Outline

Section 1

Introduction

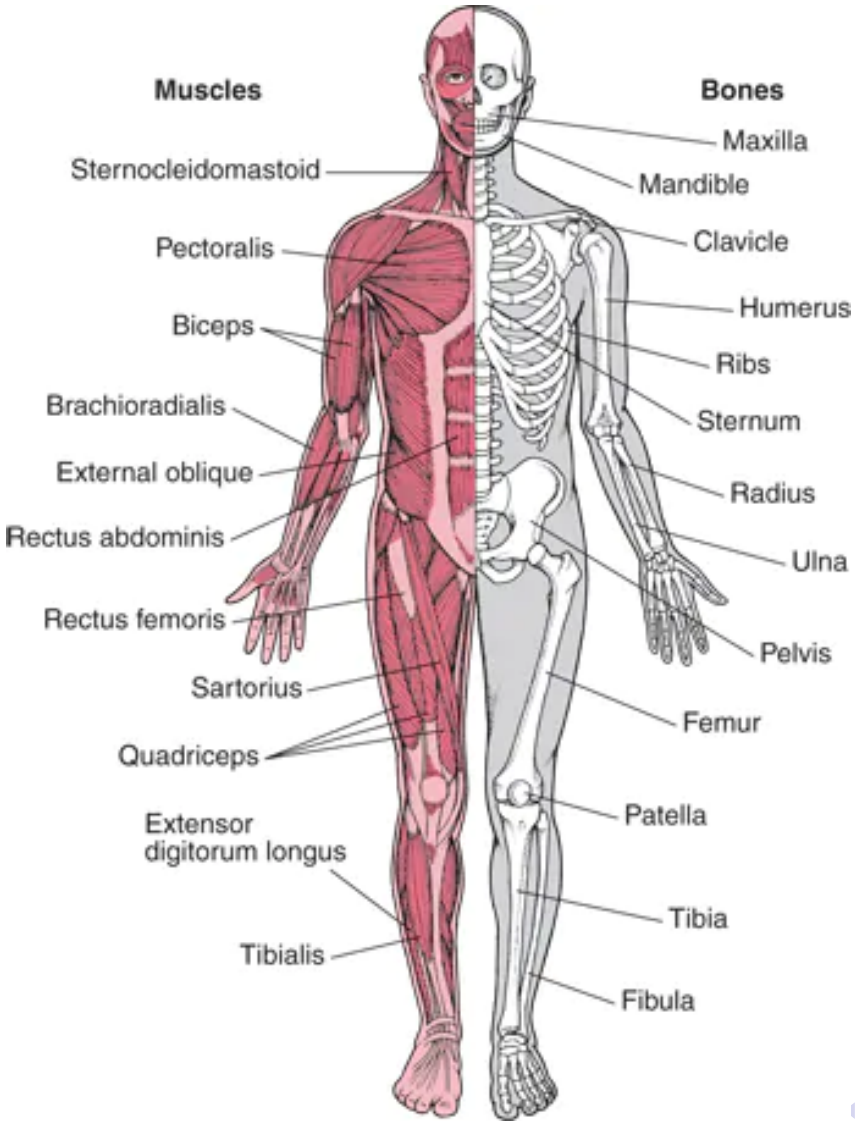
Musculoskeletal System

Musculoskeletal system provides support, stability, shape, and movement to the body. Musculoskeletal system is primarily responsible for providing required forces to perform actions. This system consists of:

- Nervous system
  - Provides control via nerve signals
  - Innervates muscles
    - Nerve heads originate in the spinal column and their long bodies(axons) extend far and deep
- Muscular system

The skeletal–muscular system consists of muscle groups attached to bones via tendons and movement is produced when nerve signals cause muscle contractions and relaxations that either pull or release the bone.

Musculoskeletal System - Graphical Overview



Section 2

Muscle Physiology

Anatomy of the Muscle

Three types of muscles exist:

- Skeletal (striated) muscle
  - Responsible for: support and movement, homeostasis
  - Attached to bones moves skeleton
  - Can voluntarily be controlled
- Smooth muscle
  - Present in the walls of hollow organs (e.g, stomach, intestines, arteries and veins
  - Can't be controlled voluntarily
- Cardiac muscle
  - Found only in the heart
  - Can't be controlled voluntarily
  - Rate of contraction is controlled via a series of impulses

Anatomy of the Muscle - Characteristics

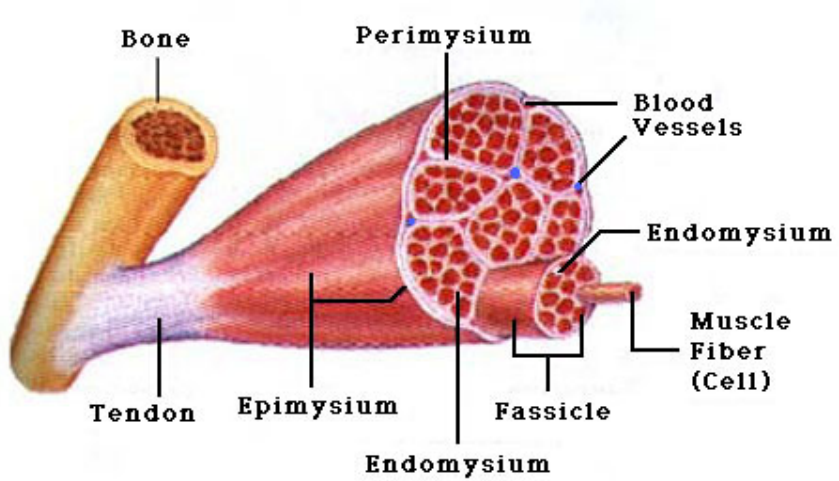
Fundamental characteristics of the muscles are:

- Excitability - responds to stimuli (e.g., nervous impulses)
- Contractility - able to shorten in length
- Extensibility - stretches when pulled

Anatomy of the Muscle

Skeletal muscles are attached to bones via tendons.

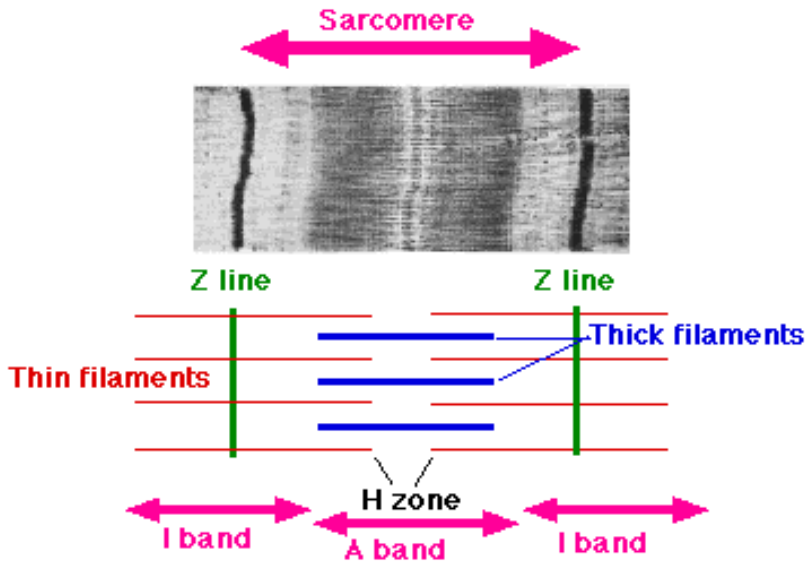
Muscle groups are composed of fassicles that are fiber bundles surrounded by a layer called perimysium.



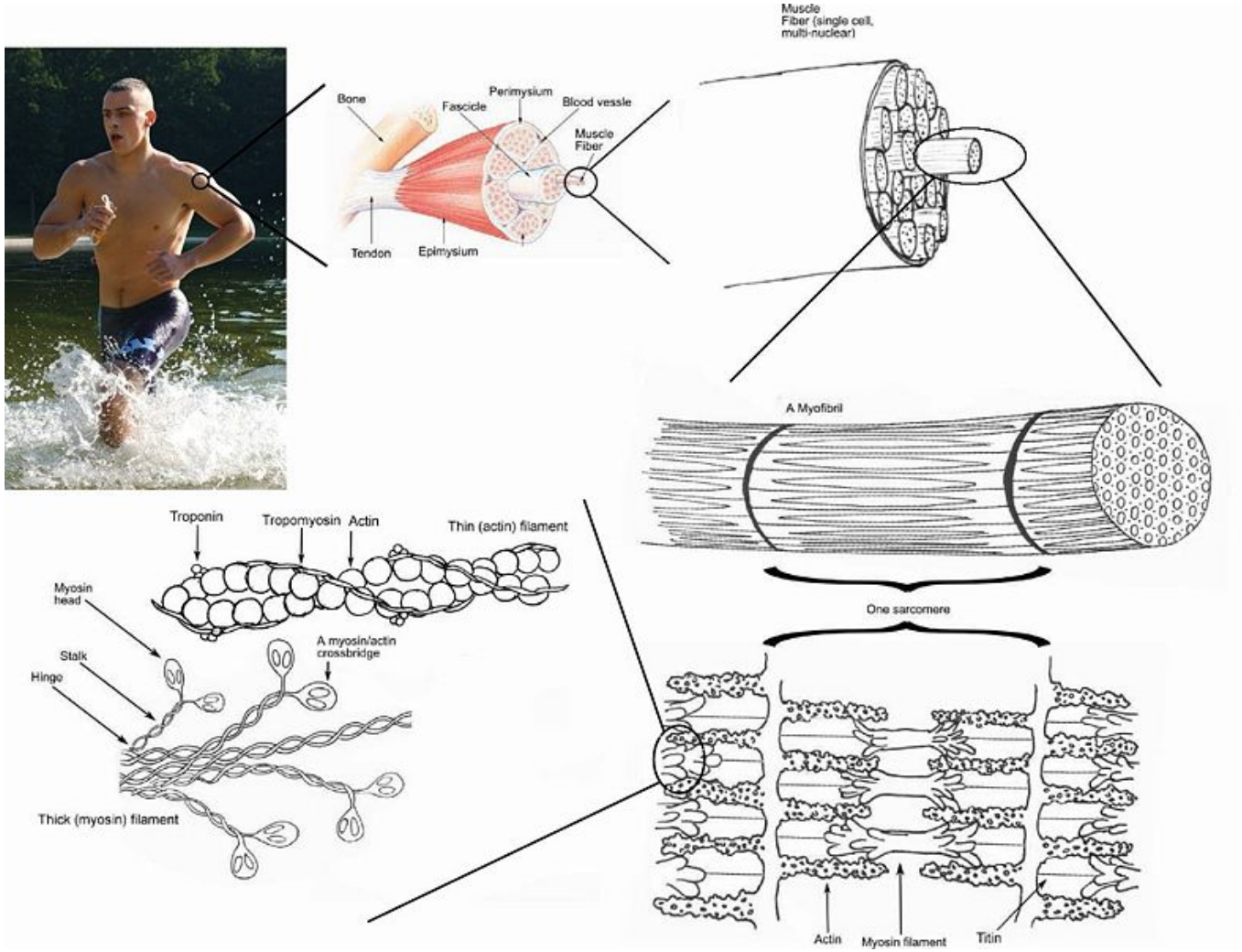
Anatomy of the Muscle

The cell membrane for each muscle fiber is called sarcolemma. Sarcolemma acts as a conductor for impulses, like neurons do for nerve impulses.
Muscle cells are composed of myofibrils that are bundles of sarcomeres.
Sarcomeres are multiprotein complexes, composed of:

- Actin
- Myosin
- Titin



Anatomy of the Muscle



Anatomy of the Muscle

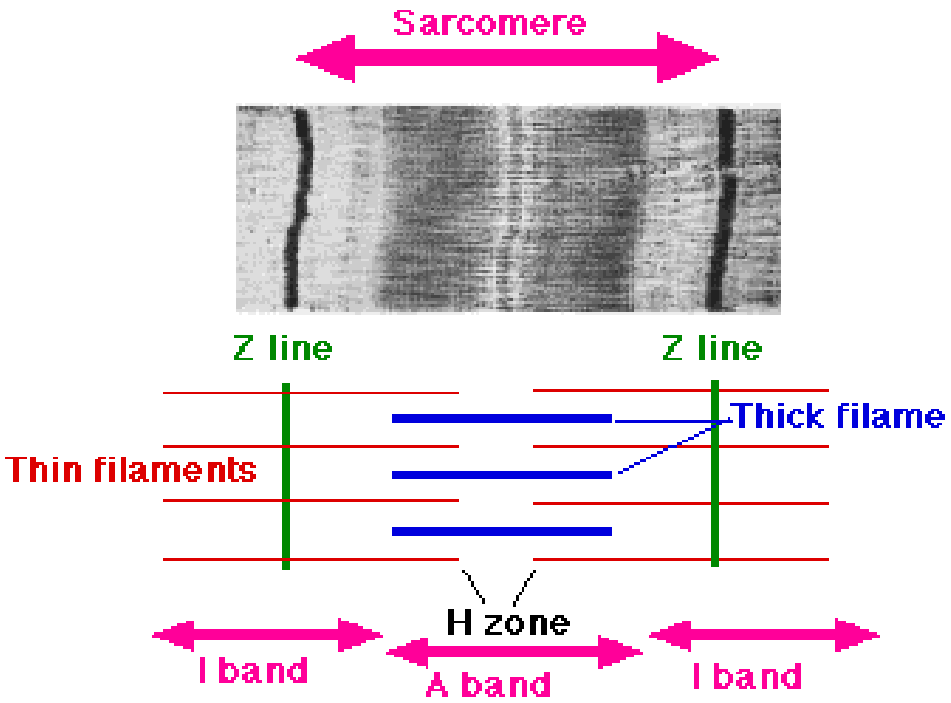
Region around Z-lines are known as isotropic bands.

- I-bands (isotropic)
- Mainly composed of actin filaments.

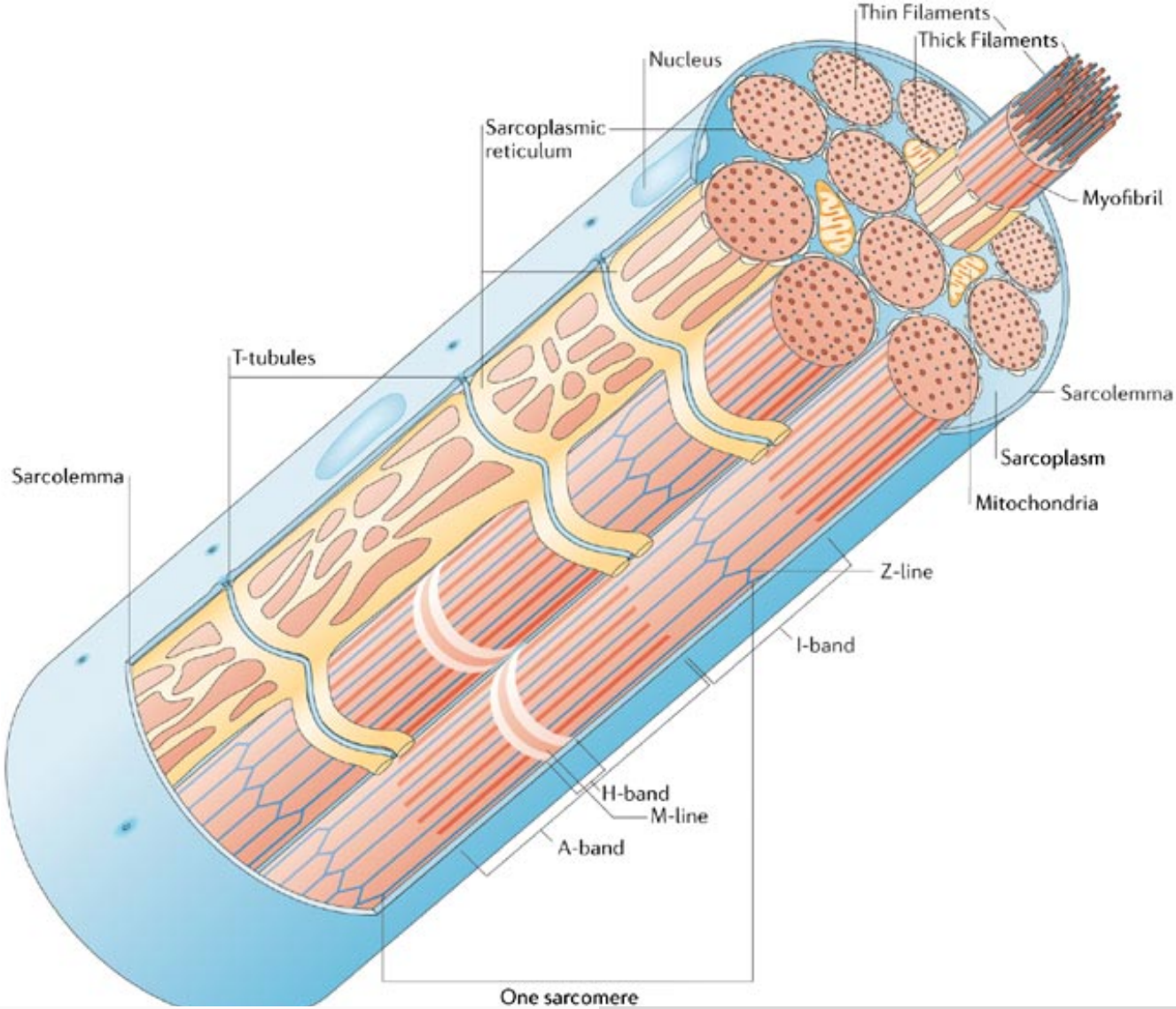
Region between the Z-lines are known as anisotropic bands.

