

ELECTRICAL STIMULATION FOR MUSCLE (INNERVATED/DENERVATED) CONTRACTION

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OBJECTIVES



OUTLINES

- Muscle contraction in innervated muscles
- Parameters for electrical stimulation of denervated muscles
- Parameters for electrical stimulation of innervated muscles
- indications for use of electrical stimulation for muscle contraction
- Contraindications/ precautions for use of electrical stimulation for muscle contraction
- Clinical case study



NEUROMUSCULAR ELECTRICAL STIMULATION (NMES)

Neuromuscular electrical nerve stimulation (NMES) is electrical stimulation of innervated/partial innervated muscles using surface electrodes to induce muscle contraction aiming for

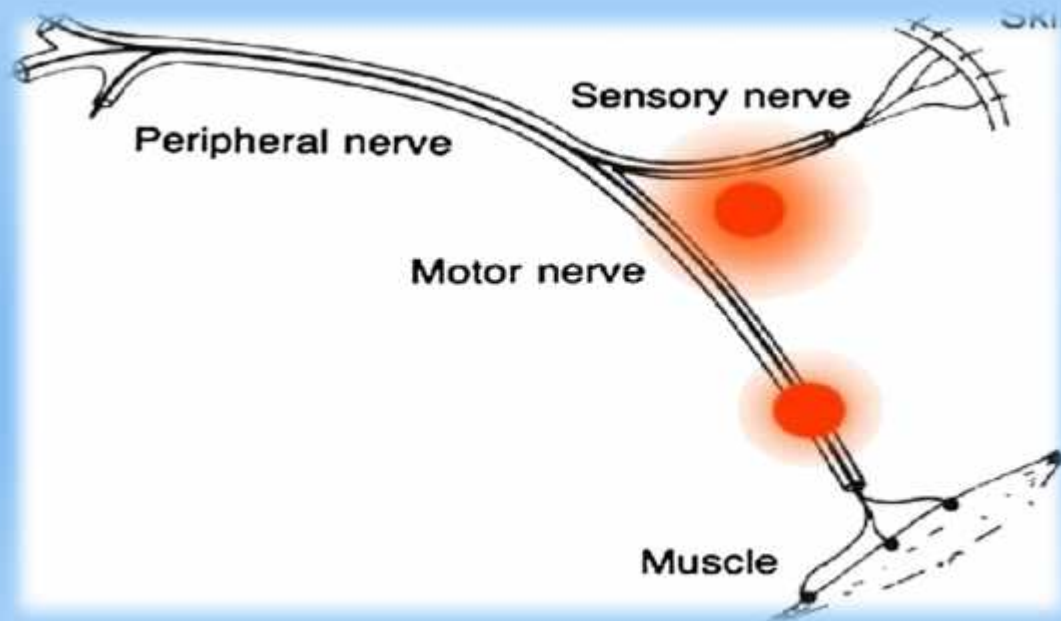
- Muscle re-education
- Prevention/Retardation of disuse atrophy
- Muscle strength and /or endurance
- Reduce edema (Muscle pump contraction)



WHAT IS THE MOTOR POINT?

Motor point

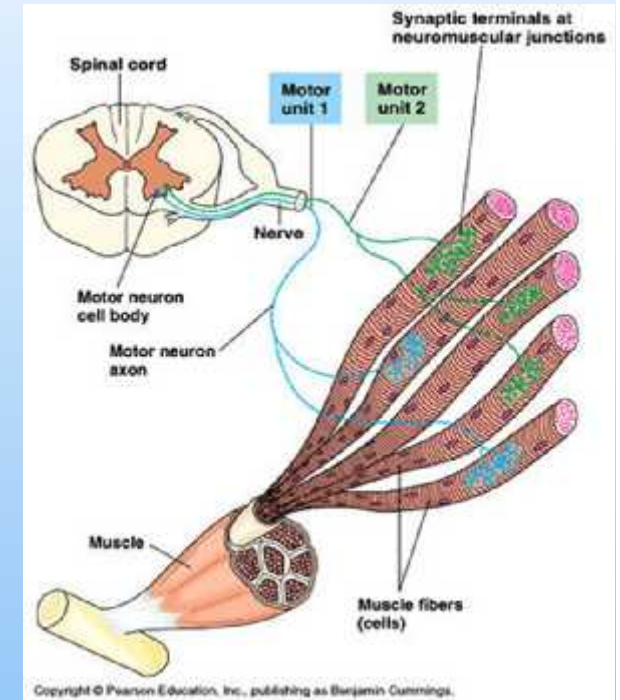
- Superficial located on the surface of the skin
- Usually located at muscles belly between the proximal one third & distal 2/3 fleshy part of the muscle fibers.
- Point of great density of terminal motor end plates
- Point of great excitability to E-stim.



WHAT IS THE MOTOR UNIT?

Motor unit

- ❖ **Single motor neuron** (alpha motor neuron) from anterior horn cell and all the muscle fibers it stimulate.
- ❖ Each motor unit supplies from 4-100 muscles fibers.
- ❖ Dependent on movement precisions
e.g. Gastrocnemius 2,000 muscle fibers per motor neuron
- ❖ Motor neuron determines fiber type



Motor unit classification

Slow

Fast fatigue resistance

Fast fatigue

Muscle fiber classification

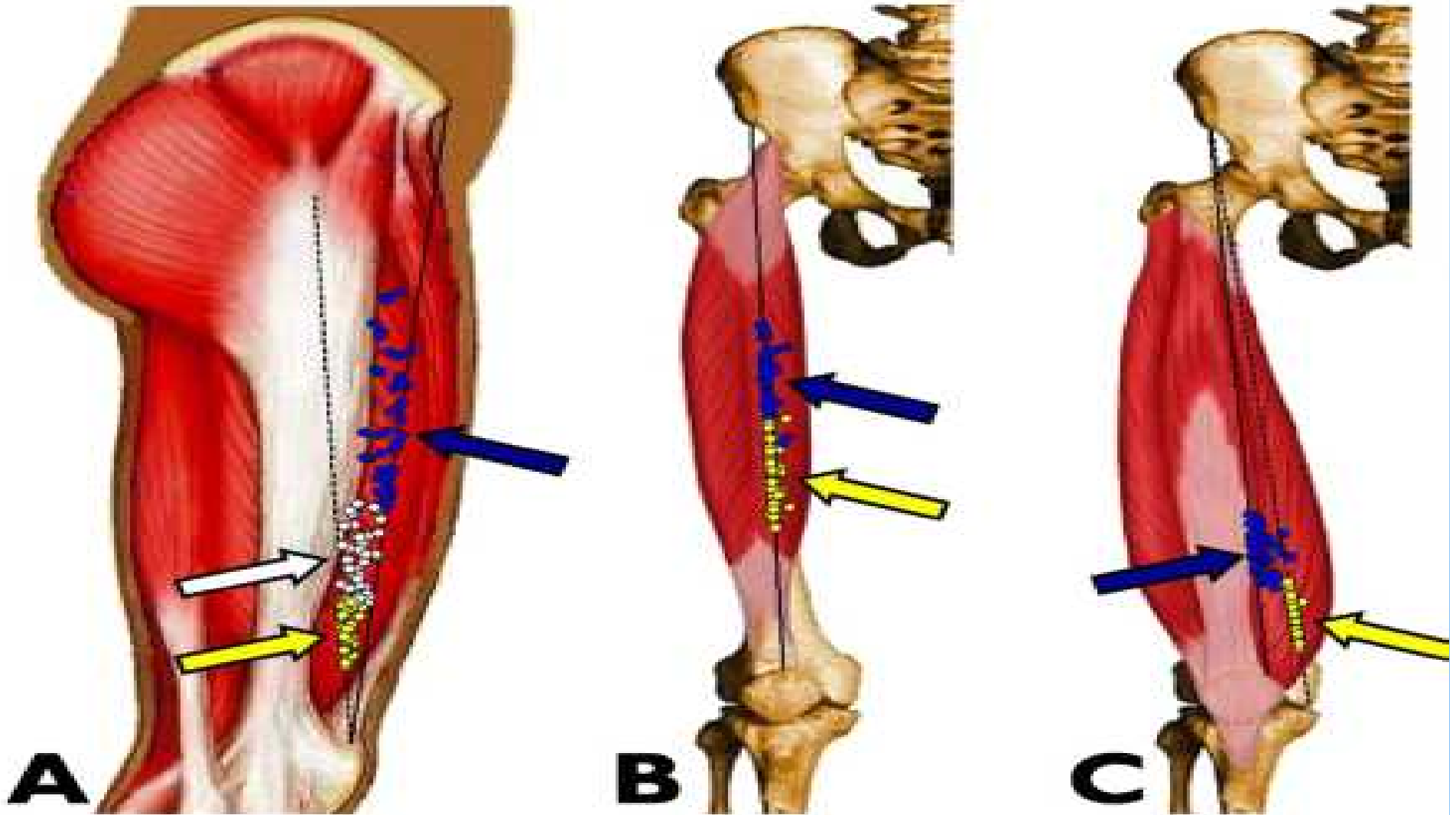
Type I slow oxidative (SO)

