of electrical evaluation are emphasized here and now take on quantitative values. Excitable tissue will respond by discharging an action potential only if an applied electrical stimulus meets certain criteria of both intensity (amplitude) or strength and pulse duration or time. The intensity of the stimulus must be strong enough to depolarize the membrane to its threshold level for excitability and in addition the stimulus must be of sufficient duration to overcome the capacitance of the membrane.

rheobase - a minimal intensity of stimulus amplitude (strength) required to elicit a minimal visually perceptible muscle contraction (for 1000 ms impulse).

chronaxie - a minimal pulse duration of stimulus of twice rheobase strength that will cause the excitable cell membrane to discharge.

Plotting an S - D curve and determining chronaxie values require an electrical - stimulation instrument capable of producing square - wave monophasic pulse of at least 10 selectable, precise pulse durations ranging from 0.01 to 1000 ms. When collecting data for an S - D curve, the motor point or area of greatest electrical sensitivity must be precisely located with the negative (cathode) stimulating electrode. Using progressively shorter pulse durations, the values of stimulus amplitude which produce a minimal muscle contraction are recorded and then plotted on the graph. Chronaxie and rheobase can be determined from the S - D curve. Normal chronaxies are less than 1 ms and usually are 0.1 ms or even less. Chronaxie for fully denervated muscle may be 30 to 50 ms.

Strength - duration curve and chronaxie measurement have been used for evaluation of variety of lower - motor - neuron pathologies. Their greatest value is for assessment of peripheral nerve injuries. Good judgement is required to plan the examination so that possible neuroanatomic sites of lesions in peripheral nerve plexus can be differentiated. When skillfully performed, these tests can provide reliable and accurate information on the status of peripheral innervation and denervation. S - D curve and chronaxie testing are as objective as nerve - conducting testing and electromyography, are noninvasive and can provide valuable information on the status and progress peripheral nerve injuries. Other applications of the S - D curve and chronaxie are for evaluation of peripheral neuritis, other peripheral nerve diseases that may involve axonal degeneration and motor - neuron disease conditions. The tests may be used to complement other evaluative procedures in differentiating between normal nerve tissue and neuropathology.

3. Nerve conducting tests

The purpose of nerve conduction testing is to assess the time and quality of the conduction of neural impulses in peripheral motor and sensory nerves. A controlled monophasic pulsed electrical stimulus is applied to the skin overlying a nerve. Instrumentation needed for nerve conduction testing includes a differential amplifier capable of detecting and accurately amplifying signals in a range from 2 microV to 50 mV, an electrical stimulator that provides square wave monophasic pulsed stimulus from 0.05 to 1 ms and output amplitude up to 500 V or 100 mA, synchronized with the sweep of a storage oscilloscope

oscilloscope - an instrument which can be used to identify and verify the characteristics of electrical signals.

The stimulus frequency capability should be variable from single to pulse trains of 50 Hz. The responses from the specific sites of interest, which may be from muscle in motor nerve conduction tests, from peripheral sensory nerves or from the scalp in evoked potential studies, are recorded. It is distinguished following tests: motor nerve conduction, f - wave nerve conduction, sensory nerve conduction, h - reflex response. These tests are useful in establishing or ruling out the presence of a peripheral neuropathy and determining and localizing a peripheral nerve entrapment or a plexopathy. Another feature of the assessment of nerve conduction test results is differentiation, when possible between nerve conduction changes consistent with a demyelinating process and those seen with an axonal disorder.

4. Clinical electromyography (EMG)

EMG is an assessment, which provides a means of monitoring and evaluating electrical activity of muscle directly - without artificial stimulation. An advantage of EMG over the other procedures is that characteristics of muscle during relaxation and voluntary contraction can be studied. The most valuable contribution of EMG is its usefulness in evaluating electrical activity of lower motor neurons and muscle fibers, as electromyography is helping in identifying electrical changes consistent with pathologic processes in these anatomic areas. The instrumentation required for EMG is basically similar to that used in nerve conduction testing, but an electrical stimulator is not needed. A sterile needle electrode is inserted directly into the muscle and endogenous electrophysiologic activity produced by depolarization and repolarization of the muscle cell membrane is transduced from the electrode and displayed on oscilloscope. Monopolar and concentric needle electrodes are most commonly used in routine EMG. Electromyographic activity is studied under the following conditions: while the muscle is at rest, that is completely relaxed; during a mild contraction, just strong enough to produce individual motor unit action potentials; and during a very strong contraction, held with enough force to recruit as many motor units as possible.