- A-bands (anisotropic)
- Mainly composed of myosin filaments.

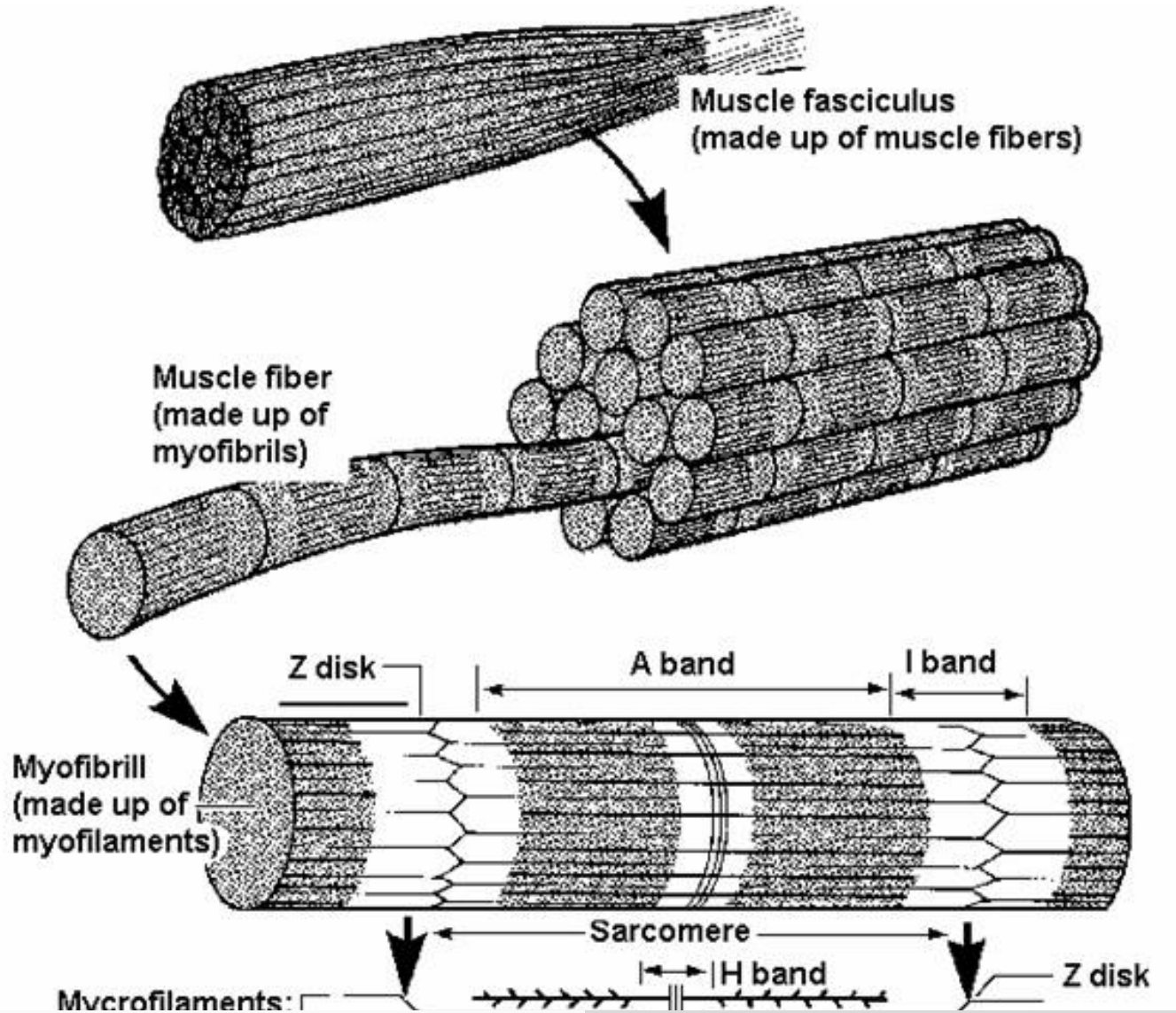
The interaction between actin and myosin filaments together with calcium ions provides the contraction properties of muscle.