Type II a fast oxidative glycolytic (FOG)

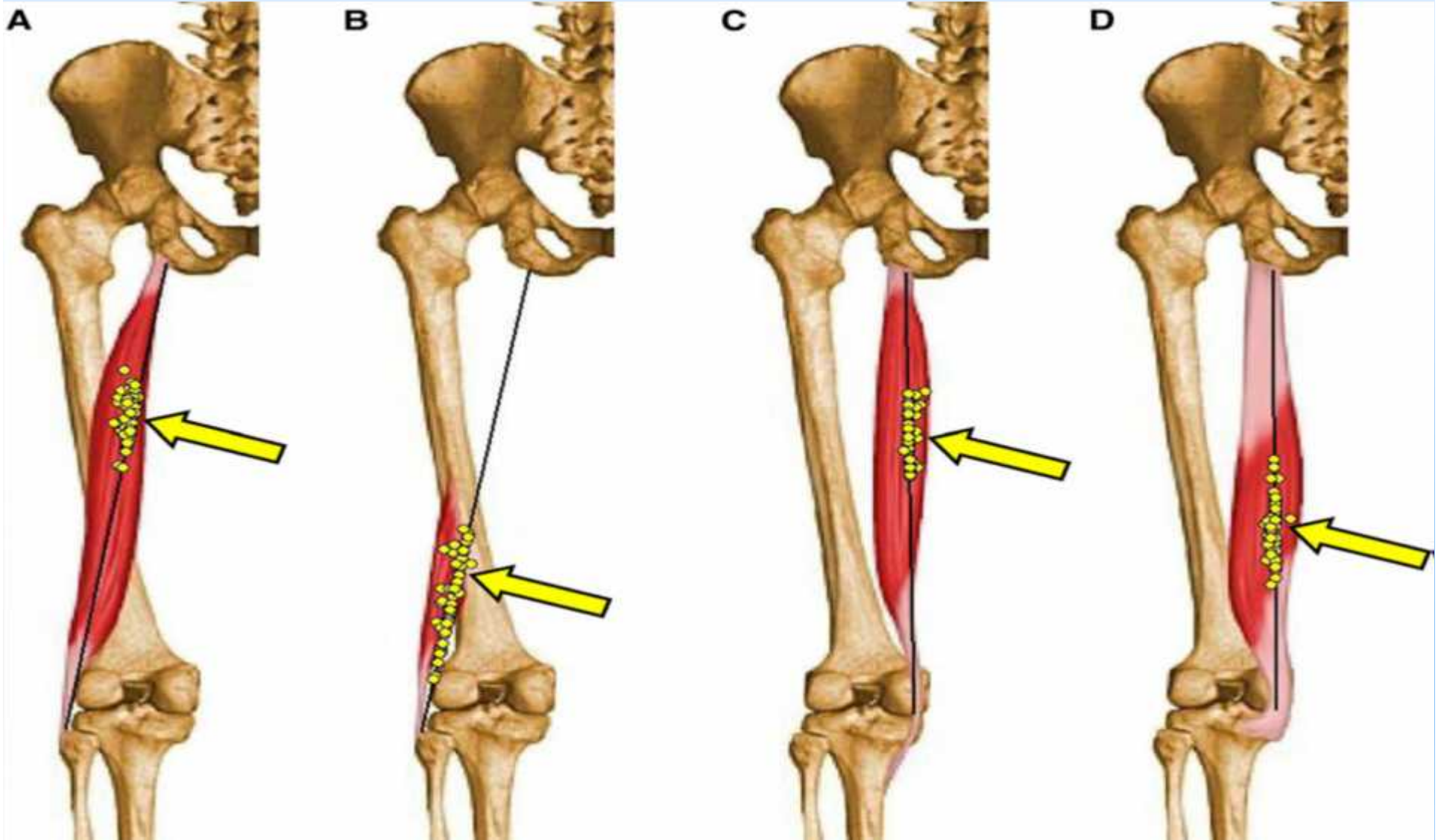
Type IIb fast glycolytic (FG)



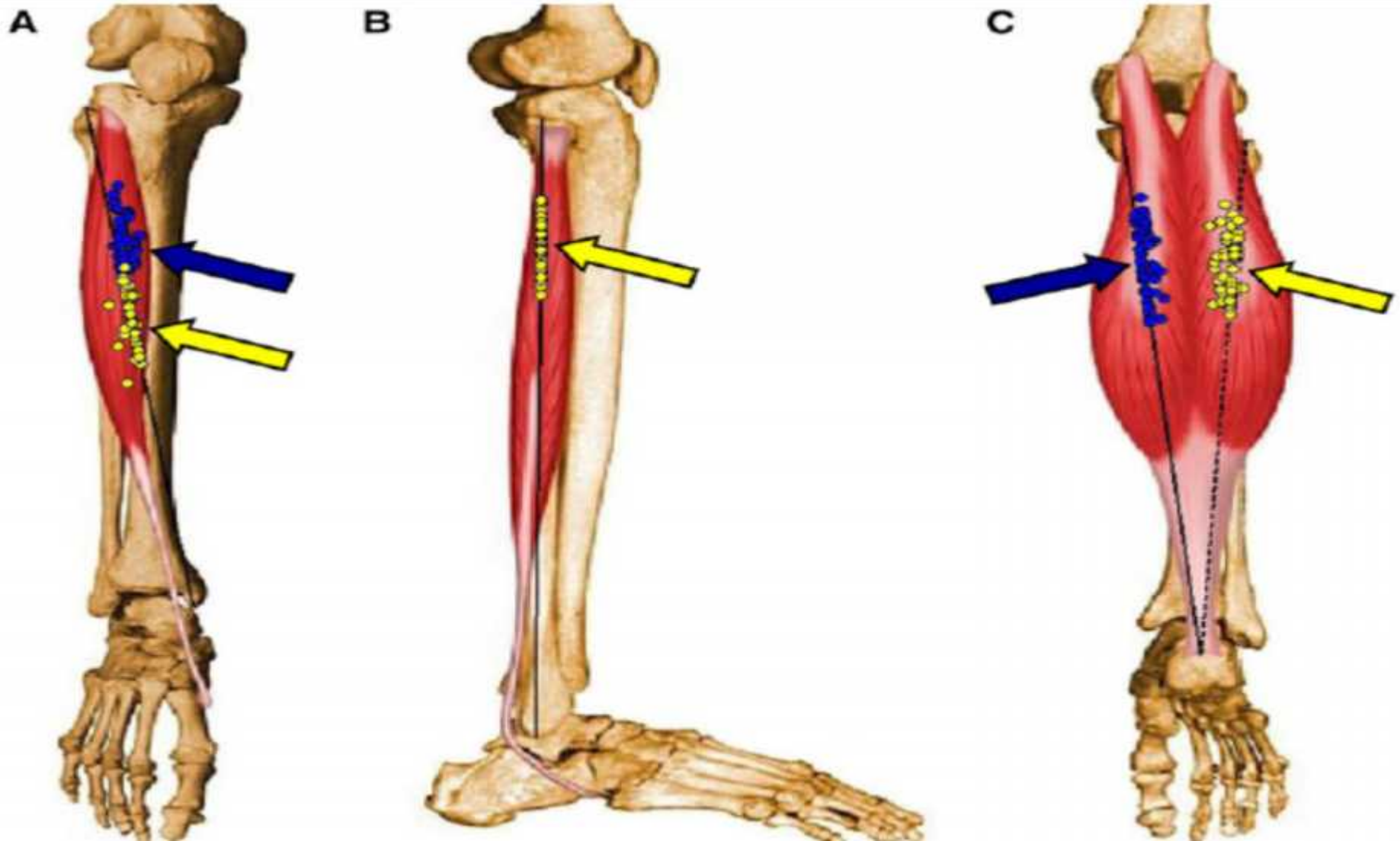
POSITION OF THE MP OF QUADRICEPS MUSCLES