CHARACTERISTICS OF NORMAL AND ABNORMAL EMG POTENTIALS

AT REST

NEUROMUSCULAR STATUS

normal
abnormal

INSERTION ACTIVITY

brief discharges
absent response
increases or prolonged

SPONTANEOUS ACTIVITY

none
fibrillation
positive sharp waves
complex repetitive discharges
myotonic potentials on percussion

MINIMUM CONTRACTION - MUSCLE ACTION POTENTIALS

STATUS	AMPLITUDE	DURATION	WAVEFORM
normal	100 - 2000 microV	3 - 15 ms	diphasic or triphasic
abnormal	absent	less than 3 ms	polyphasic

STRONG CONTRACTION

STATUS	RECRUITMENT PATTERN	AMPLITUDE
normal	full and complete interference >75%	concentric 2000 - 5000 microV
abnormal	decreased <75%	<2000 microV

Certain EMG abnormalities are usually characteristic of neuropathy, whereas other electromyography changes are characteristic of myopathy, including dysfunction of cranial and spinal nerves, nerve roots, nerve plexuses and peripheral nerves or generalized systemic peripheral polyneuropathy.

Electrotherapy

1. Transcutaneous Electrical Nerve Stimulation (TENS)

TENS is the application of electrical stimulation to the skin via surface electrodes to stimulate nerve fibres, primary for pain relief. Although the role of electricity in pain management has been acknowledged for many centuries, most progress in the use of electroanalgesia has been made in the past 30 years, following an improved understanding of pain mechanisms and the development of small, portable, battery - operated devices. The contributing factor for renewed interest in electrical stimulation was the development of dorsal column stimulation (DCS), an experimental technique for pain treatment. DCS involves surgical implantation of electrodes in the dorsal column of the spinal cord which are activated by an external battery - operated device. Dr Norman Shealy initially used the battery - operated stimulator as a screening device to establish patients' candidacy for DCS. If the patients responded favourable to a trial of such external transcutaneous stimulation, this was taken as an indication that they would respond positively to DCS. Interestingly, preliminary results from Shealy's work showed that some of his patients responded better to the transcutaneous stimulation than to DCS and so TENS was discovered, almost by accident. This discovery initiates a new era of electrical stimulation analgesia.

There are currently four TENS modes used in clinical practice:

Conventional TENS - or high frequency, low intensity TENS is the most commonly used mode of electrostimulation. The combination of parameters stimulates A beta afferents. The sensations experienced with conventional TENS is one of comfortable paraesthesia with no muscle contractions, although if the electrodes are placed over motor points, some contraction is visible with higher stimulation intensities. As the A beta fibres are stimulated this TENS mode achieves analgesia primarily by spinal segmental mechanisms. This analgesia is of relatively rapid onset because local neurophysiological mechanisms are responsible. However the analgesia tends to be relatively short, typically lasting only for up to a few hours post treatment.

Acupuncture like TENS - or low frequency, high intensity TENS is primarily stimulates A delta and C nociceptive fibres and small motor fibres. The electrodes should be positioned to

produce visible muscle contractions, over a myotome related to the painful area. The patient will experience paraesthesia and muscle contractions with this mode. The analgesia lasts longer than with conventional TENS.

Burst train TENS - or high frequency trains of pulses delivered at low frequency. This burst train mode of TENS is a really mixture of conventional and acupuncture like TENS and comprises a baseline low frequency current together with high frequency trains. This type was developed by Eriksonn & Sjolund in 1976 as a result of their experiences with Chinese electroacupuncture. The patients tolerate here the stimulus intensity required to produce the desired strong muscle twitches much better than single impulses.

Brief - intense TENS - or high frequency, long pulse duration TENS. Mannheimer & Lampe (1984) recommended that this mode can be used for painful procedures such as skin debridement, suture removal, etc.

TENS - MODES AVAILABLE

conventional - a low intensity, a high frequency - typically above 100 Hz, a pulse duration is usually short 50 - 80 microsec.

acupuncture like - a low frequency 1 - 4 Hz, a high intensity (high enough to produce visible muscle contractions), a long pulse duration 200 microsec.

burst train - a low frequency of trains 1 - 4 Hz, a high internal frequency of the trains 100 Hz, a pulse duration 100 - 200 microsec.

brief - intense - a high frequency 100 - 150 Hz, a long duration pulse 150 - 250 microsec.

2. High voltage pulsed current (HVPC)

High voltage stimulation delivers impulses with very short phase durations ranging from 5 to 65 microsec. at a very high peak - current amplitude (2000 to 2500 mA). With such short phase duration, a high- driving voltage (up to 500 V) is required to produce adequate peak - pulse charge for eliciting physiologic effects. This relationship between stimulus duration and amplitude demonstrates the classic strength - duration relationship. Because the interval between paired pulses generated by HVPC devices make up as much as 99% of each second that the current flows the total current delivered to the tissue per second does not exceed 1.2 to 1.5 mA. When HVPC is used for electroanalgesia and applied through pad electrodes for 20 to 30 minutes. It is effective for relieving acute, superficial pain and also in bedsore, ulceration and trauma swelling therapy.