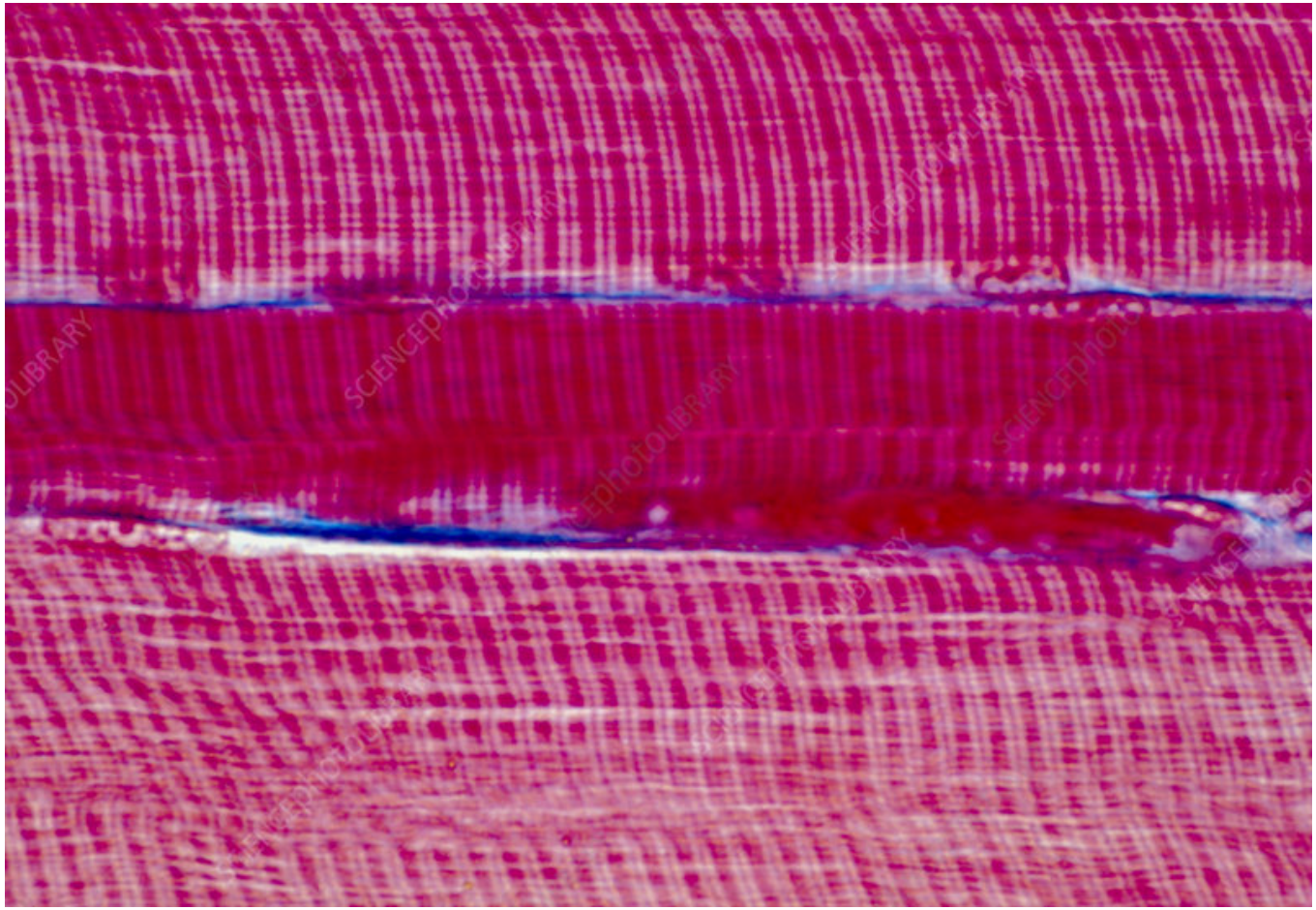
Anatomy of the Muscle



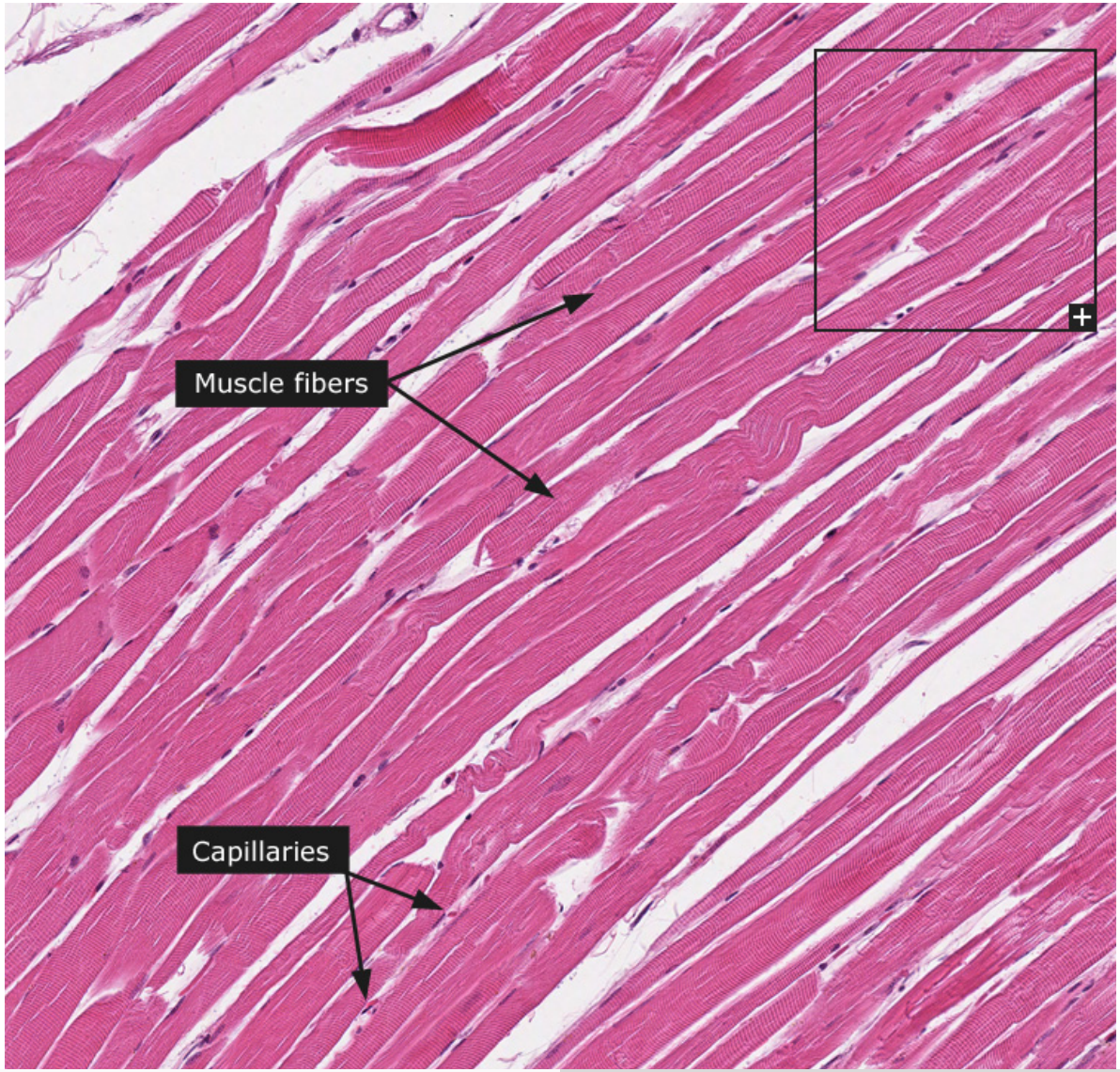
Anatomy of the Muscle



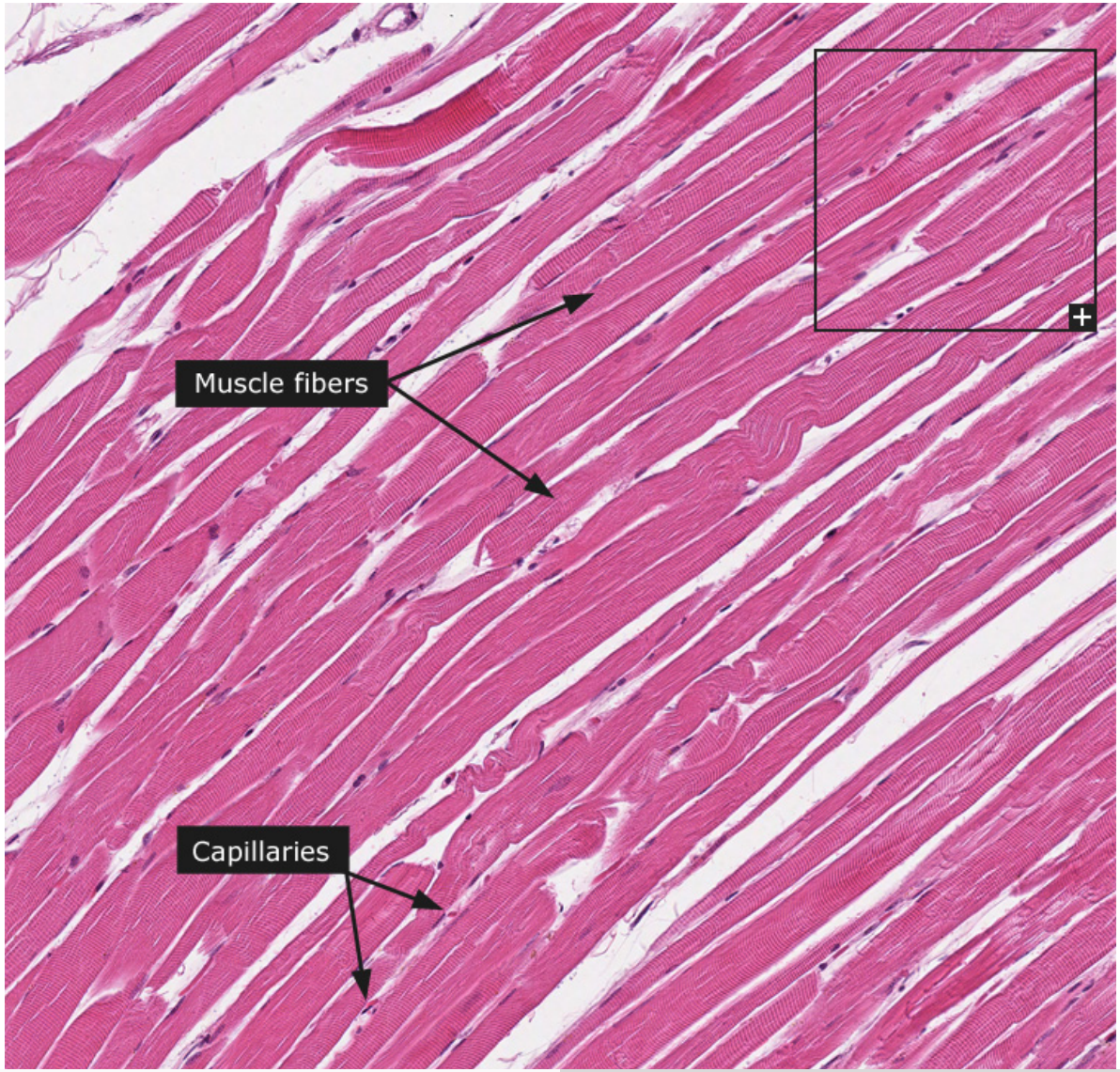
Skeletal Muscle - Micrograph



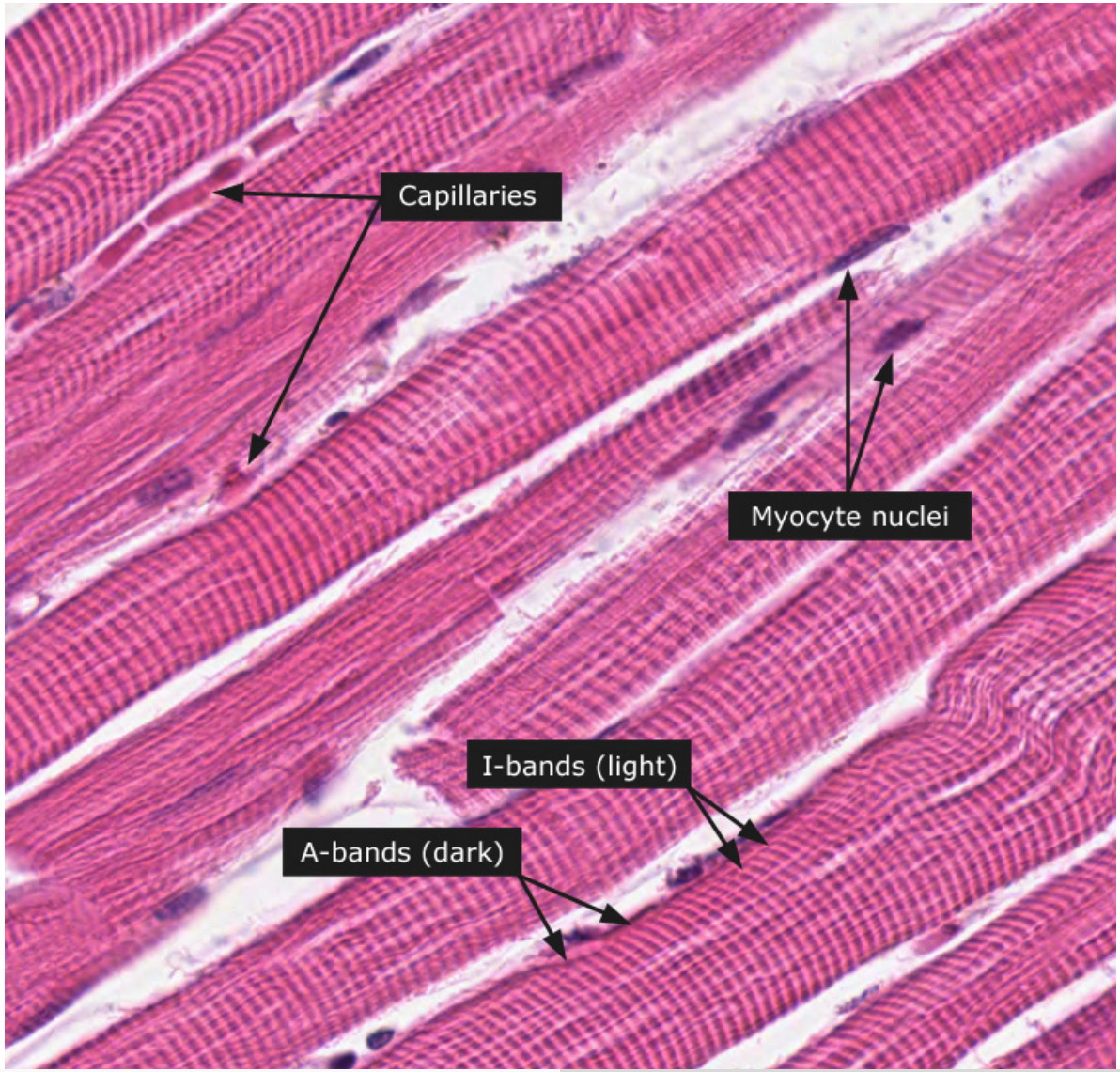
Skeletal Muscle - Micrograph



Skeletal Muscle - Micrograph (Zoomed)



Skeletal Muscle - Micrograph (Zoomed)



Muscle Contraction - Sliding Cross-Bridge Action

- The sarcolemma of muscle fibers contains several hollow passages known as transverse (T) tubes that wrap around the myofibril and connect to other locations in the sarcolemma.
- They do not open into the interior of the muscle because their sole function is to conduct action potentials travelling on the surface of the sarcolemma deep into the muscle core where the sarcoplasmic reticulum resides.

Muscle Contraction - Sliding Cross-Bridge Action

- The sarcoplasmic reticulum is a hollow reservoir for storing Calcium ions (Ca2+), which is a key chemical component for sustaining contraction.
- The membrane of the sarcoplasmic reticulum is equipped with "pumps," which work using active transport in which energy is used to move ions across the membrane.

Muscle Contraction - Sliding Cross-Bridge Action

- The membrane also has "gates," which allow the ions through.
- Calcium is continuously pumped into the sarcoplasmic reticulum from the cytoplasm of the muscle fibers (sarcoplasm).
- In the relaxed state, the sarcoplasmic reticulum has a high concentration of calcium ions compared to the muscle fibers or myofibrils.
- The ionic gates are closed and calcium ions cannot flow back into the muscle fibers creating a large ion diffusion gradient.

Muscle Contraction - Sliding Cross-Bridge Action

- The motion of muscle fibers is due to the interaction between thick and thin myofilaments.
- This cross-bridge contains adenosine triphosphate (ATP) molecules, which represent stored energy to be released and also molecule-binding sites for actin molecules.
- Thin myofilaments are composed of actin, troponin, and tropomyosin protein molecules.

Muscle Contraction - Sliding Cross-Bridge Action

- Actin molecules form the long chain of the myofilament whereas tropomyosin are single individual chains, which wrap around the actin chain.
- At the end of the tropomyosin chain lies a troponin molecule.
- In the muscle's relaxed state, the tropomyosin chain lies in contact with the myosin heads and although this configuration is maintained, the muscle remains relaxed.
- Troponin molecules have binding sites for calcium ions, which cause the molecule structure to change shape in the presence of calcium ions.

Muscle Contraction - Sliding Cross-Bridge Action

- At the onset of contraction, a nerve impulse travels down the sarcolemma into the sarcoplasmic reticulum.
- As the electrical impulse crosses the surface of the sarcoplasmic reticulum, the ionic gates open and calcium ions diffuse into the myofibril filaments along the concentration gradient.
- In the presence of calcium ions, troponin molecules change shape and drag the tropomyosin chains along causing the myosin head to come into contact with an actin molecule.

Muscle Contraction - Sliding Cross-Bridge Action

- When contact is achieved, the myosin head binds with an actin molecule in the presence of ATP.
- This chemical combination transforms ATP into adenosine diphosphate (ADP), which is accompanied by a release of energy.
- The chemical equation for this transformation is represented by

$$A + M + ATP => A + M + ADP + P + Energy$$

Muscle Contraction - Sliding Cross-Bridge Action

- This sudden release of energy causes the myosin head to swivel or move, which pulls the actin chain or thin myofilament along.
- A combination of these movements in the many hundreds of thousands of thin myofilaments is observed as a single united movement of the muscle fiber.

Muscle Contraction - Sliding Cross-Bridge - Summary

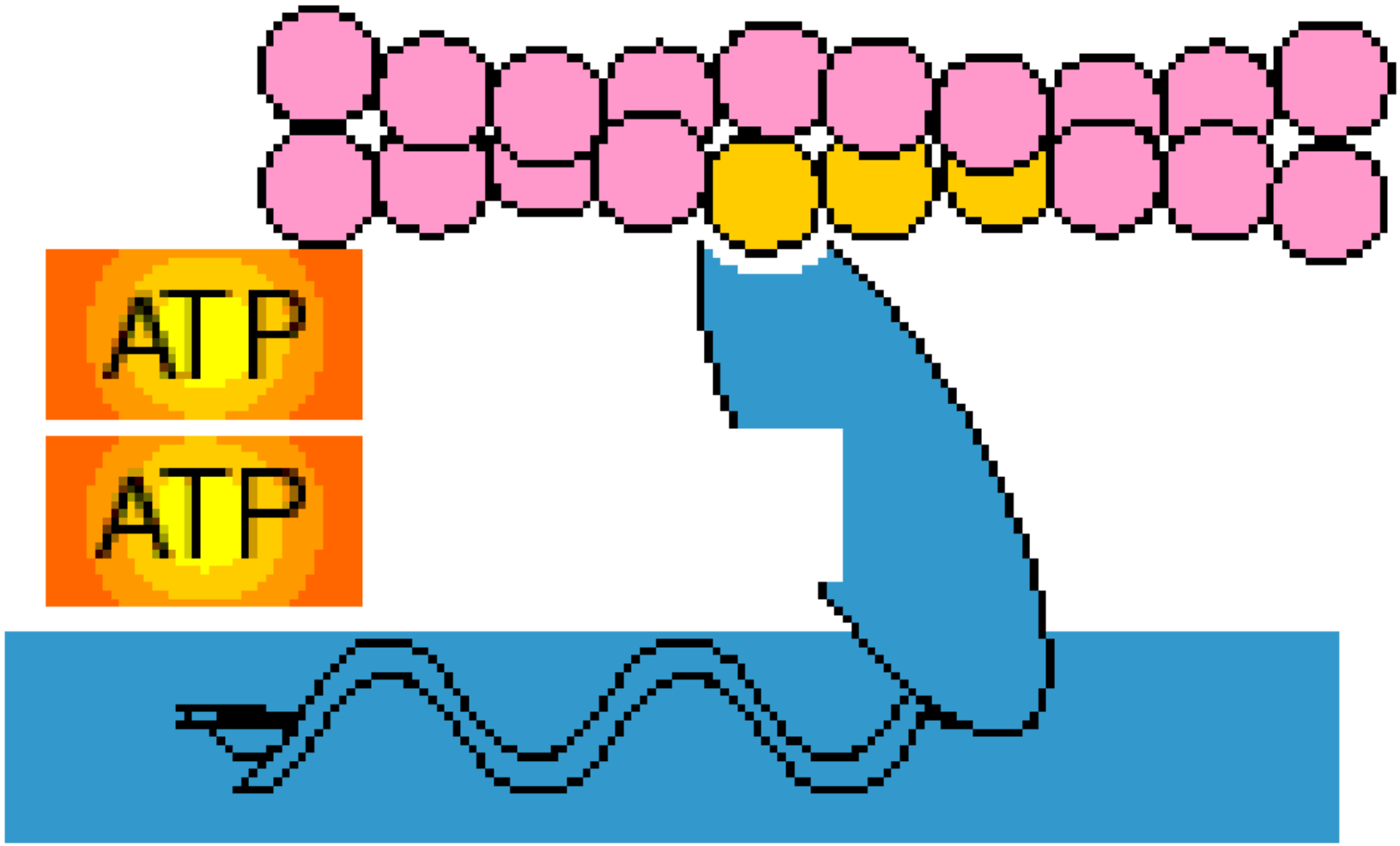
- Thick myofilaments are composed of a protein called **myosin**.
- Each **myosin** molecule has a tail which forms the core of the thick myofilament plus a head that projects out from the core of the filament.
- These **myosin heads** are also commonly referred to as **cross-bridges**.

Muscle Contraction - Sliding Cross-Bridge - Summary

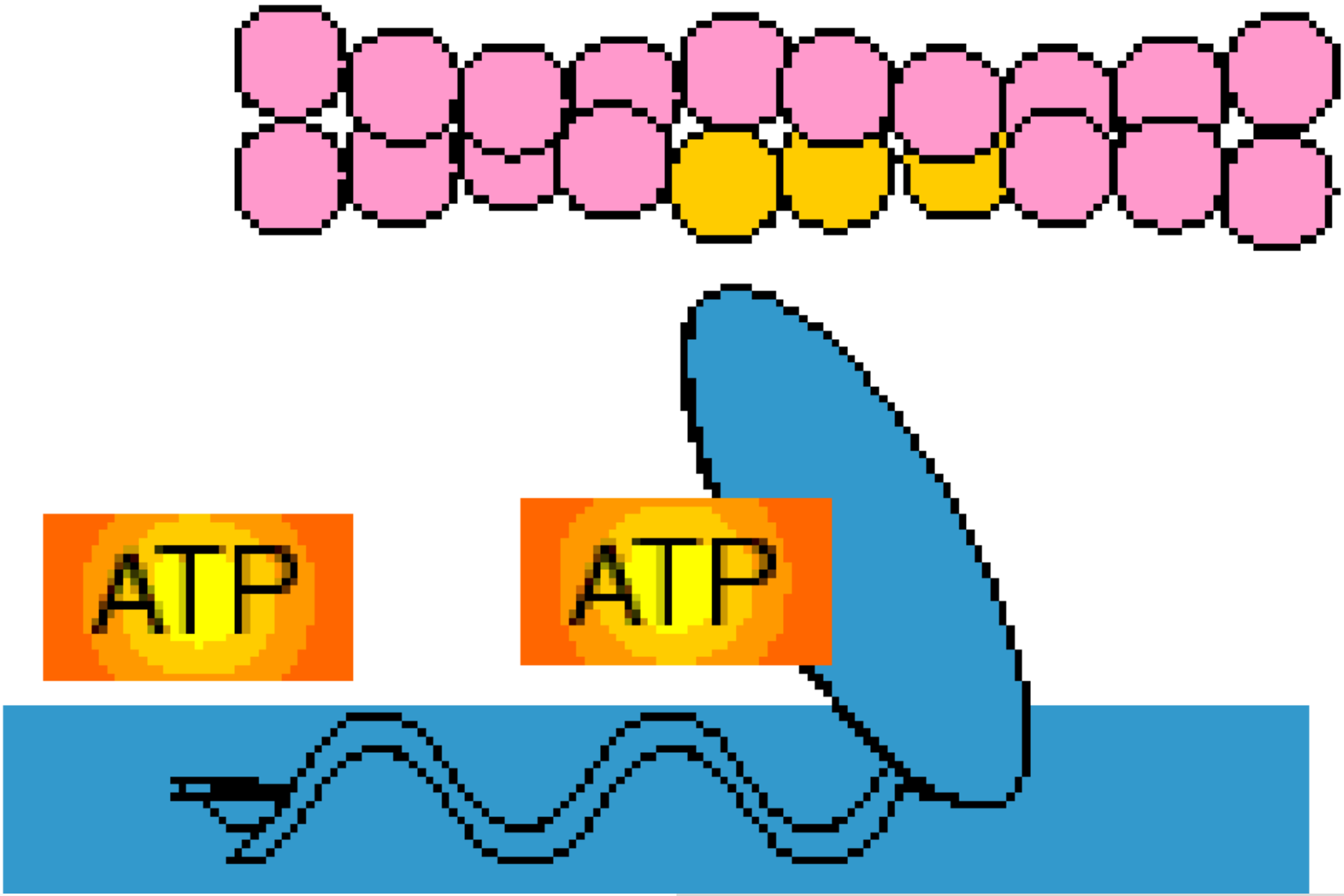
The cross-bridges have several important characteristics:

- They have ATP-binding sites into which fit molecules of ATP. ATP represents potential energy.
- It has actin-binding sites into which fit molecules of actin.
- They have a **"hinge"** at the point where it leaves the core of the thick myofilament.
- This allows the cross-bridge to swivel back and forth, and the **"swivelling"** causes muscle contraction.