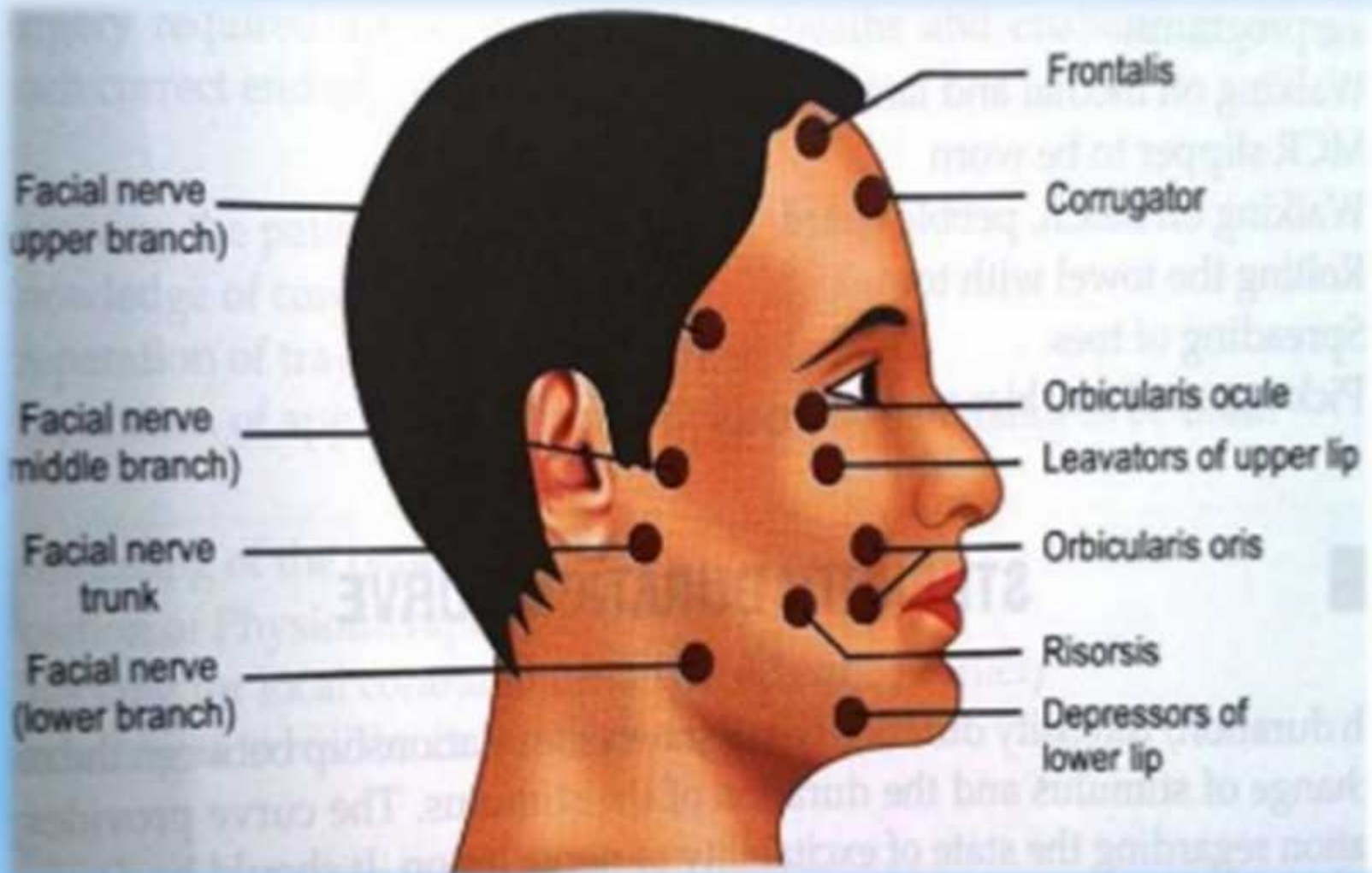
POSITION OF THE MP OF HAMSTRING MUSCLES



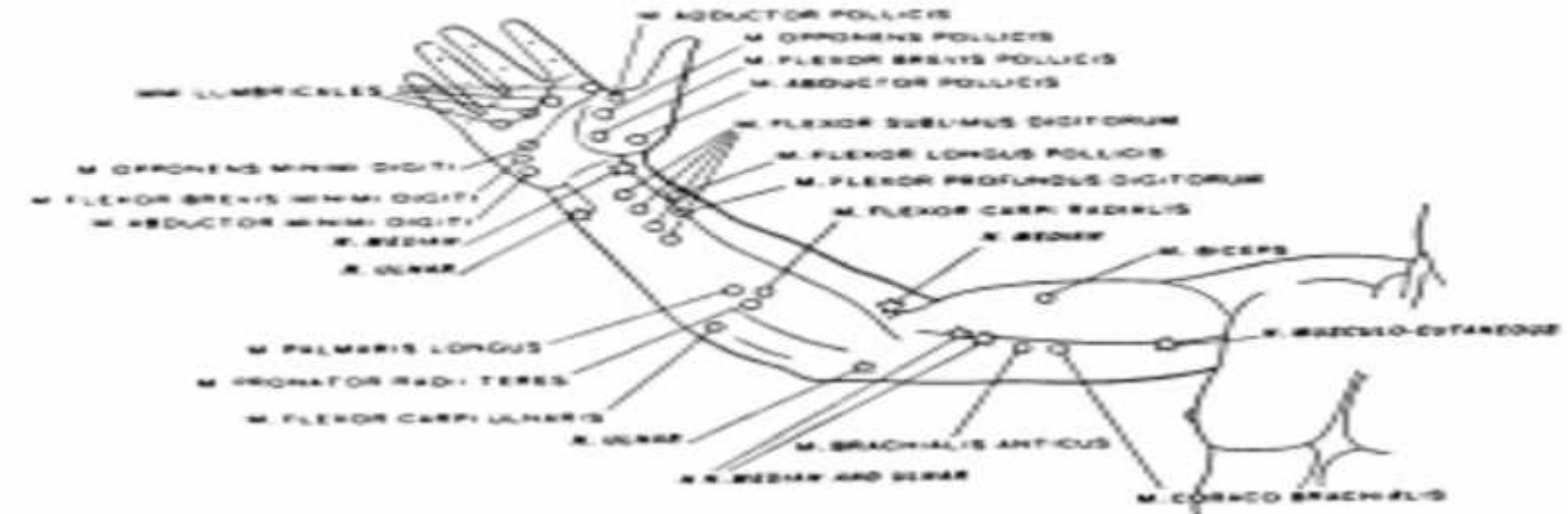
POSITION OF THE MP OF LEG MUSCLES



POSITION OF THE MP OF FACIAL NERVE



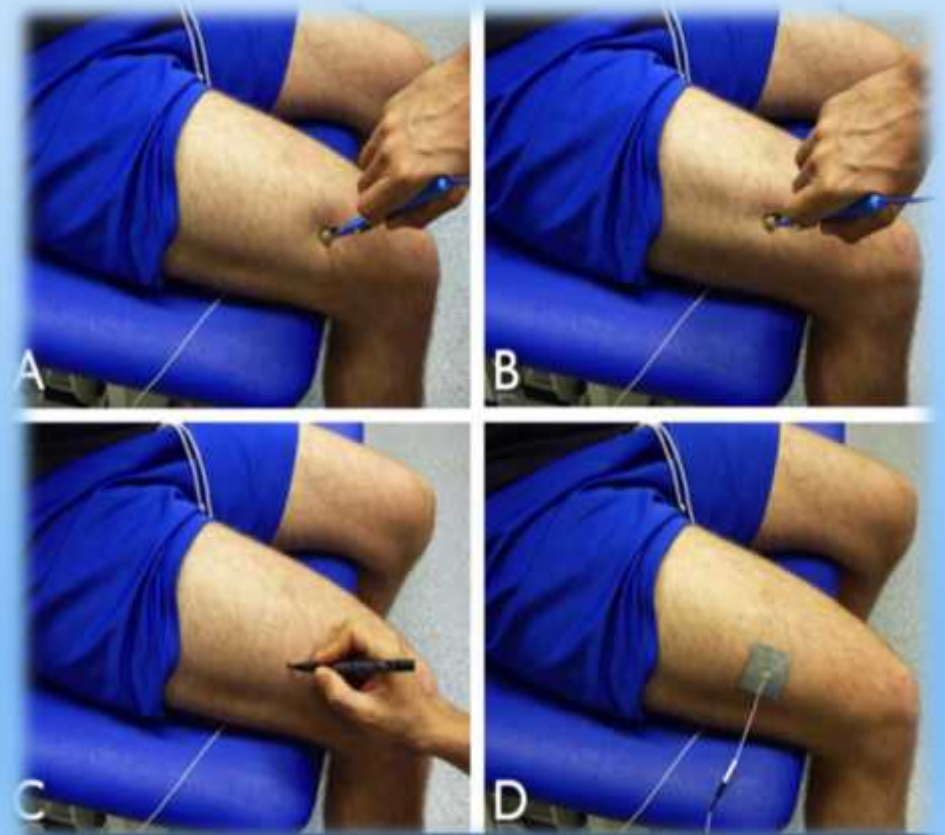
LOCATIONS OF THE MOTOR POINTS



CLINICAL PRACTICE; DETERMINATION OF MP

To trace motor point

1. Interrupted direct current at **0.1ms** ($100\mu\text{s}$) for **innervated muscle**
 2. Interrupted direct current at **10ms** for **denervated muscle**
- ES parameters
 - F(1-20Hz)
 - Intensity (start 1mA)
 - Pulse duration 100-1000 $\mu\text{seconds}$
 - Pen electrodes (active)
 - Dispersive electrode
 - Alcohol swap (cotton) and markers
 - A, B, C, D,



<http://www.youtube.com/watch?v=ltQTB5ekhf4>



VOLUNTARY VERSUS E-STIMULATION CONTRACTION

	E-stimulation contraction	Voluntary MS contraction
Order of recruitment	Fast twitch type II, then slow twitch type I	Slow twitch type, followed by fast twitch Type I MU fire first, then Type II. Type IIb brought in last of
Pattern of recruitment	Synchronize	A Synchronize