3. Diadynamic currents.

Diadynamic currents (from the Greek, dia - through and dynamis - force) were first described and used in clinical practice in 1950 by Bernard, a French dental surgeon. These currents are delivered transcutaneously through anode and cathode as monophasic, half - wave or full - wave pulses rectified from 50 Hz alternating current. Individual pulses have duration of 10 ms. As with impulse current, diadynamic current holds the potential for accumulation of an undesirable quantity of residual charge in the tissues, which may produce skin irritation. Devices that produce diadynamic currents allow selection of six current forms.

The first variation of diadynamic current called diphasic fixe - DF is the preferred current for pain modulation. DF produces a vibrating, prickling sensation which subsides gradually as sensory accommodation occurs in response to the constant amplitude stimulation. It is

especially recommended for pain conditions of sympathetic origin.

Monophasic fixed - MF produces a strong vibratory sensation and much slower sensory accommodation occurs because of the 10 ms delay between successive pulses. It is more suitable used to elicit muscular contraction and is generally not used for isolated pain conditions. Courtes Periods - CP combines MF and DF currents, so that each one alternates at intervals of 1 s to prevent sensory accommodation. CP is usually recommended for treatment of pain states associated with sprains, strains, contusions, radiculopathy.

Longues Periods - LP also combines the MF and DF current modes such that during 5 s periods MF and DF occur together but out of phase, with DF being amplitude modulated. This is followed by 10 s of MF current. LP is recommended for providing longer - lasting pain relief in acute pain conditions.

Last impulses RS and MM are generally used for muscle stimulation application.

4. Interference current

Interference current is mostly applied in pain therapy too. It is caused by amplitude - modulated beats of impulsed current produced by summation and cancellation of superimposed phases from two independent circuits.

beat - a physical phenomenon in which amplitude modulation occurs by summation of two intersecting sine waves that are either exactly in phase or are one, two, three or more wavelength out of phase with the other wave.

5. Neuromuscular Electrical Stimulation (NMES)

Neuromuscular electrostimulation is the application of electrical current to elicit a muscle contraction. Although a variety of waveforms are available in electrical devices, two waveforms have been used traditionally: the asymmetrical biphasic rectangular and the symmetrical biphasic rectangular waveforms. Both waveforms allow an equal amount of current to flow in either phase, thus avoiding undesirable electrochemical effects and possible skin irritation. The rectangular wave is characterized by fast - rising leading edge of the pulse, flat plateau at peak and rapid return to zero at the end. The intensity or amplitude of current is measured by the height of the waveform as it deviates from the isoelectric line. Most devices have maximum output of 100 mA. As amplitude is increased there is an increase in the number of motor units recruited, thus an increase in the muscle force developed. Many NMES devices have a fixed - phase duration of between 0.2 and 0.4 ms. Neuromuscular electrostimulation is a versatile modality that can be integrated into treatment plans for a variety of patient problems. It is applied in treatment of disuse atrophy, increase and maintenance of range of motion, muscle re - education and facilitation, spasticity management, orthotic substitution, augmentation of motor recruitment in healthy muscle.

Spasticity management

Spasticity is a condition associated with hyperreflexia, including resistance to passive movement, hyperresponsive deep tendon reflexes and clonus. Spasticity interferes with recovery of functions after central nervous system trauma. For many years NMES has been used to manage the problems associated with spasticity, but optimal treatment techniques have not been established. Levin, Knott, Kabat applied a biphasic current to create a tetanic contraction in the muscle antagonist to the spastic muscle. They reported the results of such treatment in patients with hemiplegia, paraplegia, multiple sclerosis. Patients demonstrated relaxation of the spastic muscles as measured by increased range of motion and improved function. Electrical stimulation was applied to the spastic quadriceps muscle of spinal cord injured patients by Robinson, Kett, Bolam. Strong contraction of the muscles was obtained

with a current intensity of 100 mA, a phase duration of 0.5 ms and short on and off times of 2.5 s each. The stimulation lasted 20 minutes. The results showed an immediate decrease in quadriceps spasticity. Similar observations noticed Vodovnik, Stefanovska and Bajd in gluteus muscle.

Orthotic substitution

Gait training.