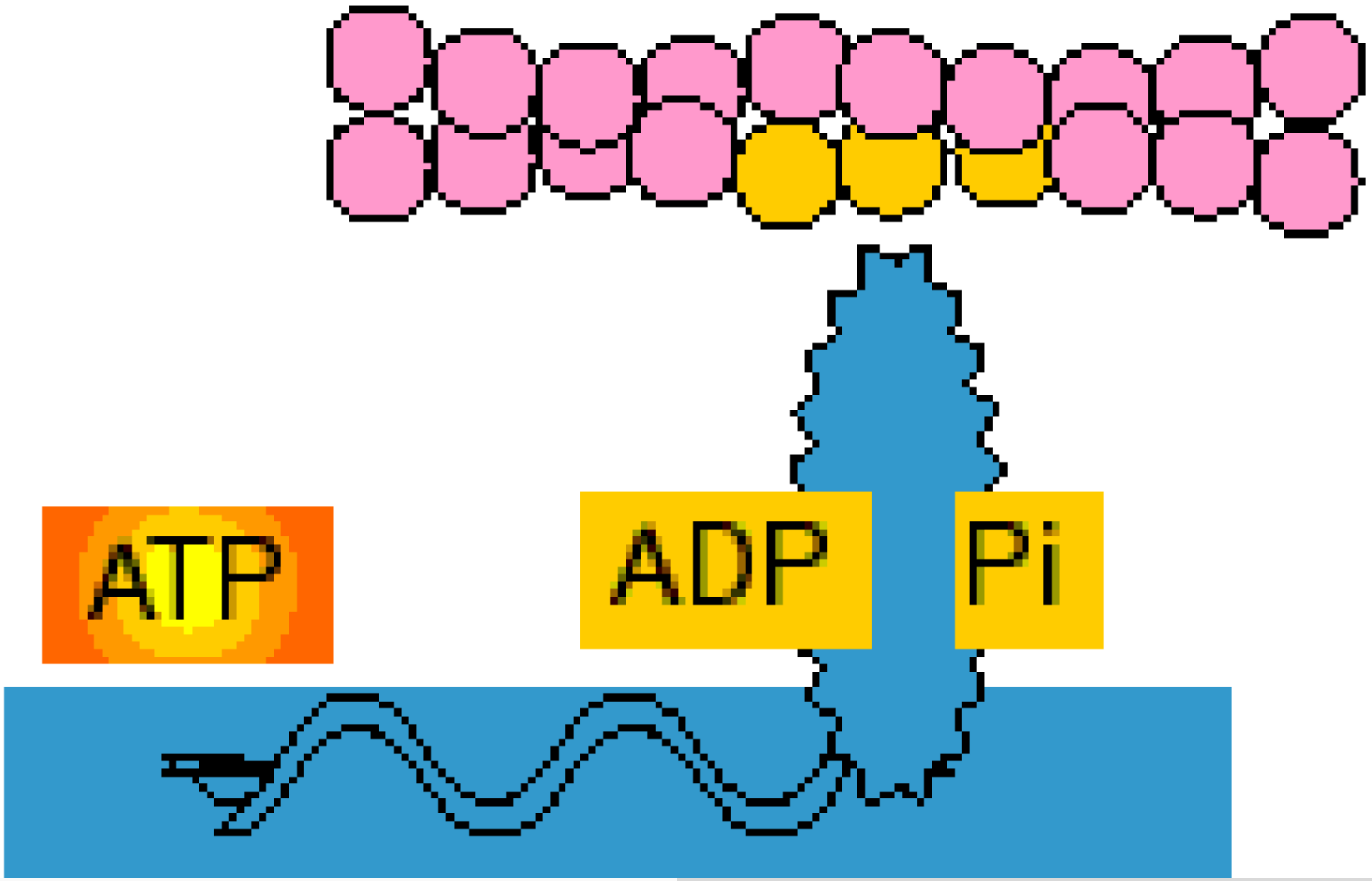
Muscle Contraction - Sliding Cross-Bridge - Summary



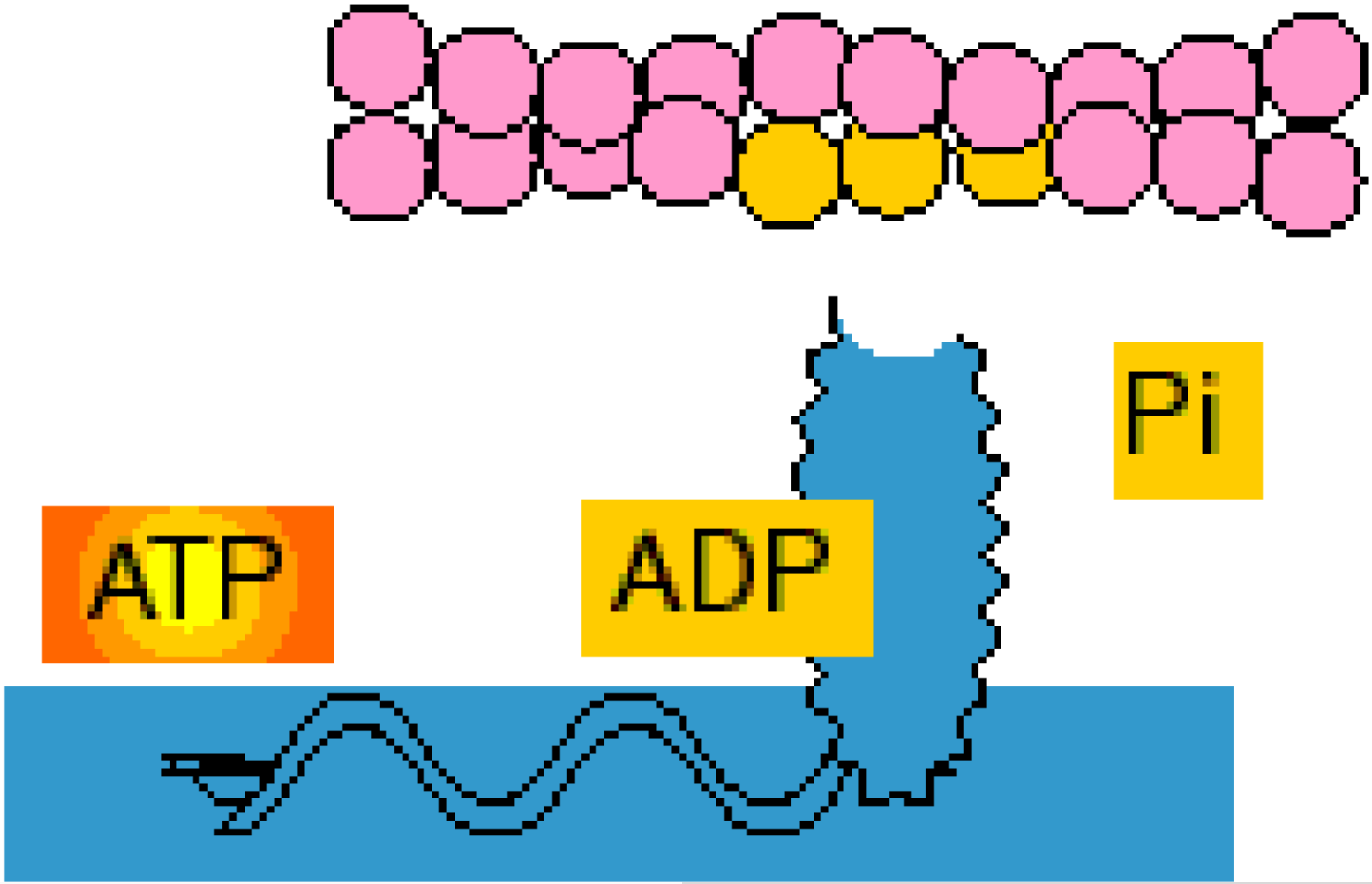
Muscle Contraction - Sliding Cross-Bridge - Summary



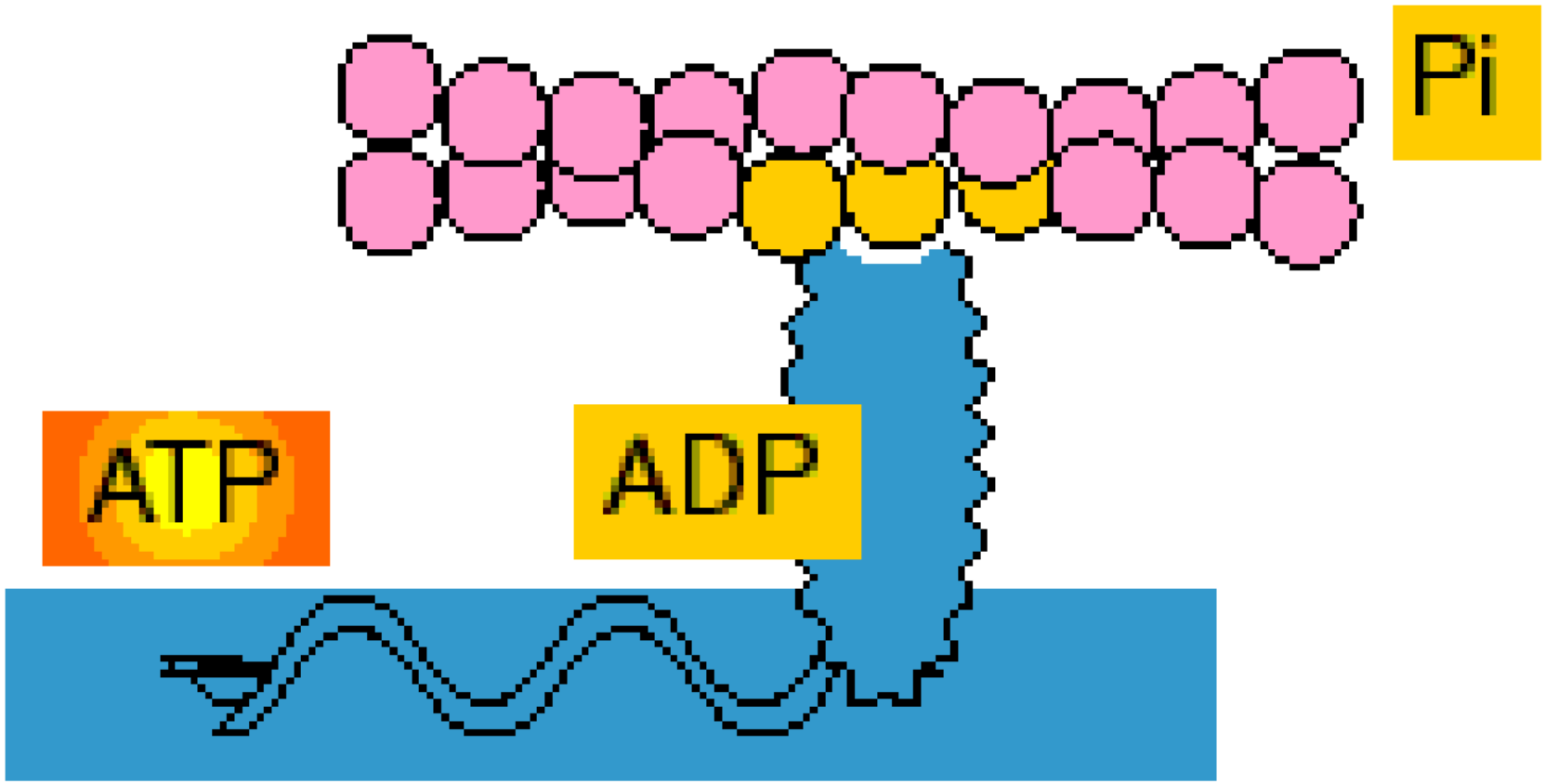
Muscle Contraction - Sliding Cross-Bridge - Summary



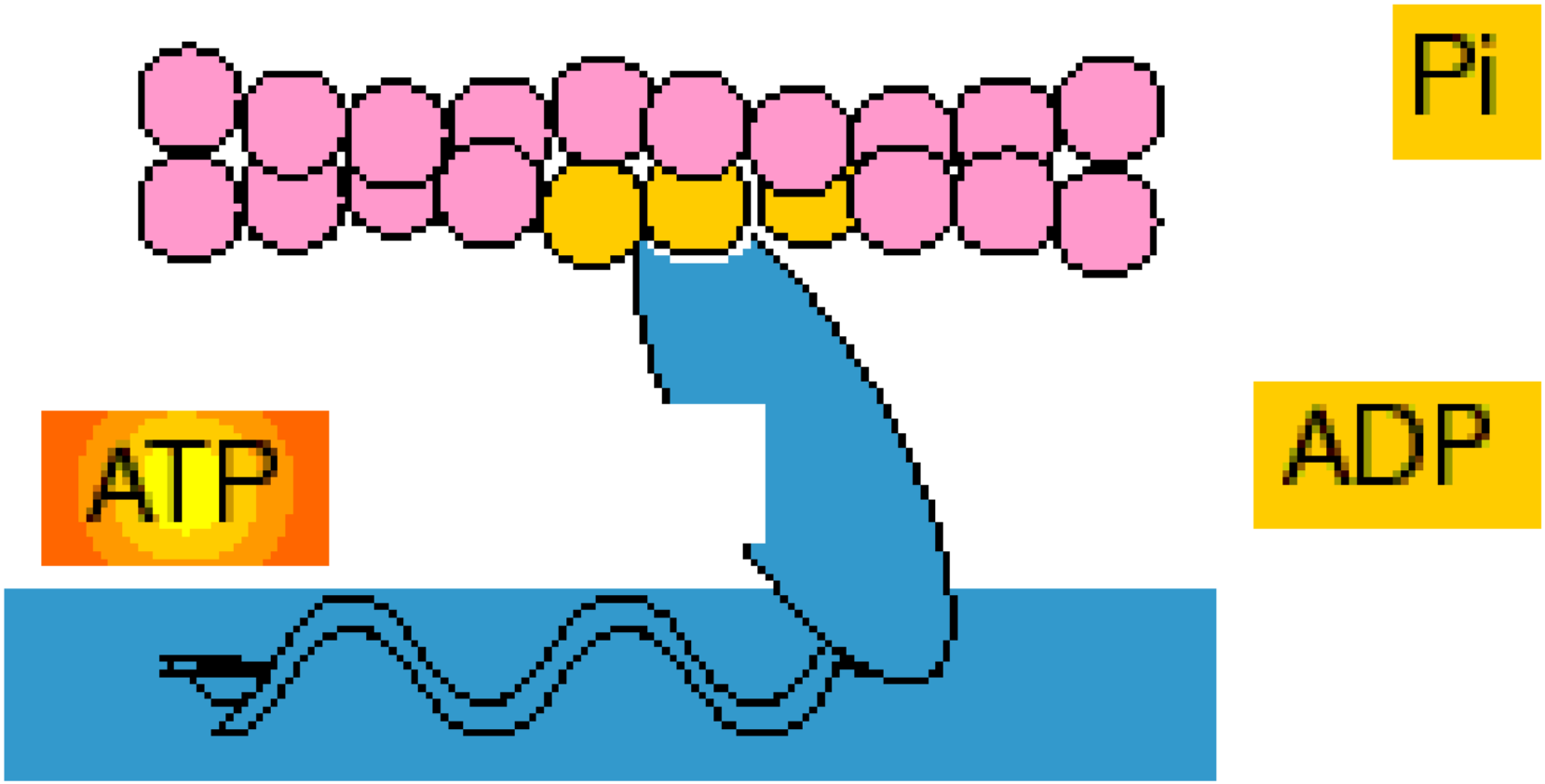
Muscle Contraction - Sliding Cross-Bridge - Summary



Muscle Contraction - Sliding Cross-Bridge - Summary

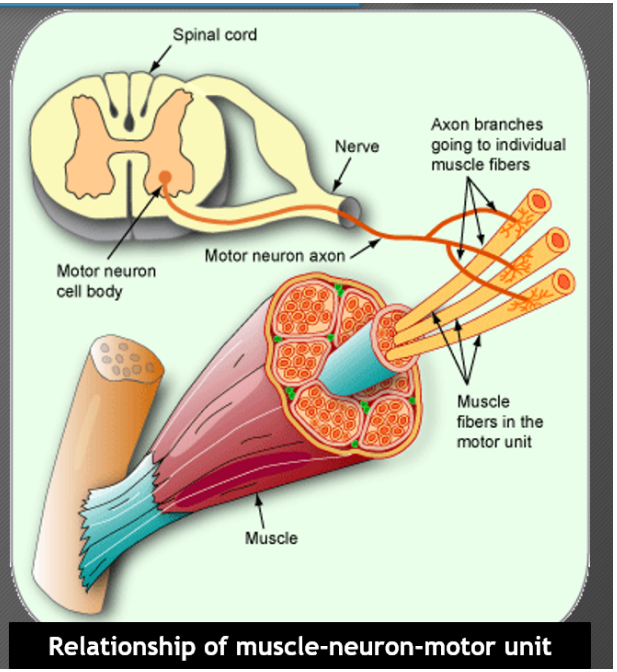


Muscle Contraction - Sliding Cross-Bridge - Summary



The Motor Unit Action Potential

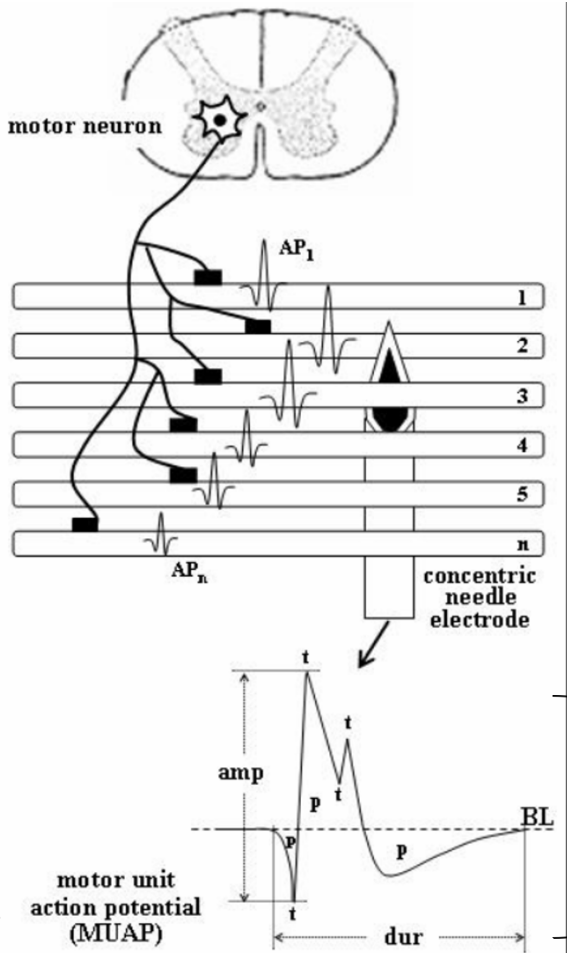
- Motor unit (MU) represents the anatomical and functional element of the neuromuscular system.
- MU is formed by the alpha spinal motor neuron and its innervated set of muscular cells.
- Activity of the MU generated electrical changes are called MUAP.