Pattern of AP propagation	Two direction	Ortho-dromic
Fatigability	Easy and rapid	Resistance & delayed
Force of contraction	Quicker & Strongest	Slower and low force
Onset of contraction	Rapid & jerky	Slow and smooth



How To Differentiate Between innervated /denervated muscles

- History
- Physical examination
- S-D curve
- NCV
- EMG



DENERVATED MUSCLES

Loss of its peripheral nerve secondary to disease, chemical toxicity, physical injury, or intentional surgical interruption of a nerve causes muscles denervation

- Complete denervation (CD), all motor unit loses all innervation
- Partial denervation (PD) some of motor unit in the muscles lose its innervation

Anatomical

Biochemical

Physiological

- ❖ Loss of voluntary and reflex activity,
- ❖ Muscle atrophy (Decrease size, and diameter of individual muscles fibers)
- ❖ Changes in muscle excitability:
 - ❖ (Decrease amount of tension and Increase time required for contraction)
- ❖ Muscles fibrosis (within 2 years)



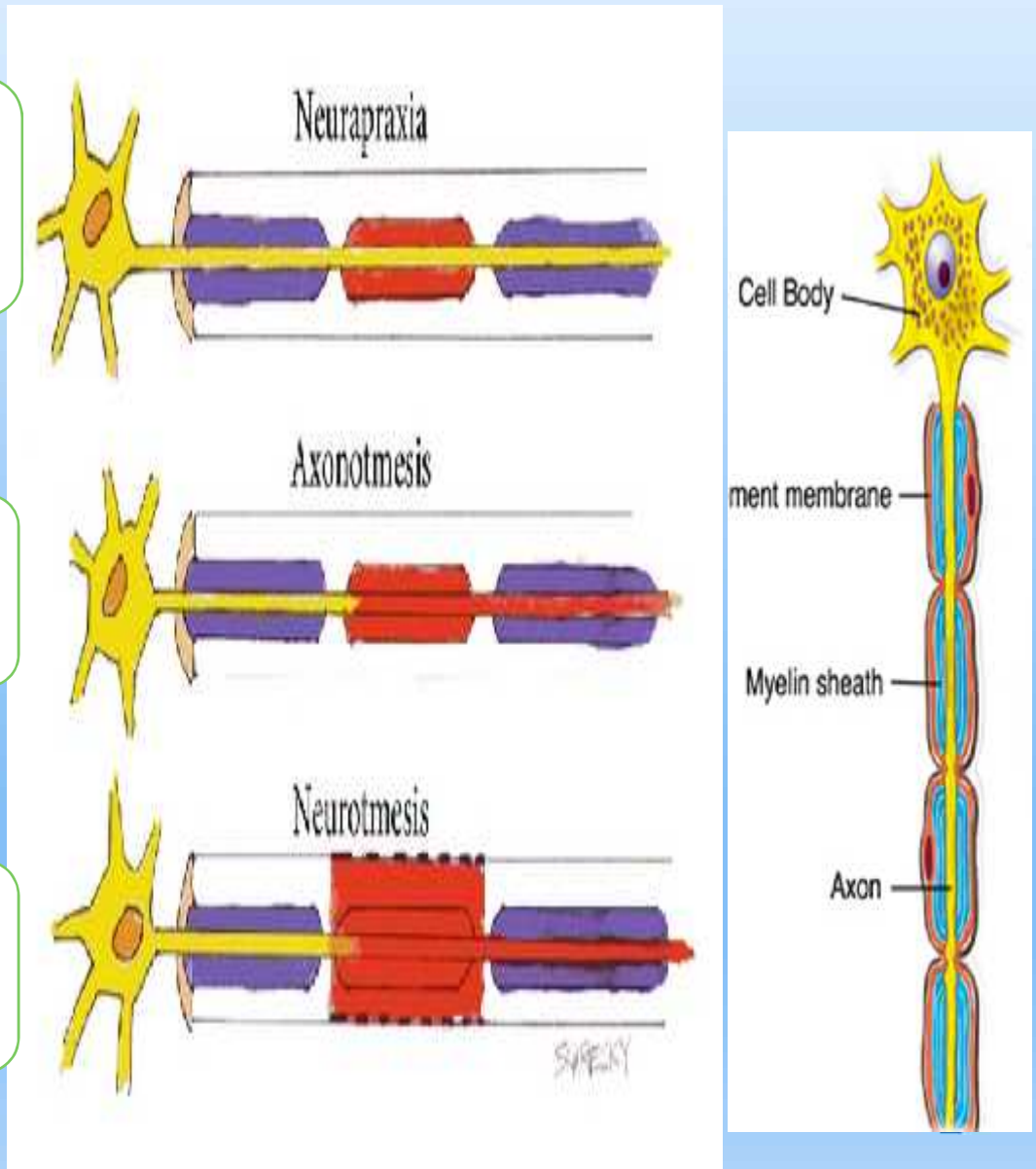
CLASSIFICATION OF THE PERIPHERAL NERVE INJURY