Neuromuscular electrical stimulation may be used to enhance the functions of patient's paralyzed or weak muscles. First in 1961 Liberson reported on the use of a pressure - sensitive switch to trigger electrical stimulation of the muscles innervated by the peroneal nerve during gait. The heel switch is a pressure - sensitive contact switch arranged to open the circuit (stop stimulation) when the heel is in contact with the floor and provide stimulation when the heel leaves the floor during the swing phase of gait. NMES has been used to increase torque output from the ankle dorsiflexors and reciprocally decrease spastic reflexes in the plantarflexors, which improved the gait pattern of hemiplegic patients. The stimulator is situated on the pants belt. The electrodes are under the knee.

Idiopathic scoliosis

Scoliosis is an abnormal lateral curvature of the spine. It may develop secondary to muscle imbalances from neuromuscular disease or congenital spinal deformities. Idiopathic scoliosis describes a condition for which the cause is unknown and patients are generally healthy, young and active. The usual form of treatment for progressive scoliosis curve consists of bracing the spine for 23 hours per day. For most patients bracing is undesirable in that the brace may be uncomfortable, restrictive and may adversely affect self - image and coping skills. Patients are often reluctant to wear the brace as prescribed and poor compliance may cause the treatment to fail. In the 1970s the use of NMES as an electrical orthosis was initiated. Application involves placing surface electrodes on the convex side of the curve. Contraction of the spinal musculature produces a force to reduce the lateral curvature. The electrodes are placed superior and inferior to the apex of the curve in either a paraspinal, intermediate or lateral array. Stimulation is applied during nighttime hours when the patients is sleeping, totaling 8 to 10 hours.

Augmentation of motor recruitment in healthy muscle.

The goal of improving human performance in sport and exercise has been a fascinating topic for coaches, athletic trainers, physiologists and athlete alike. In 1977 a Russian physician Yakov Kots presented his theories and results of training protocols at a Canadian - Soviet Exchange Symposium. He reported a 30 to 40% increase in strength of the quadriceps femoris muscles following electrical stimulation in elite athletes. Although dr Kots research is not well documented. The frequency of each train of pulses is 1500 to 10000 ms. The single impulse lasts 25 ms.

6. Electrical stimulation of denervated muscle.

Electricity has been used to stimulate denervated muscle for almost 100 years. The rationale for electrically stimulating denervated muscle is to exercise the muscle in an effort to maintain the denervated muscle in a healthy state while the injured axons regenerate and reinnervate the muscle. It is assumed that if the denervated muscle is maintained in a fairly

healthy state and can be exercised while denervated, functional recovery is facilitated following reinnervation. It is apparent that the effectiveness of the electrical stimulation of denervated muscle depends upon many factors, including the type of current, duration of the stimulus, current amplitude, type of contractions, length and frequency of therapy sessions.

It is applied faradic (balanced, asymmetrical, biphasic waveform), neofaradic (symmetrical, monophasic waveform) or faradiclike current having a short pulse duration (less than 1 ms). The transcutaneous electrical stimulation of denervated muscle is accomplished through surface electrodes. The electrode configuration is usually monopolar with the active or treatment electrode positioned over the part of the denervated muscle that is most electrically excitable. The inactive or dispersive electrode is placed over a distant body part. The size of the active electrode is very small (1 - 2 cm²). The size of the inactive electrode is large enough that current flow under the electrode is not perceived by the patient. An alternate configuration would be bipolar stimulation with the active on the most excitable part of the muscle and the dispersive electrode over the tendon.

The usually used parameters are suggested by Gillert.

STIMULUS PARAMETERS USED FOR TREATMENT OF DENERVATED MUSCLE

MUSCLE STATUS	PULSE DURATION	INTER PULSE DURATION
very hard	400 - 1000 ms	2000 - 5000 ms
hard	150 - 400 ms	1000 - 3000 ms
medium	50 - 150 ms	500 - 1000 ms
soft	10 - 50 ms	50 - 150 ms

EXERCISES

1. Applying a therapy in use of TENS in acute peroneal nerve pain.

The inactive electrode (anode) is placed on the frontal part or back of thigh

The small handheld active electrode (cathode) is placed in motor point of peroneal nerve

Program the electrostimulator (Asterint or Diatronic) on TENS therapy: pulse duration - 100 microsec and frequency - 100 Hz.

2. Applying a therapy in use of TENS in chronic peroneal nerve pain.

The inactive electrode (anode) is placed on the frontal part or back of thigh

The small handheld electrode (cathode) is placed in motor point of peroneal nerve

Program the electrostimulator (Asterint or Diatronic) on TENS therapy: pulse duration - 100 microsec and frequency - 5 Hz

3. Detecting a rheobase for peroneal nerve

The active electrode (cathode) is placed in motor point under the knee

The inactive electrode (anode) is placed on frontal part of thigh

Program the Astym electrostimulator on pulsed rectangular current: pulse duration - 1000 ms

LITERATURE

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