Relationship of muscle-neuron-motor unit

The Motor Unit Action Potential

Schematic representation of a motor unit with n muscle fibers.

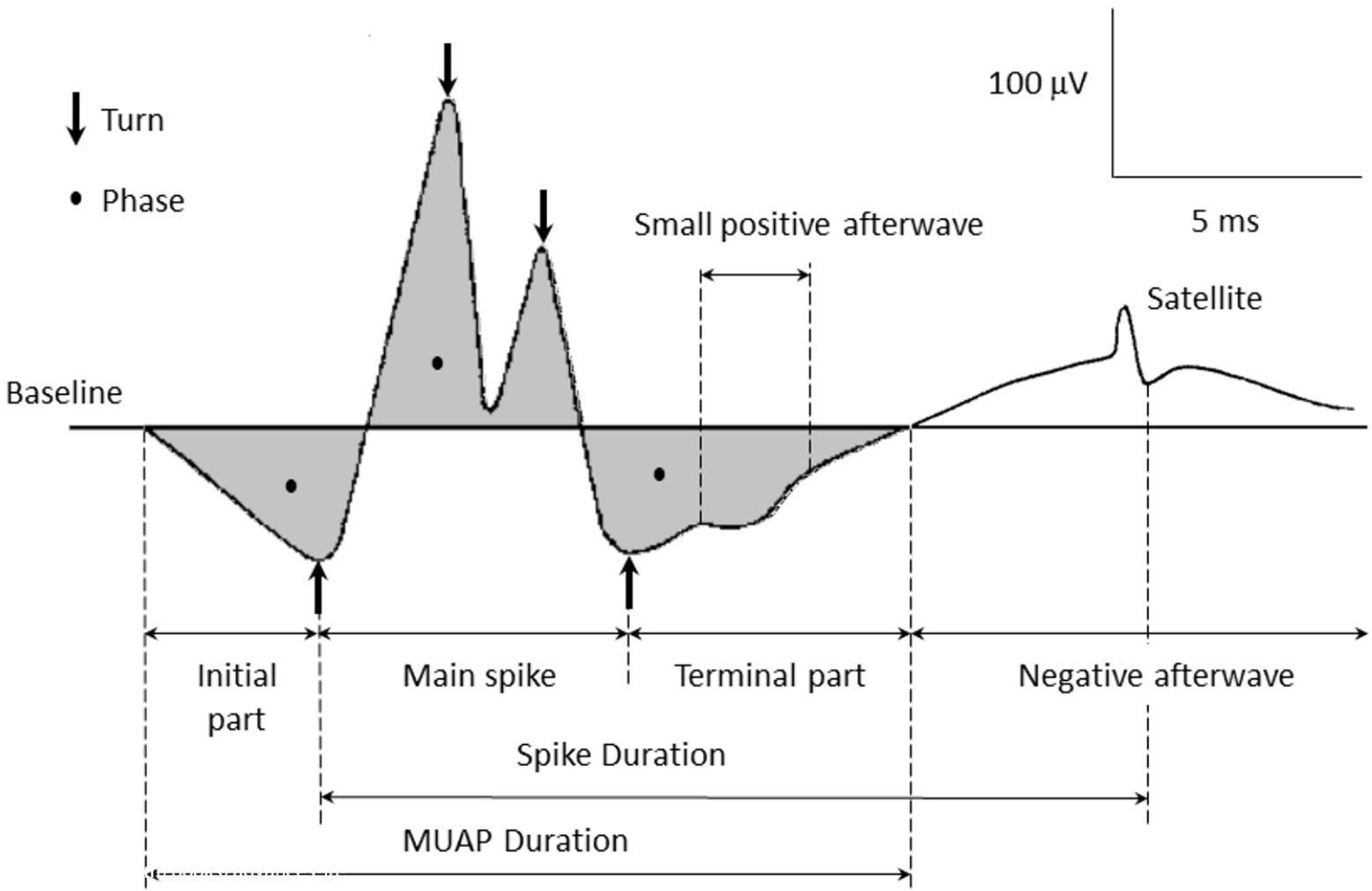


The algebraic summation of the action potentials (AP) of all the single fibers present in the recording uptake area of the electrode (AP1+AP2+...+APn) generates the motor unit action potential (MUAP).

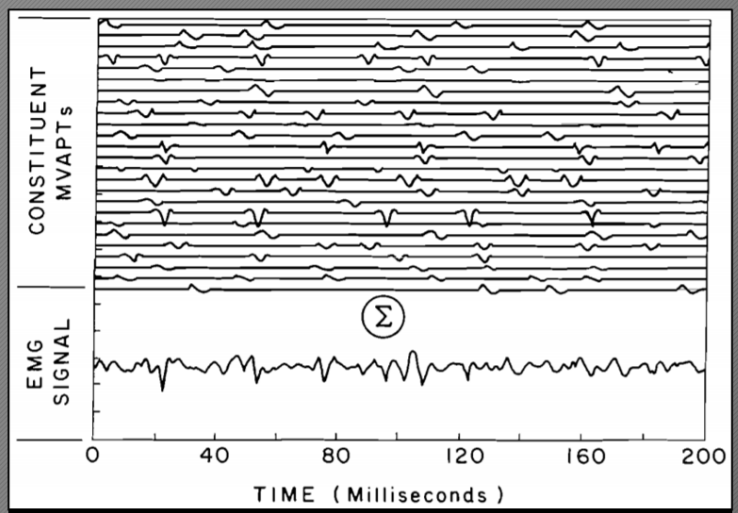
The main parameters of the MUAP waveform are indicated: amp = amplitude; dur = duration; p = phase; t = turn. BL = baseline.

https://www.intechopen.com/books/advances-in-clinical-neurophysiology/motor-unit-action-potential-duration-measurement-and-significance

The Motor Unit Action Potential



The Motor Unit Action Potential

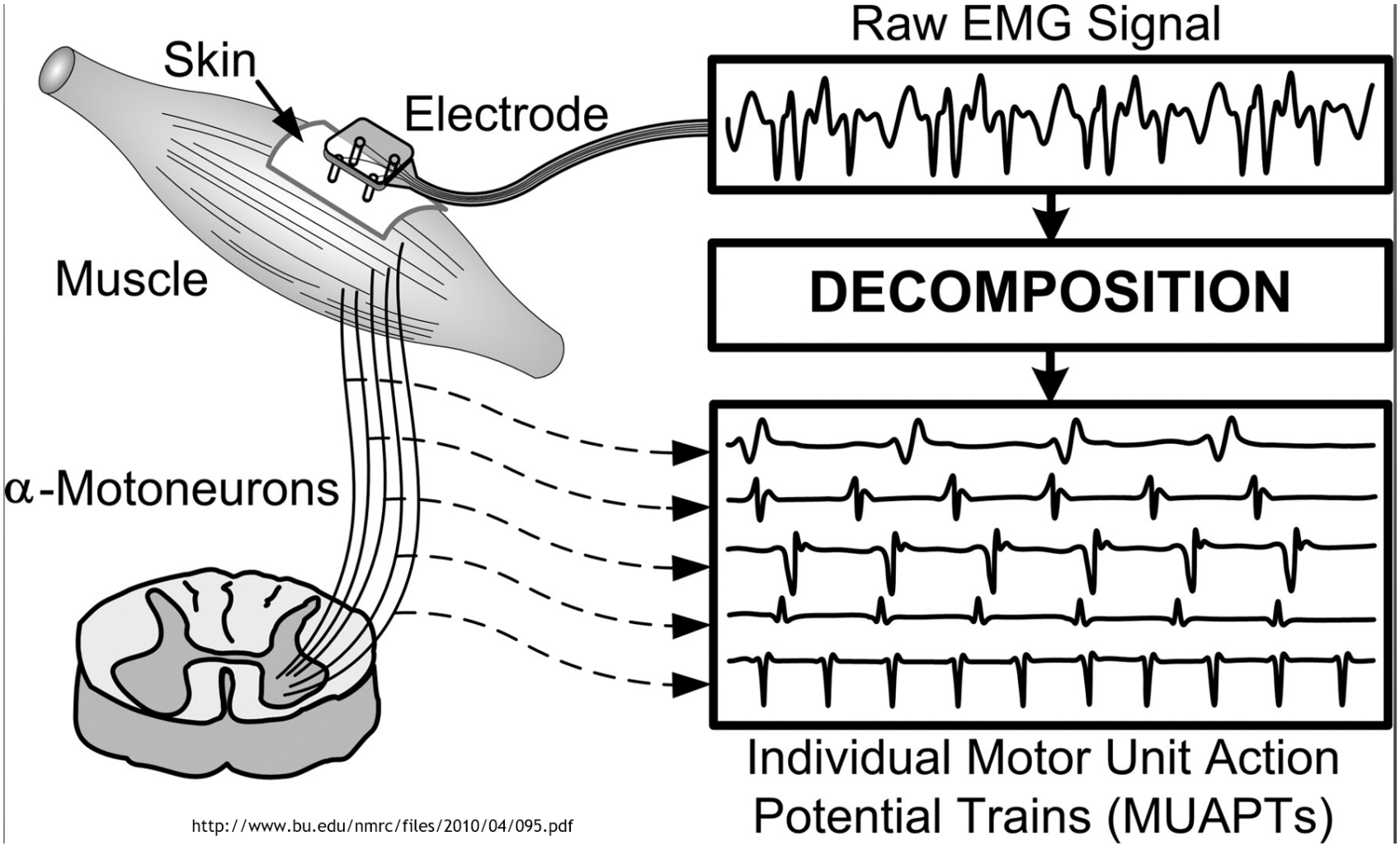


EMG Signal formation by superimposing 25 different MUAPs

https://www.delucafoundation.org/download/bibliography/de-luca/books_muscles-alive-03.pdf

- EMG signals are composed by superimposing motor unit action potentials (MUAPs) from several motor units.
- Different motor units tend to have different characteristic shapes
  - But MUAPs recorded by the same electrode from the same motor unit are typically similar.
  - MUAP size and shape depend on where the electrode is located with respect to fibers, so positioning my change the apperance.

The Motor Unit Action Potential



Section 3

Neuromuscular Disorders

Overview

- Neuromuscular disorders are generally diseases of the peripheral nervous system.
- These disorders can be categorized depending on the location or point of origin.
  - Neuropathies are disorders of the nerves themselves
  - Myopathies are complications with the muscle usually caused by muscle degradation or muscle death

Neuromuscular Disorders

Table Shows Categorization of Neuromuscular Disorders and some Specific Diseases Associated with Each Group

Neuropathy (Mono and Poly)
- Entrapment
- Demyelinating
- Axonal
- Mononeuritis multiplex

Radiculopathy
- Disk herniation
- Spondylosis
- Neoplastic
- Infarction
- Infections
- Inflammatory

Motor neuron disease
- Amyotrophic lateral sclerosis
- Polio
- Spinal muscular atrophy
- Monomelic amyotrophy

Neuromuscular junction disorders
- Myasthenia gravis
- Lambert–Eaton myasthenic syndrome
- Congenital Myasthenic Syndrome
- Botulism

Sensory neuronopathy
- Paraneoplastic
- Autoimmune
- Infections
- Toxins

Plexopathy
- Radiation induced
- Entrapment
- Neoplastic
- Diabetic
- Hemorrhagic
- Inflammatory

Myopathy
- Muscular dystrophy
- Congenital
- Metabolic
- Inflammatory
- Toxic
- Endocrine

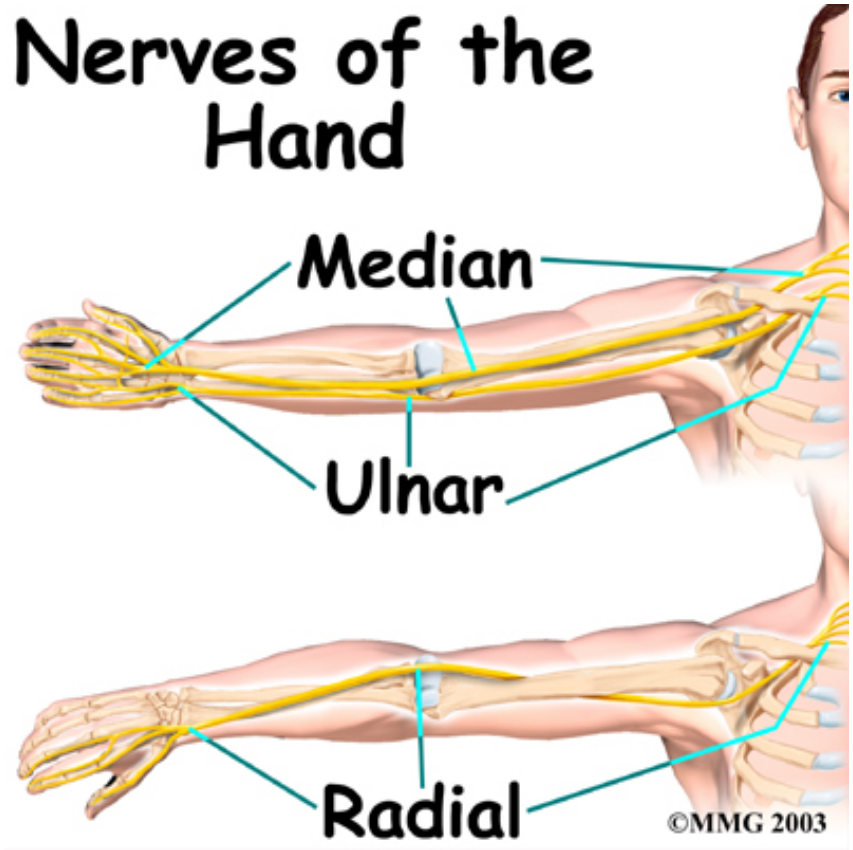
Neuropathy Disorders: Mononeuropathies and Polyneuropathies

- Neuropathic disorders can be categorized into mononeuropathies and polyneuropathies depending on the number of nerves involved:
  - In mononeuropathies, a single nerve is involved causing pain and some disability.
  - In polyneuropathies a group or all of the nerves can be affected.
- In both cases, the nerve is affected either through disease or some form of injury.

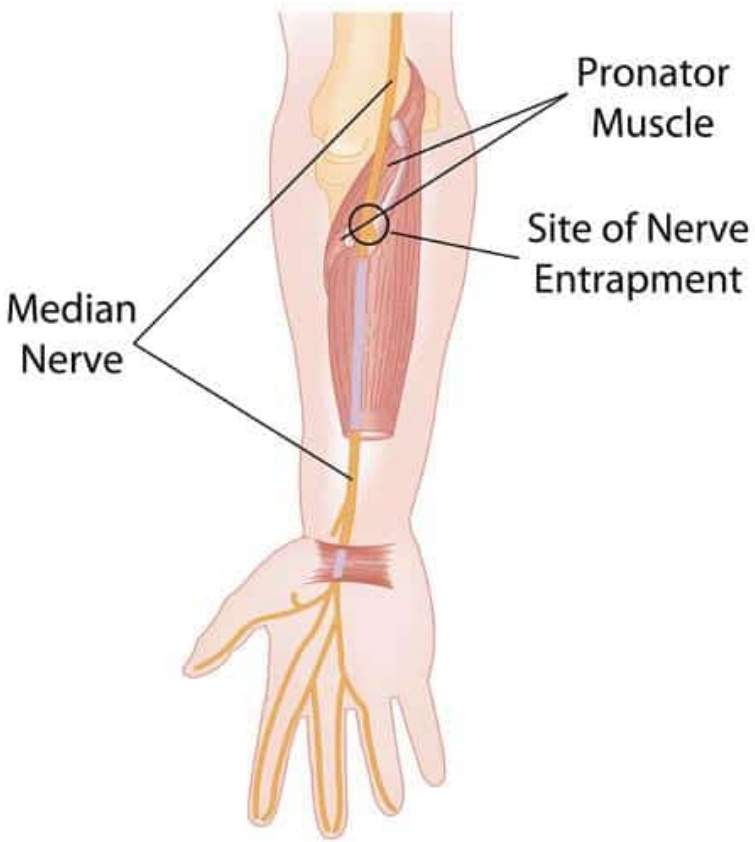
Neuropathy Disorders: Mononeuropathies and Polyneuropathies

- The most common form of mononeuropathy in the upper extremities of the body (arms and hands) is **median nerve entrapment** in the wrist.
- Entrapment means that the nerve is compressed or placed in an abnormal position that disrupts its function.
- The disorder usually occurs in the carpal tunnel of the wrist where the nerve is compressed causing pain and disabling the hand.
- EMG is generally used to differentiate this problem from lesions of the proximal median nerve, brachial plexus, and cervical nerve roots.