Neuropraxia

Compression on nerve
100ms, rectangular

Axonotmesis: partial denervation
100-600ms,
triangular, trapezoidal

Neurotmesis
Complete denervation
100-2000ms /triangular, saw-tooth



Strength Duration Curve (SD-curve)

The **SD curve** is a graph representation of non-linear relationship between intensity and duration of current.

The purpose of **S-D curve** is to know whether the stimulated muscle is innervated, denervated (CD and/or PD)

It depends on;

- **Numbers of motor units recruitment**
- **Intensity and frequency of current.**
- **Placement of electrodes.**
- **Degree of injuries**

Optimum timing of SDC:

10 – 14 days post injury



STRENGTH DURATION CURVE (SDC)

Methods of SDC:

E-stim unit with rectangular waveform with pulse duration i.e. 0.2, 0.4, 0.6, 0.8, 1, 1.2, 10, 30, 100, 300ms and constant current.

Put the active electrode over the fleshy belly of the muscle

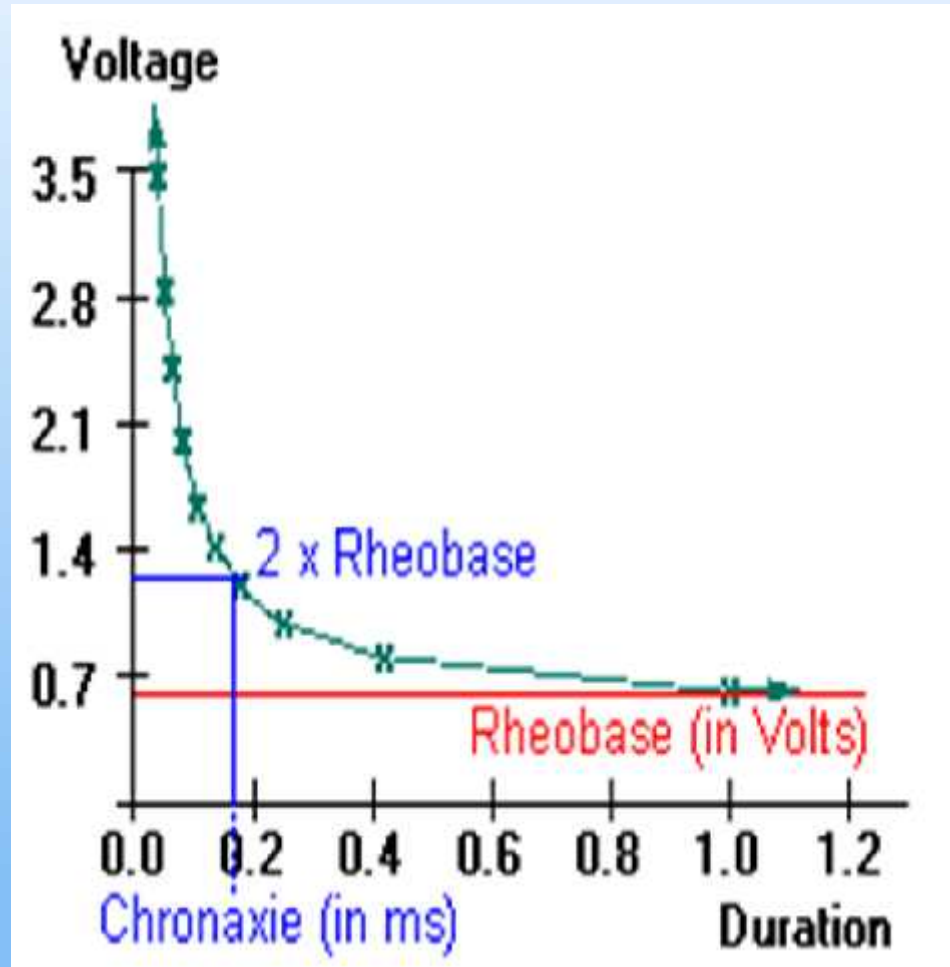
First apply current having longest duration and look for minimal perceptible contraction.

Gradually shorten the impulse duration and note the corresponding increase in current strength.

The electrode placement should not be changed through out the test. Plot of SD graph



STRENGTH DURATION CURVE (SDC)



Rheobase is a minimal current intensity (amplitude) required to produce a minimal visually perceptible muscle contraction (giving a long duration; 300ms).

- Normal values are (2-18mA)

Chronaxie is the length/duration of pulse in milliseconds with the two-fold intensity of the rheobase to produce muscle contraction

- Chronaxie of innervated muscles is less than 1ms (range 0.05-0.5ms).
- Chronaxie of fully denervated muscle may be 30 to 50ms



STRENGTH DURATION CURVE (SDC)

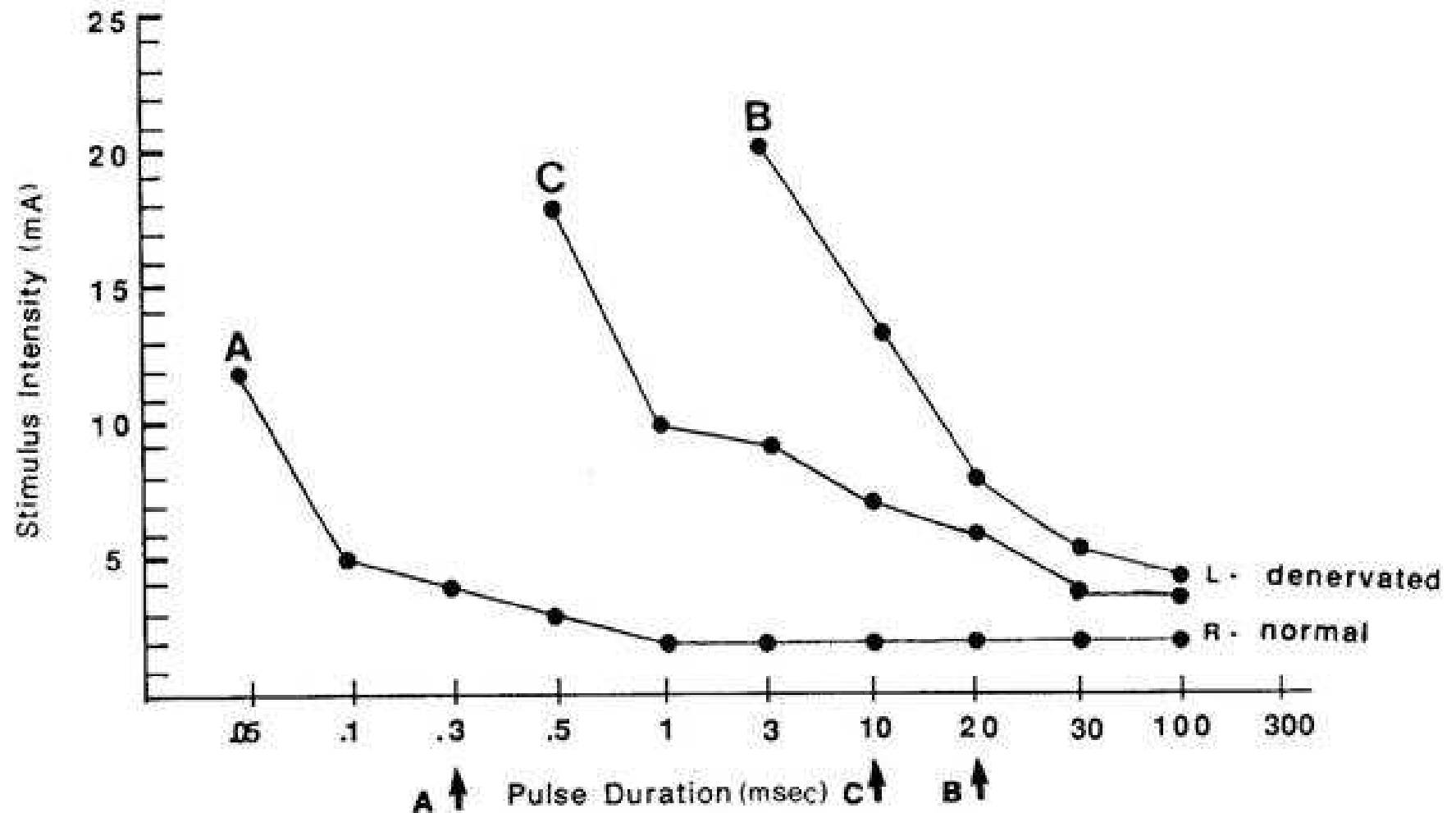


FIGURE 4-3. Plot of strength duration test values recorded in Figure 4-2 with chronaxi marked by arrows. (A) Normal abductor digiti minimi muscle on right hand, chronaxie 0.3 ms; (B) denervated muscle on left hand 2 weeks after injury, chronaxie 20 ms; and (C) partially reinnervated muscle on left hand 6 weeks after injury, chronaxie 10 ms.

STIMULATION OF DENERVATED MUSCLES



LONG DURATION INTERRUPTED DIRECT CURRENT

Unidirectional, interrupted direct current with following characteristic;

Pulse duration

Long pulse duration
(100ms-600ms)
100-300ms PD
 ≥ 300 ms CD

Inter-pulse interval

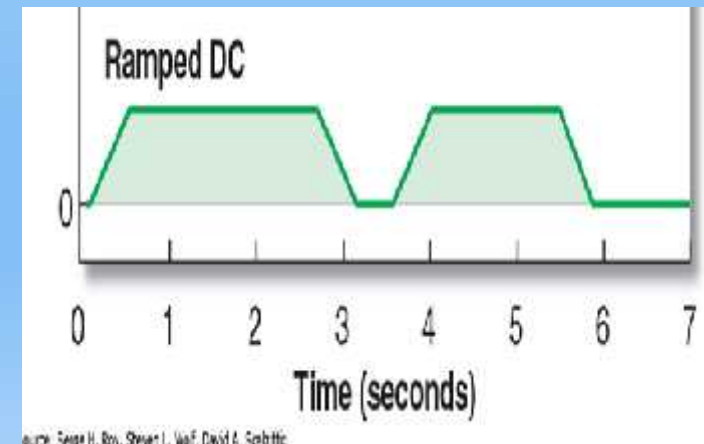
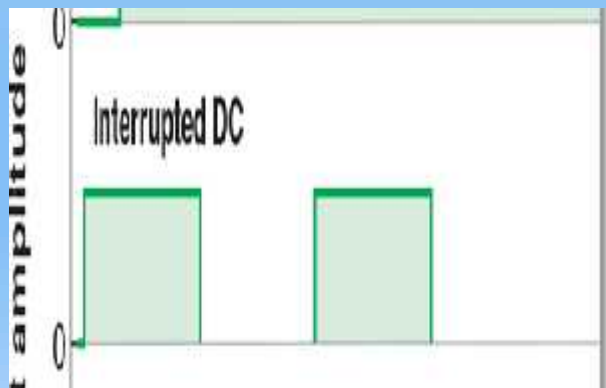
3-5times of pulse duration.

Frequency

Depends on pulse duration e.g. If Pulse duration = 100ms
Frequency of 30 Hz

Waveforms

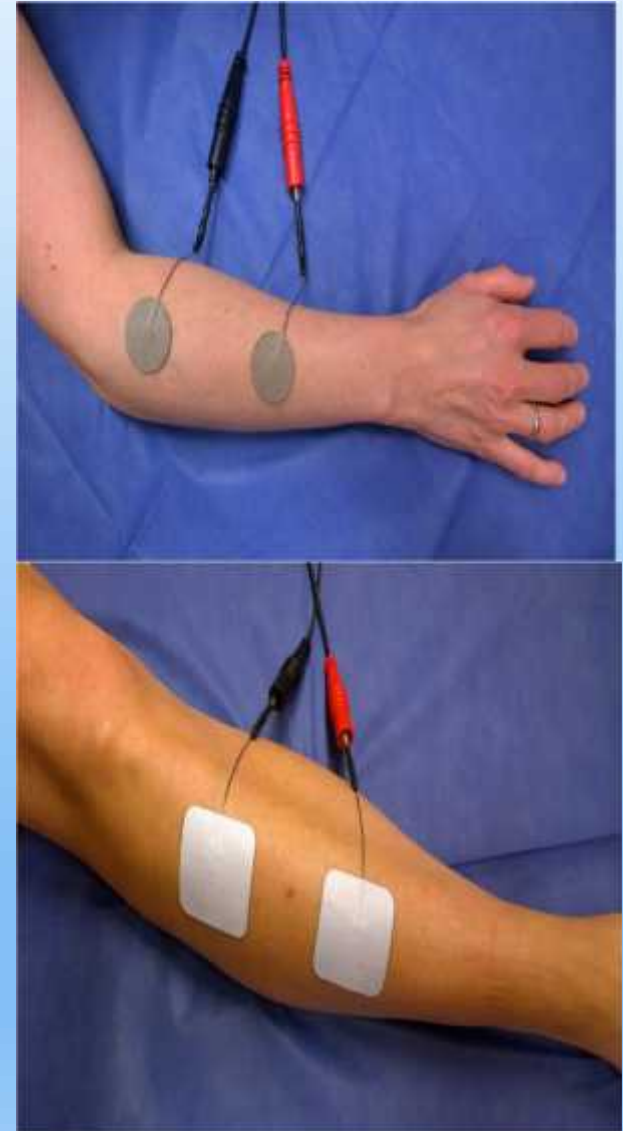
Pulsed monophasic
Saw-tooth,
Triangular, &
Trapezoid