Neuropathy Disorders: Nerves Related to Hand



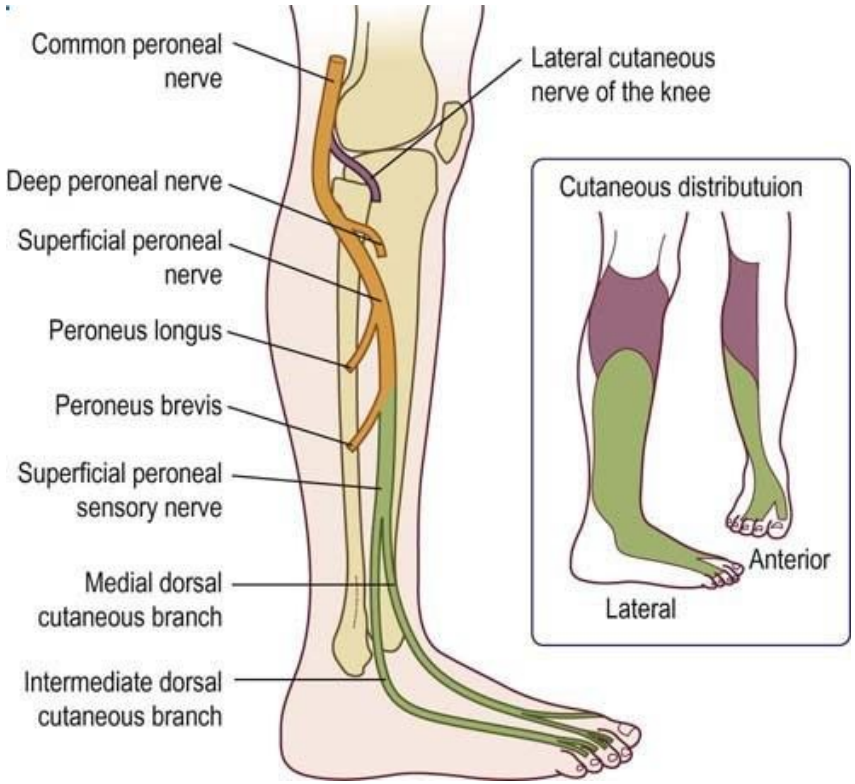
Neuropathy Disorders: Median Nerve Entrapment



Neuropathy Disorders: Mononeuropathies and Polyneuropathies

- The most common disorder in the lower extremities is **peroneal neuropathy**, commonly in the fibular neck of the calf where the peroneal nerve runs.
- Patients with peroneal neuropathy experience sensory disturbances of the calf and foot area usually reporting numbness and weakness.

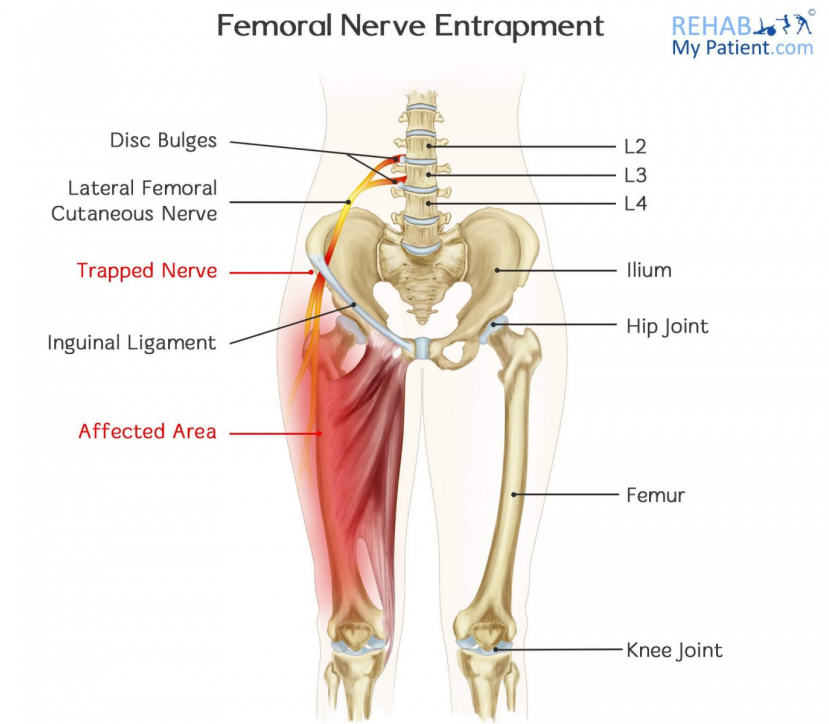
Neuropathy Disorders: Peroneal Neuropathy



Neuropathy Disorders: Mononeuropathies and Polyneuropathies

- Another disorder is **femoral neuropathy**, which is generally not observed in EMG laboratories because the more common lumbar plexus lesions in peroneal neuropathy have a similar appearance.
- Patients with femoral neuropathy usually report buckling knees, difficulty in raising the thigh, dragging of feet, and some numbness and weakness around the thigh and calf.
- Although similar to the carpal tunnel syndrome in the wrist, the tarsal tunnel syndrome is extremely rare and more often observed in older patients.

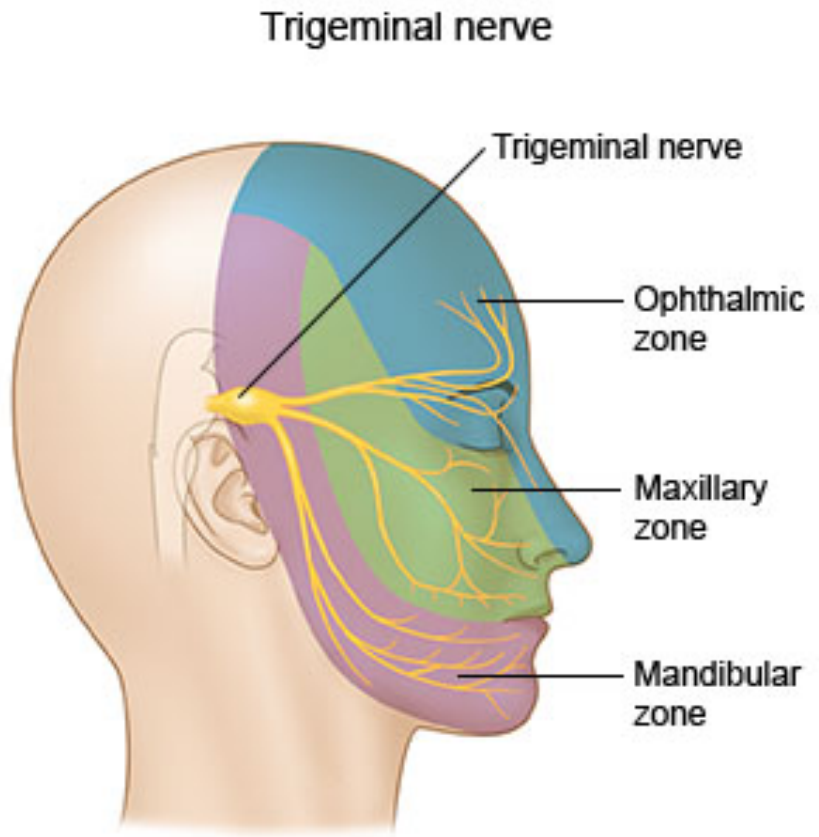
Neuropathy Disorders: Femoral Neuropathy



Neuropathy Disorders: Mononeuropathies and Polyneuropathies

- Mononeuropathies are not restricted to limbs but may also occur in the face and around the cranium (head), which are innervated by several major nerves.
- Although EMG studies are most suited to the study of the limbs, they may also be employed in the investigation of cranial nerves.
- Mononeuropathies afflicting the facial and trigeminal nerves are the most common lesions found.

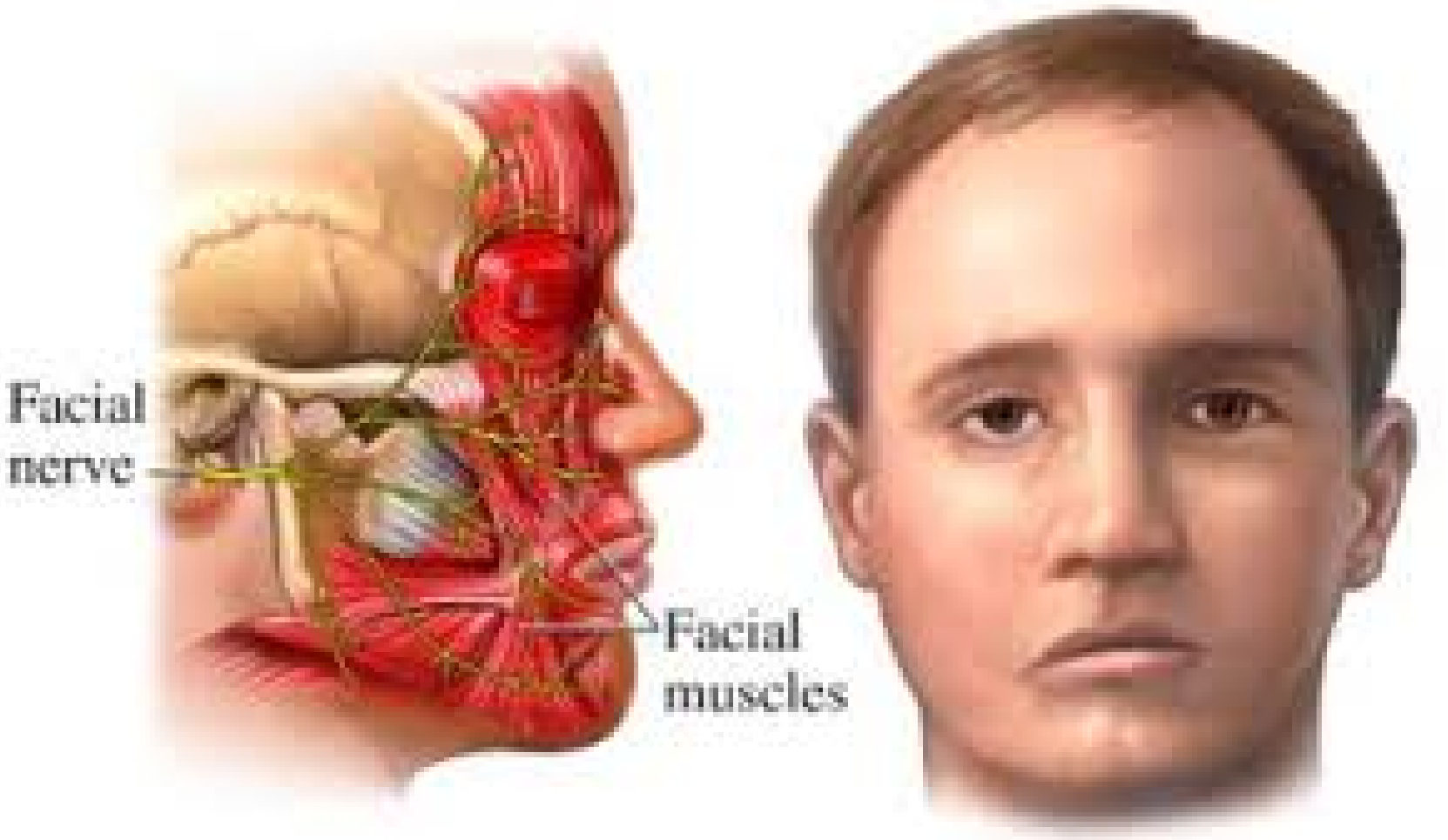
Neuropathy Disorders: Trigeminal Nerve Neuropathy



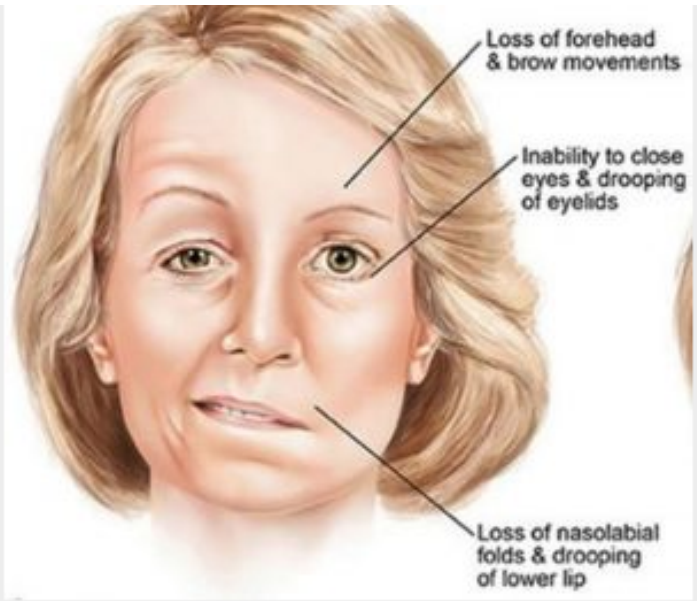
Neuropathy Disorders: Mononeuropathies and Polyneuropathies

- The most common facial mononeuropathy is facial nerve palsy, which generally manifests as the idiopathic Bell's palsy.
- This facial nerve dysfunction is also associated with several disorders such as diabetes, herpes zoster, lymphoma, leprosy, and stroke.
- The symptoms depend on the location, pathophysiology, and severity of the lesion, for example, a central lesion presents as weakness in the lower facial region.

Neuropathy Disorders: Facial Palsy



Neuropathy Disorders: Facial Palsy



https://patient.info/doctor/facial-nerve-palsy

Neuropathy Disorders: Mononeuropathies and Polyneuropathies

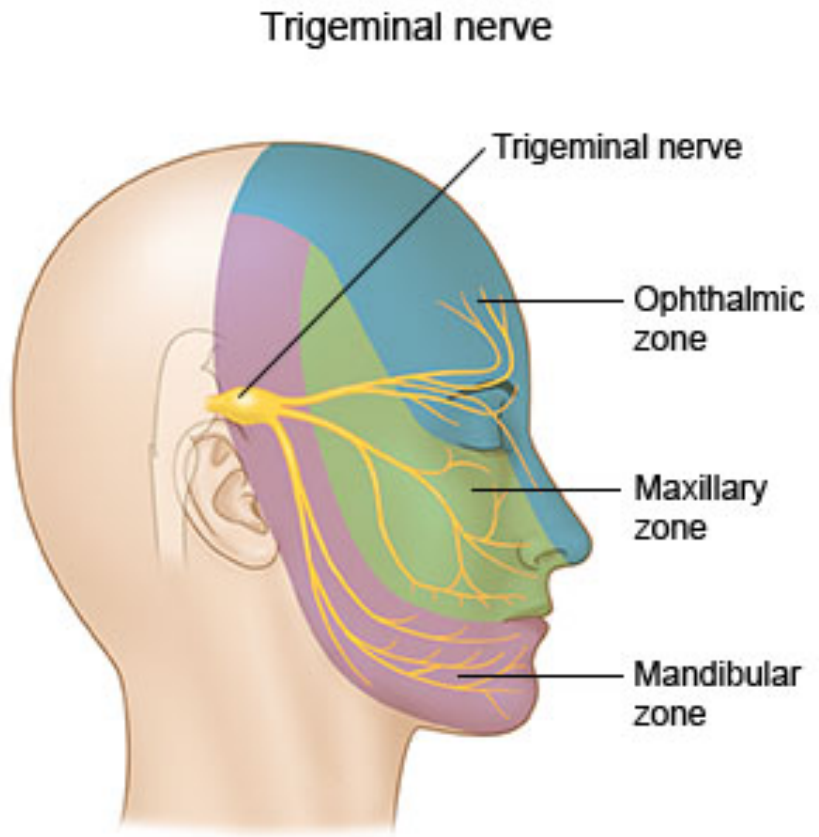
- Compression and injury to the facial nerve can also cause hemifacial spasm, which is characterized by involuntary contractions and spasms in the face.

Neuropathy Disorders: Hemifacial Spasm

Neuropathy Disorders: Mononeuropathies and Polyneuropathies

- Trigeminal neuropathy is another disorder affecting the trigeminal nerve (cranial nerve V), which is responsible for carrying nerveimpulses to the face and motor fibers.
- Damage or dysfunction in this nerve causes numbness over the ipsilateral face and difficulty in opening the mouth or chewing.
- Trigeminal neuralgia is a less common disorder where severe pain is present in one or more branches of the trigeminal nerve and can be triggered by a light touch or brushing of the facial skin causing acute pain.