Source: Seiler H., Rov, Steven L., Wolf, David A., Seibritt

STIMULATING DENERVATED MUSCLE

- First 2 weeks.
 - Use asymmetric, biphasic waveform and pulse duration $< 1\text{mSec}$
- After 2-3 weeks,
- Interrupted long duration DC of square/triangular waveform with a pulse duration of 200 -500mSec, and inter-pulse interval 3 to 5 times longer
- Use monopolar or bipolar electrode setup with small diameter active electrode (negative) placed over most **electrically active point**.
- Stimulation using 3 sets of 5 -20 repetitions, 3/ per week



Parameters of E-Stim of Denervated Muscles

Long Duration Interrupted direct current (LIDC)

- Retardation of denervated atrophy
- Utilization of substrates
- Prevent venous & lymphatic stasis
- Working hypertrophy
- Maintenance of muscle extensibility



NMES- FARADIC CURRENT

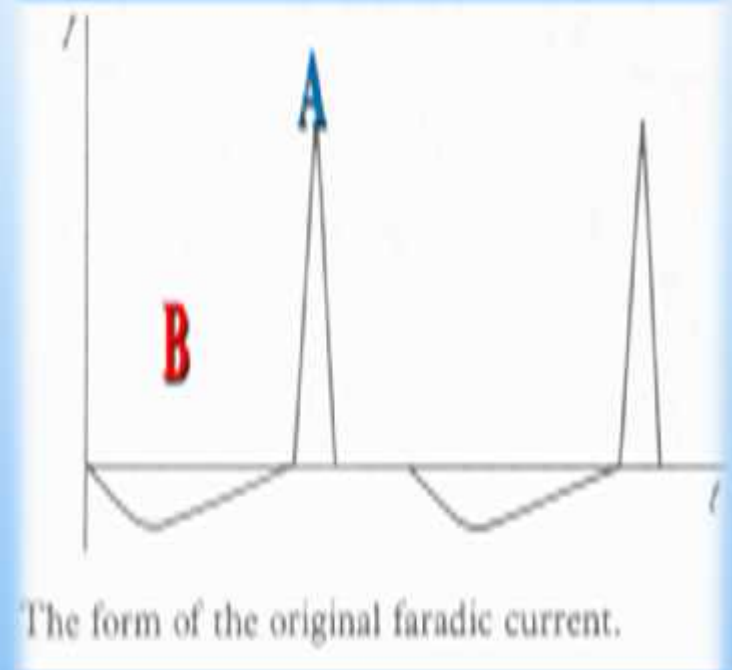


FARADIC CURRENT STIMULATION

- **Faradic current** is biphasic unevenly alternating current, with frequency 1-150Hz. Each pulse consists of two unequal phases

B-Negative: Low intensity long duration

A-Positive: High intensity short duration



FARADIC CURRENT STIMULATION

Faradic current

Interrupted direct current (why?)

pulse duration of 0.1 to 1ms,

frequency of 30 -100Hz

Surged form of current (why?)



FC-STIMULATION PARAMETERS

FC-stimulation Parameters

- Frequency
- Waveforms
- Amplitude
- Pulse duration
- Pulse interval



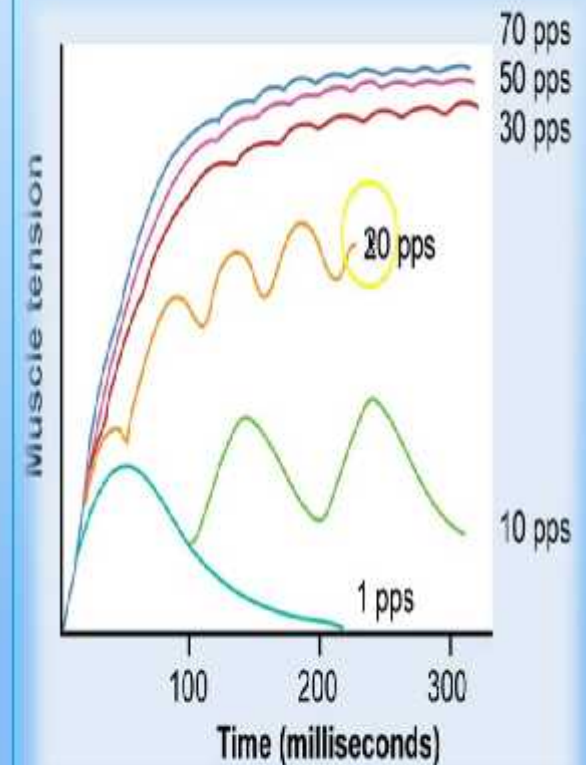
PARAMETERS OF CURRENT STIMULATION

Frequency

Types of muscles contraction is frequency dependence. So Frequency range (10, 50, 75, 100 Hz)

In order to achieve a constant contraction, the stimulus must be applied at rate of 30-80Hz.

- ❖ For small muscles(20-30pps).
- ❖ For large muscles (50-80pps)



FARADIC CURRENT STIMULATION

Waveforms

Pulsed biphasic

Asymmetrical biphasic usually used

Normal muscle:

Rectangular waveform is more comfortable than triangular pulse

In disuse atrophy:

triangular waveform can be used.



FARADIC CURRENT STIMULATION

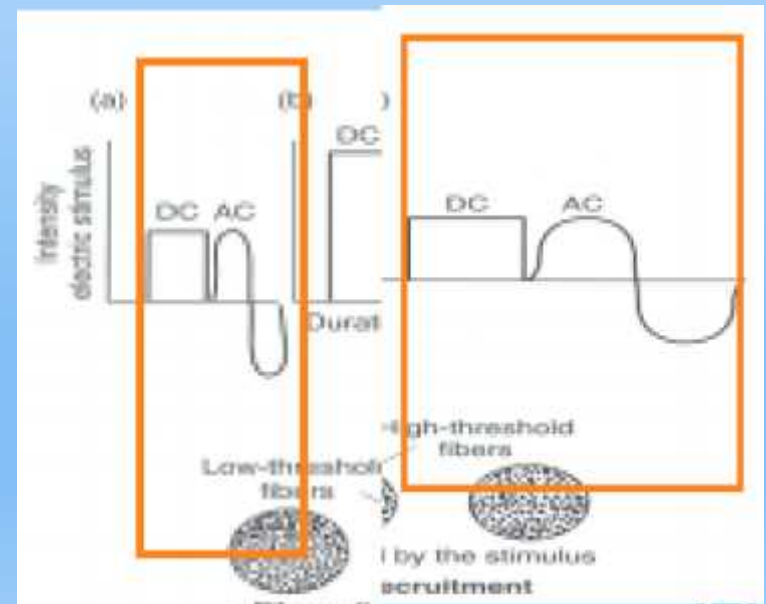
Pulse duration

Therapeutic selection 0.02, 0.05, 0.1 & 1ms.

Normal muscles: recommended PD is .15-0.35Msec.

Pulse duration > 10msec is indicated to neurological disorders.

As the pulse duration is shortened, the higher current amplitude is required to achieve the same strength of contraction produced by longer pulse duration,



FARADIC CURRENT STIMULATION

Pulse interval

The current must be interrupted (off-time) to allow the muscles to relax following period of contraction (on-time), to prevent **muscle fatigue**.