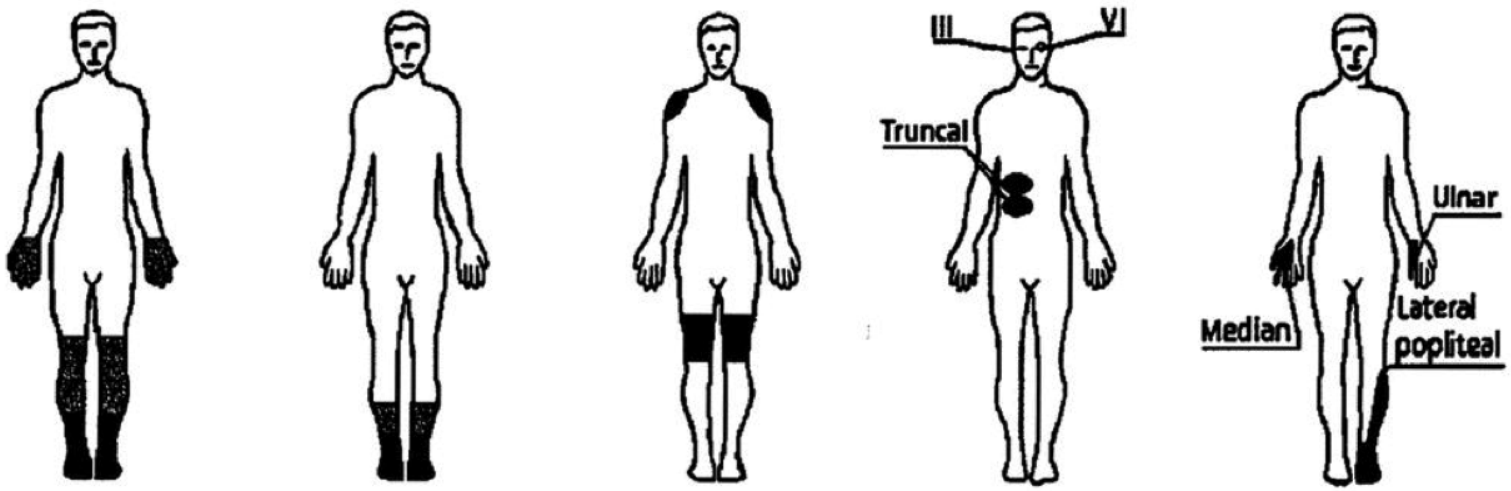
Neuropathy Disorders: Trigeminal Nerve



Neuropathy Disorders: Mononeuropathies and Polyneuropathies

- Although mononeuropathies are the result of injury to a single nerve, polyneuropathies arise from disorders in a nerve bundle or a whole group of peripheral nerves.
- Examination of the nerve fibers involved and the fiber size can help pinpoint the etiology; however, EMG is of limited usefulness because patients with pure small fiber polyneuropathy have normal electrophysiological characteristics.

Neuropathy Disorders: Polyneuropathy

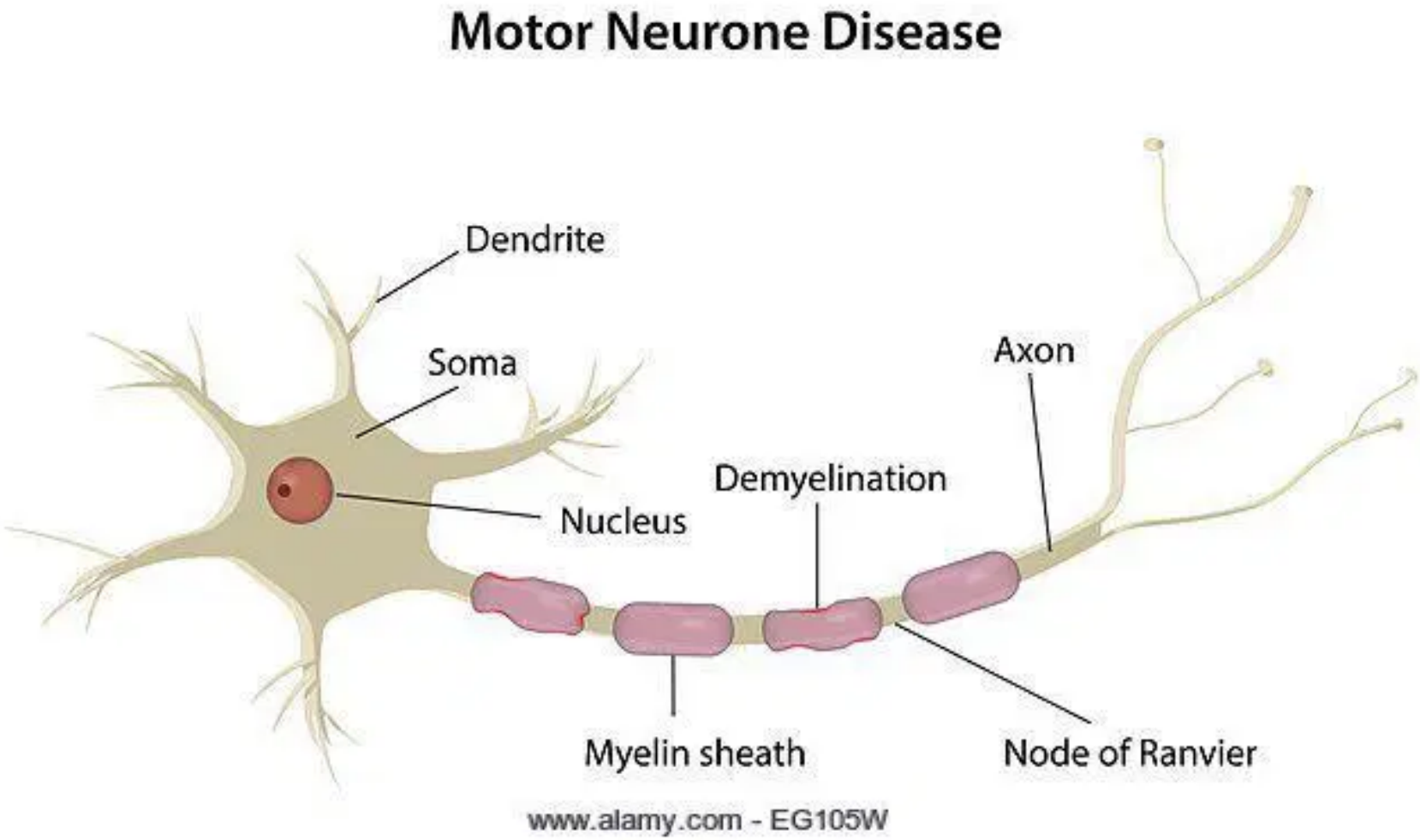


Large fiber Neuropathy	Small fiber Neuropathy	Proximal motor Neuropathy	Acute mono Neuropathies	Pressure Palsies
Sensory loss: 0→ +++ (Touch, vibration) Pain: + → +++ Tendon reflex: N → ↓↓↓ Motor deficit 0 → +++	Sensory loss: 0 → + (thermal , allodynia) Pain: + → +++ . Tendon reflex: N → ↓ Motor deficit: 0	Sensory loss: 0 → + Pain: + → +++ Tendon reflex: ↓↓ Proximal Motor deficit: + → +++.	Sensory loss: 0 → + Pain: + → +++ Tendon reflex: N Motor deficit: + → +++	Sensory loss in Nerve distribution: + → +++ Pain: + → ++ Tendon reflex: N Motor deficit: + → +++

Neuropathy Disorders: Motor Neuron Disease

- Motor neuron disease (MND) designates serious diseases characterized by degeneration of the motor neurons, leading to muscle atrophy and in moresevere cases death.
- EMG readings in these cases show MUAPs with either longer than normal durations, larger amplitudes, or irregular firing patterns.
- These observations are a result of temporal dispersion of action potentials in the area either due to slowed conduction in the nerve fibers or increased conduction in the end plate zone

Neuropathy Disorders: Motor Neuron Disease



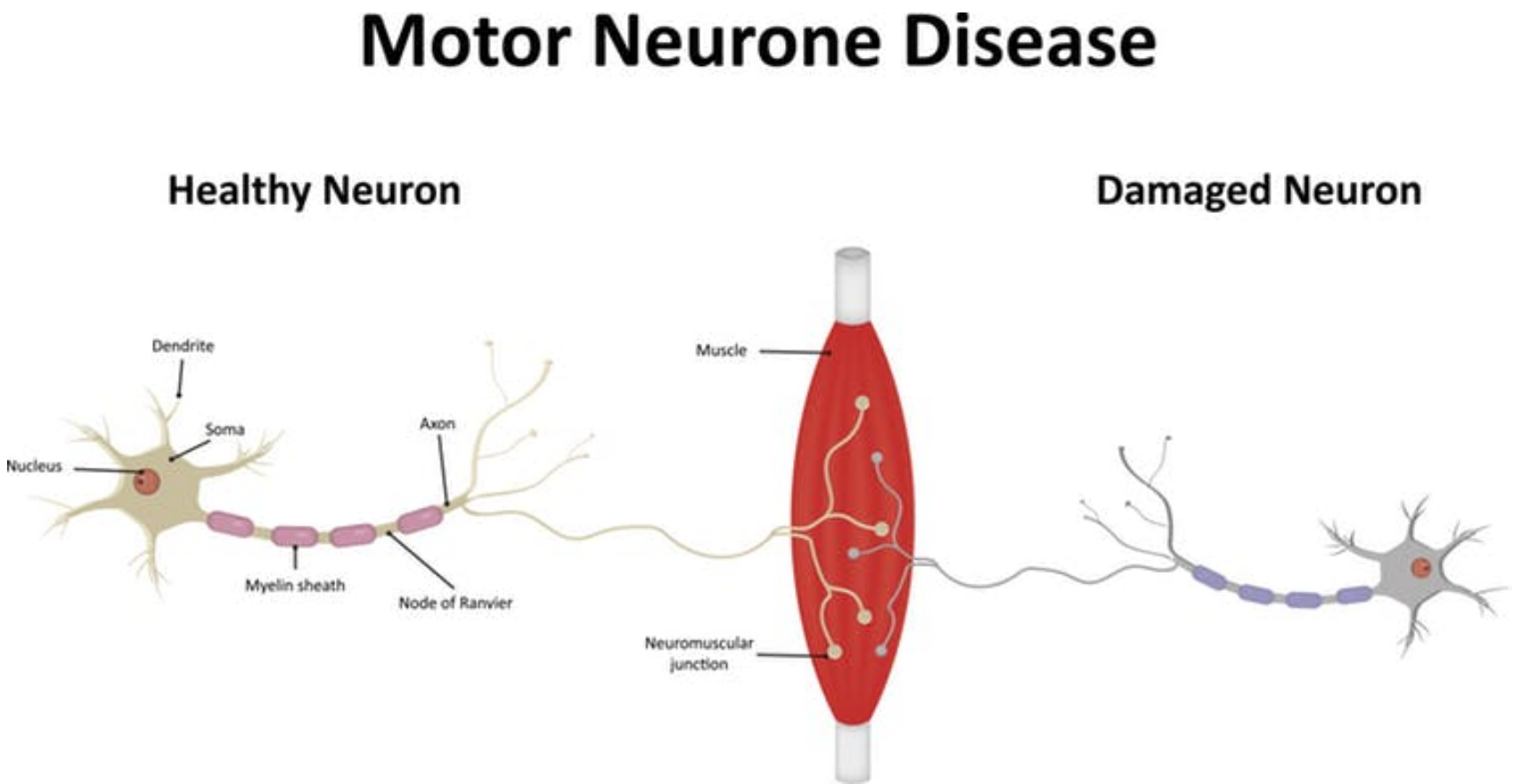
Neuropathy Disorders: Motor Neuron Disease

- The most common form of MND was first described in 1869 by French neurologist Jean-Mertin Charcot
- This disease is known as **amyotrophic lateral sclerosis** derived from the Greek word **amyotrophic** or "no nourishment to the muscle" and **lateral sclerosis** referring to scarring of the nerves in the lateral spinal column due to nerve death (ALS).
- These observations are a result of temporal dispersion of action potentials in the area either due to slowed conduction in the nerve fibers or increased conduction in the end plate zone

Neuropathy Disorders: Motor Neuron Disease

- ALS unfortunately possesses a uniformly poor prognosis, being fatal in all cases, with death on average of 3 years after onset with approximately 10 percent of patients surviving longer.
- This disease is known as **amyotrophic** The diseases usually affect those above 55 years of age but is sometimes also found in younger children.
- Death usually results from respiratory failure as the nerves controlling the respiratory process die and respiratory control is lost whereas other complications include pulmonary embolus, sepsis, and pneumonia.

Neuropathy Disorders: Motor Neuron Disease



Neuropathy Disorders: Motor Neuron Disease

- Another group of MNDs, less common and less fatal is the atypical MNDs.
- These diseases have similar symptoms to ALS but can be differentiated using EMG studies.
- Infectious atypical MNDs can be secondary to other diseases such as paralytic poliomyelitis, West Nile encephalitis (caused by a single ribonucleic acid (RNA) strand virus carried in mosquitoes), or retroviral disorders (HIV). Rarer disorders include monomelic amyotrophy usually found in younger males, motor neuron injury due to electrical shocks, or radiation and paraneoplastic injury due to certain cancers.
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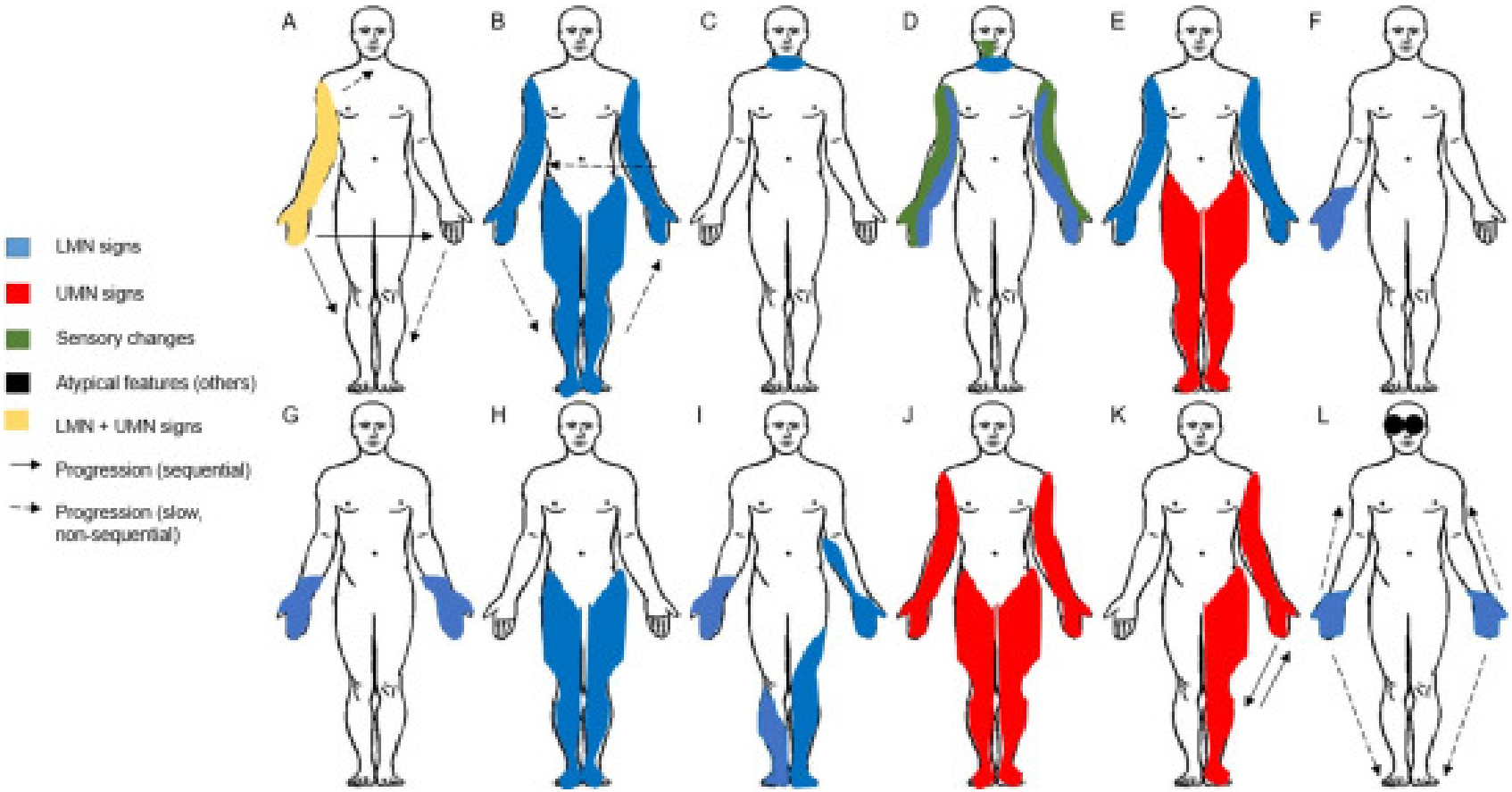
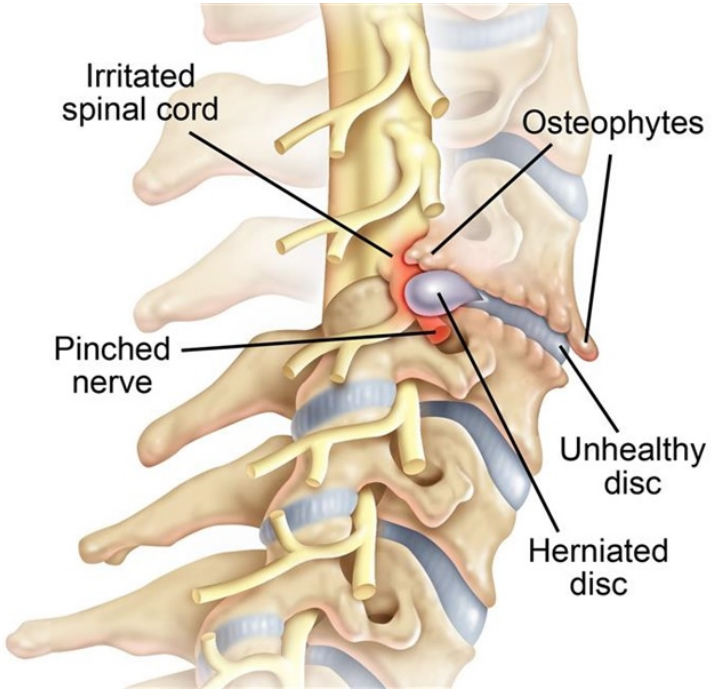
Neuropathy Disorders: Motor Neuron Disease