The recommended on: of ration as following

- ❖ In case of muscle strength 1:3 -1:5
- ❖ In case of muscle spasm 1:1
- ❖ In case of muscle pump (edema) 1:1 or 1:2



FARADIC CURRENT STIMULATION

Amplitude

The strength of muscles contraction is amplitude dependence

The recommended amplitude as following

Goals

Normal
muscles

Strength
Muscles

50% of MVIC

Muscles
Recovery form
injury /disuse

Strength Muscles
functional recovery

10% of MVIC

Muscle
reeducation

Functional
recovery

Sensory
higher motor
Lower motor

Muscle
spasm/edema

Decrease spasm
Decreased edema

Visible
MS. contraction

Recommended Parameter Settings For Electrically Stimulated Muscle Contractions

Parameter Settings/ Treatment Goal	Pulse Frequency	Pulse Duration	Amplitude	On:Off Times and Ratio	Ramp Time	Treatment Time	Times per Day
Muscle strengthening	35-80 pps	150-200 μ s for small muscles, 200-350 μ s for large muscles	To >10% of MVIC in injured, >50% MVIC in uninjured	6-10 seconds on, 50-120 seconds off, ratio of 1:5, initially. May reduce the off time with repeated treatments	At least 2 seconds	10-20 min to produce 10-20 repetitions	Every 2-3 hours when awake
Muscle reeducation	35-50 pps	150-200 μ s for small muscles, 200-350 μ s for large muscles	Sufficient for functional activity	Depends on functional activity	At least 2 seconds	Depends on functional activity	NA
Muscle spasm reduction	35-50 pps	150-200 μ s for small muscles, 200-350 μ s for large muscles	To visible contraction	2-5 seconds on: 2-5 seconds off. Equal on:off times	At least 1 second	10-30 min	Every 2-3 hours until spasm relieved
Edema reduction using muscle pump	35-50 pps	150-200 μ s for small muscles, 200-350 μ s for large muscles	To visible contraction	2-5 seconds on: 2-5 seconds off. Equal on:off times	At least 1 second	30 min	Twice a day

TREATMENT TIMES & FREQUENCY

- To be effective 2 & 3 treatments per week for the first 8-12 weeks
- Treatments last 15-20 minutes but no longer than 30 minutes
- It is better to have 3 short treatments per week than 1 long treatment
- For muscle strength several time/day for short time 10minutes is effective



EFFECTS OF FARADIC STIMULATION

Sensory nerves

- **Mild pricking** due to stimulation of sensory nerve .
- **Mild erythema** due to local reflex vasodilatation of superficial blood vessels, which causes slight reddening of the superficial tissues.

Motor nerves

- Faradic current stimulates the motor nerves /muscle, causes contraction of the muscles.
- Because the stimuli repeated 50 times (50Hz) or more, the contraction is tetanic.
- To avoid muscle fatigue secondary to this contraction the current becomes surged

E-stimulation causes MS-strength through Overload principle and specificity mechanisms



EFFECTS OF MUSCLE CONTRACTION

- Increased muscle metabolism.
- Increase oxygen demand by the muscles.
- Increase output of waste product & metabolites (carbon dioxide, lactic acid).
- Dilatation of capillaries and arterioles
- Increased blood flow
- Increase local temperature.
- Increase venous and lymphatic drainage
- Changes in muscle structure (fast twitch to slow twitch)
- Increase joint range of motion.



CLINICAL APPLICATION OF ELECTRICAL STIMULATION INDUCED MUSCLES CONTRACTION



FACILITATION OF MUSCLE CONTRACTION & RE-EDUCATION

- Pain & muscle spasm,
 - Quadriceps e.g. vastus medialis after knee injury & diseases
- Prolonged disuse, wasting and imbalance
 - Following knee surgery (e.g. ACL, TKR)
 - Scoliosis.
 - Prolonged period of immobilization (following fracture)
- Muscle and nerve repair and transplantation.
- Peripheral Nerve injury
- Pelvic floor Muscle (stress incontinence)



IMPROVE VENOUS AND LYMPHATIC DRAINAGE

Electrical stimulation of the muscle causes increase venous and lymphatic return, increase blood velocity and flow, alter cell membrane permeability, these causes reduction of edema.

The treatment is most effective if the current is applied by the method, termed faradism under pressure

Faradism under pressure is stimulation of the muscle that generally act as the pump muscles and is combined with compression and elevation of the limb to increase venous and lymphatic drainage and hence relive edema.



E-STIMULATION FOR NEUROLOGICAL DISORDERED

Stroke: E-stim of weakened lower limb agonist muscles can improve

- ❖ Voluntary recruitment of motor units
- ❖ Improve gait
- ❖ Increase ankle dorsiflexion torque
- ❖ Assist or support joint position during movement
- ❖ Can substitute for ankle foot orthosis
- ❖ Can substitute for hand function in ADL (e.g. NESS hand rehabilitation system)

- <https://www.youtube.com/watch?v=Px6CJUfZOhQ>



RETARDATION OF MUSCLE ATROPHY

Maintenance of muscle tissue after injury that prevent normal muscle contraction can be achieved through using an electrical stimulated muscle contraction, which produce the physical and chemical events associated with normal voluntary muscle contraction and helps to maintain normal muscle function.

INCREASING RANGE OF MOTION

Muscle contraction pulls the joint through limited range. The continued contraction of this muscle group over an extended time make the contracted joint and muscle tissues modify and lengthen



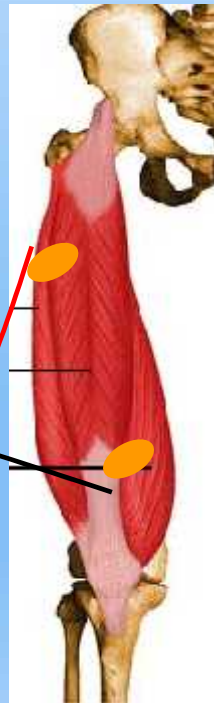
APPLICATIONS



The right quad has atrophied or wasted. Stimulation of the quad can prevent atrophy and increase strength.

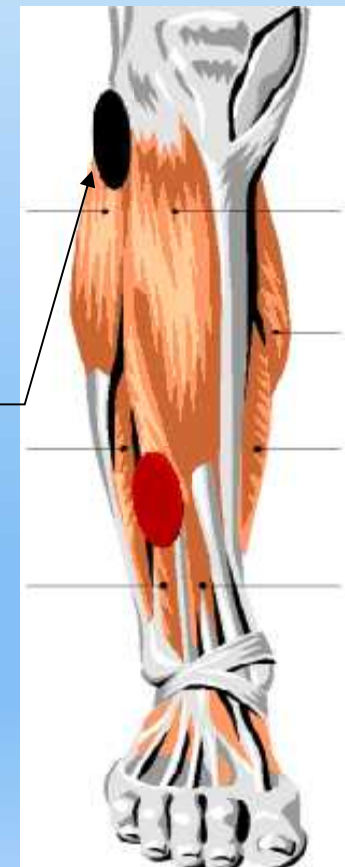


The person with foot drop is unable to dorsiflex their foot.



Placement for quad weakness/atrophy.

The approximate electrode placements for foot drop. The negative is placed over the peroneal nerve.



MUSCLE RE-EDUCATION

■ Post op ACL

- Problem: Quadriceps atrophy
 - Goal: Decrease atrophy, increase strength.
 - Waveform: Symmetric
 - Duty cycle: 25% (4:12)
 - Placements:



■ Rotator cuff repair

- Problem: Rotator cuff atrophy, poor scapular stability
 - Goal: Decrease/ reverse atrophy, scapular stabilizer re-ed.
 - Waveform: Symmetric/ asymmetric
 - Duty cycle: 25%, hand switch
 - Placements:



Isometric Abduction

Scapular depression



CONTRAINDICATION FOR FARADIC CURRENT STIMULATION

- Skin lesion & dermatological conditions such as eczema.
- Infection such as osteomyelitis.
- Vascular diseases such as thrombosis, & thrombophlebitis.
- Marked loss of skin sensation (chemical burn).
- Unreliable patients.
- Superficial metal (concentration of electricity).
- Metal and cardiac pacemaker
- Over recent or non-union fractures
- Over potential malignancies



Electrodes Placement For Muscles Contraction

tibialis Anterior muscles



Rectus femoris



Vastus medialis



Wrist extensor