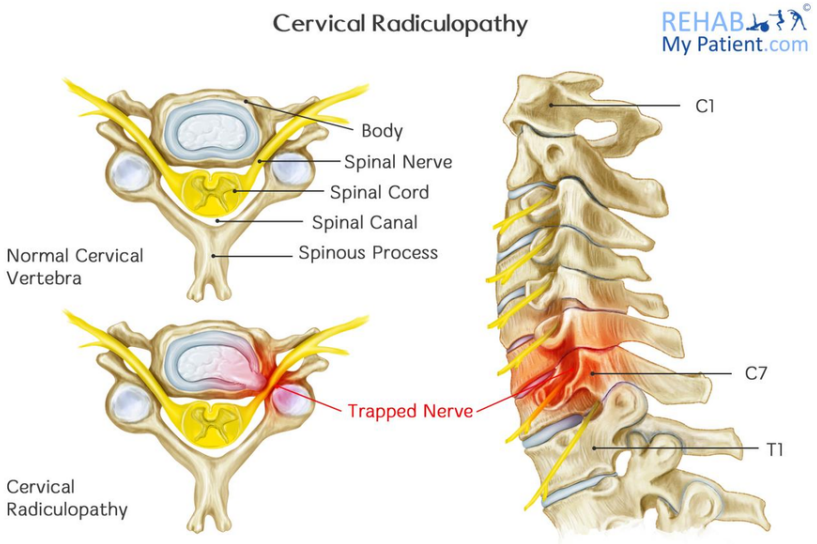
Neuropathy Disorders: Radiculopathy

- A group of disorders that have been successfully referred to EMG study is radioculopathy because imaging studies are inadequate in detecting the etiology.
- Radiculopathy is caused by a degenerative bone and disc disease usually around the cervical and lower lumbosacral segments of the spinal column.
- Disorders in this group are characterized by pain and paresthesis radiating from the nerve root, sometimes accompanied by sensory loss and paraspinal muscle spasm. Sensory loss are minor and rarely develop into frequent sensory disturbances.

Neuropathy Disorders: Radiculopathy



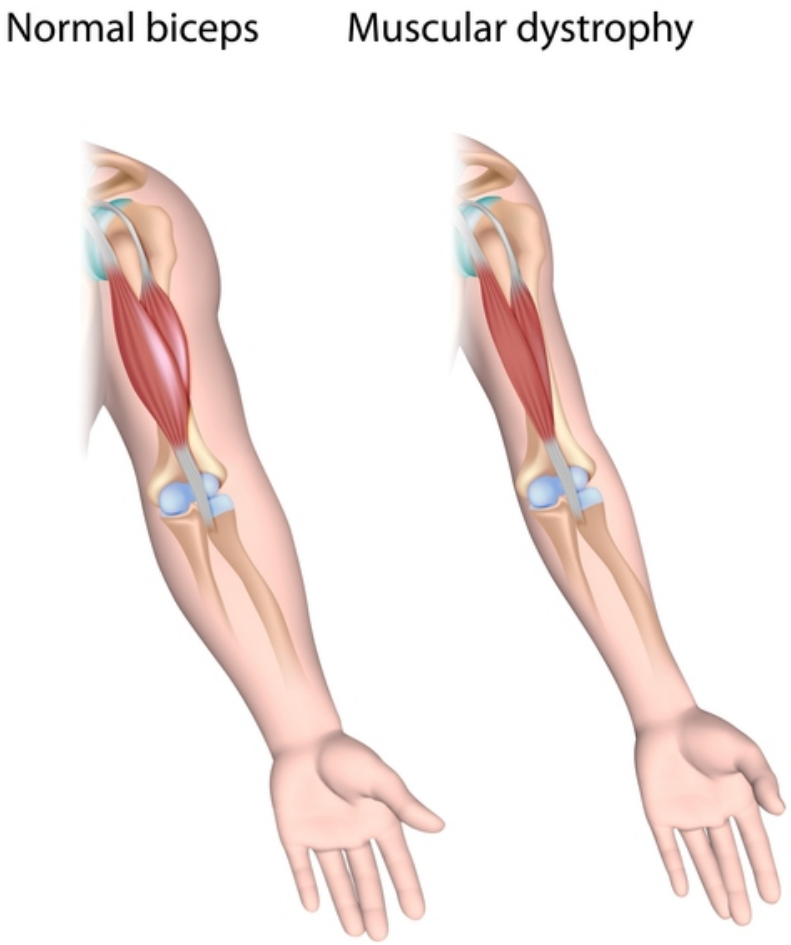
Neuropathy Disorders: Radiculopathy



Myopathy Disorders

- Myopathy disorders are associated with injury to the muscle group itself, usually skeletal muscles.
- The most common form is muscular dystrophy, which results in degenerative muscle states, which also forms one of the major myopathy disorders and it can be either hereditary or acquired.
- EMG readings in these cases are characterized by MUAPs with shorter durations and reduced amplitudes, which are thought to be caused by a decrease in muscle fibers within the motor unit. Sensory loss are minor and rarely develop into frequent sensory disturbances.

Myopathy Disorders



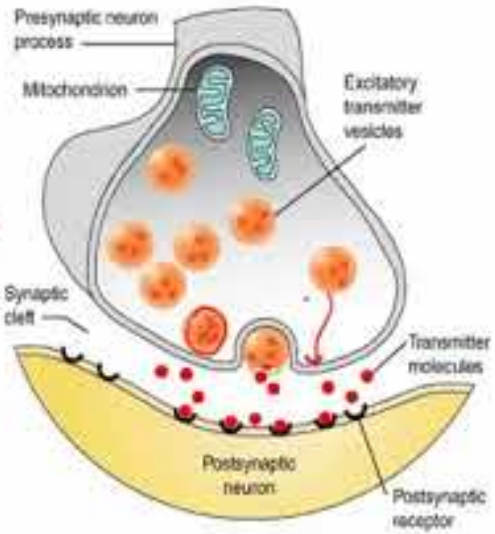
Neuropathy Disorders: Neuromuscular Junction Disorders

- The NMJ acts as an interface for transferring electrical nerve impulse to impulses in the muscle itself.
- Diseases of the NMJ usually disrupt the receptor interaction and inhibit the function of the neurotransmitter acetylcholine.
- EMG readings show distinct instability of the MUAP waveform (jitter) where no two successive waveforms are exactly the same This characteristic is due to instability in the damaged NMJ and can be best detected by single-fiber electromyography (SFEMG).

Myopathy Disorders: Neuromuscular Juntion Problems

Neuromuscular Junction Problems

- Decreased acetylcholine (Ach) release
  - Botulinum toxin blocks ACh release
- Decreased acetylcholine effects on muscle cell
  - Curare is a drug that blocks ACh receptors (poison darts)
  - Myasthenia gravis - autoimmune
- Decreased acetylcholinesterase activity results in acetylcholine having a stronger effect on the muscle cell
  - Organophosphates from pesticides block AChase
  - Several effective drugs increase ACh activity by reducing AChase activity



Section 4

Electromyograph

Electromyography, Electromyograph

Electromyography (EMG) is a diagnostic procedure to asses the health of muscles and the nerve cells that control them (i.e, motor neurons)
Briefly, EMG results can reveal:

- Nerve dysfunction (Neuropathy)
- Muscle dysfunction (Myopathy)
- Problems with nerve-to-muscle signal transmission

EMG Signal

EMG signal is considered to be a complex signal since it's affected by:

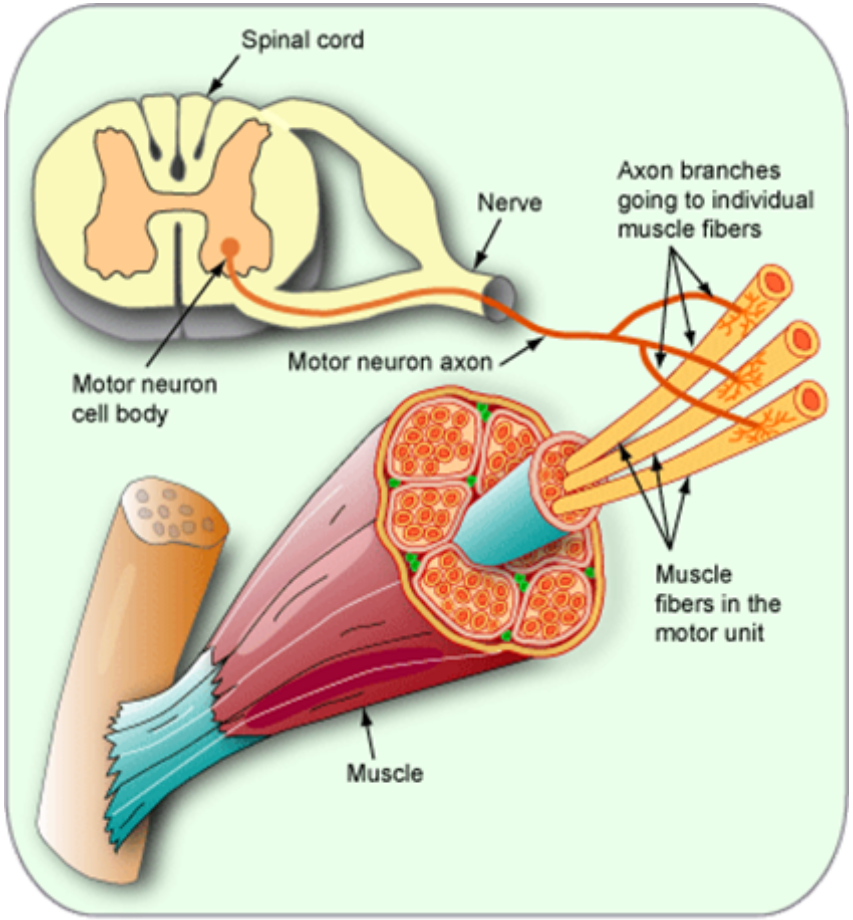
- Anatomical and physiological properties of the muscle
- Control scheme of the peripheral nervous system
- Characteristics of the recording instrument

EMG Keywords

- Electromyography is the technique.
- Electromyograph is the instrument that records.
- Electromyogram is the name of the record produced by the instrument.

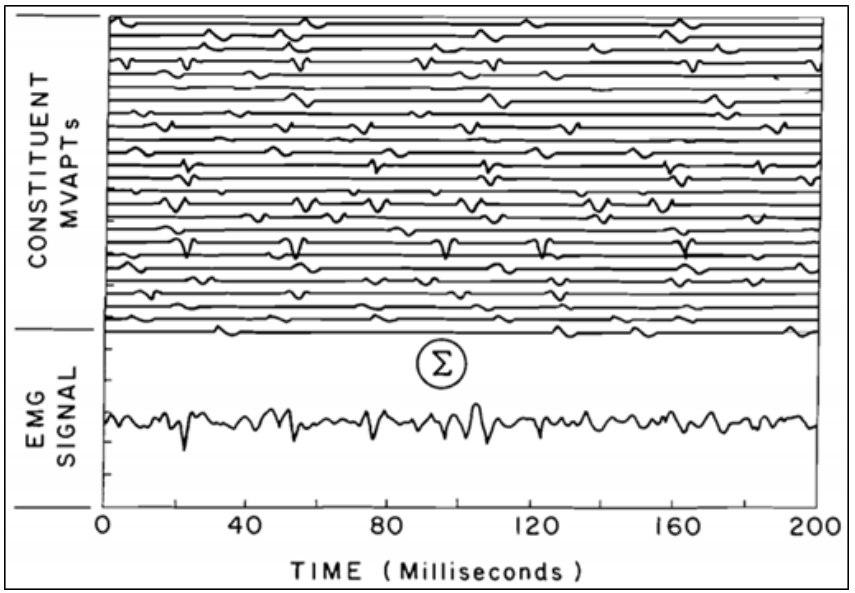
Motor Unit Action Potential

- Motor unit (MU) represents the anatomical and functional element of the neuromucular system.
- MU is formed by the alpha spinal motor neuron and its innervated set of muscular cells.
- Activity of the MU generated electrical charges are called motor unit action potentials (MUAP).

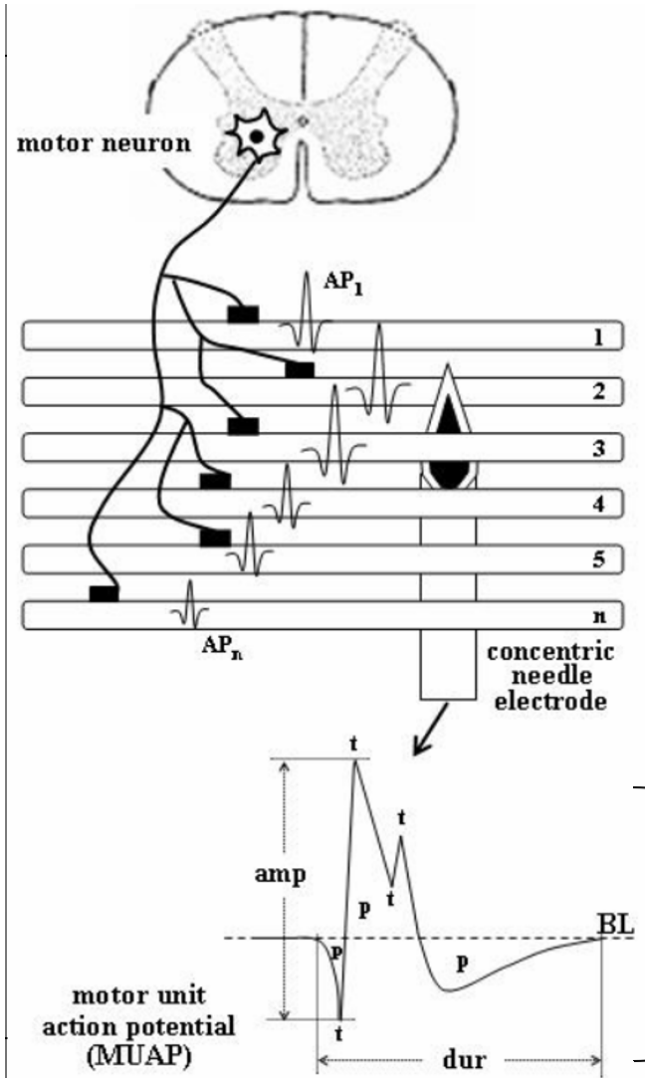


Formation of EMG Signal

- EMG signals are composed by superimposing MUAPs from several motor units.
- Different motor units tend to have different characteristics.
  - MUAPs recorded by the same electrode from the same motor unit are typically similar.
  - MUAP size and shape depend on where the electrode is located WRT fibers, so positioning may change the appearance.



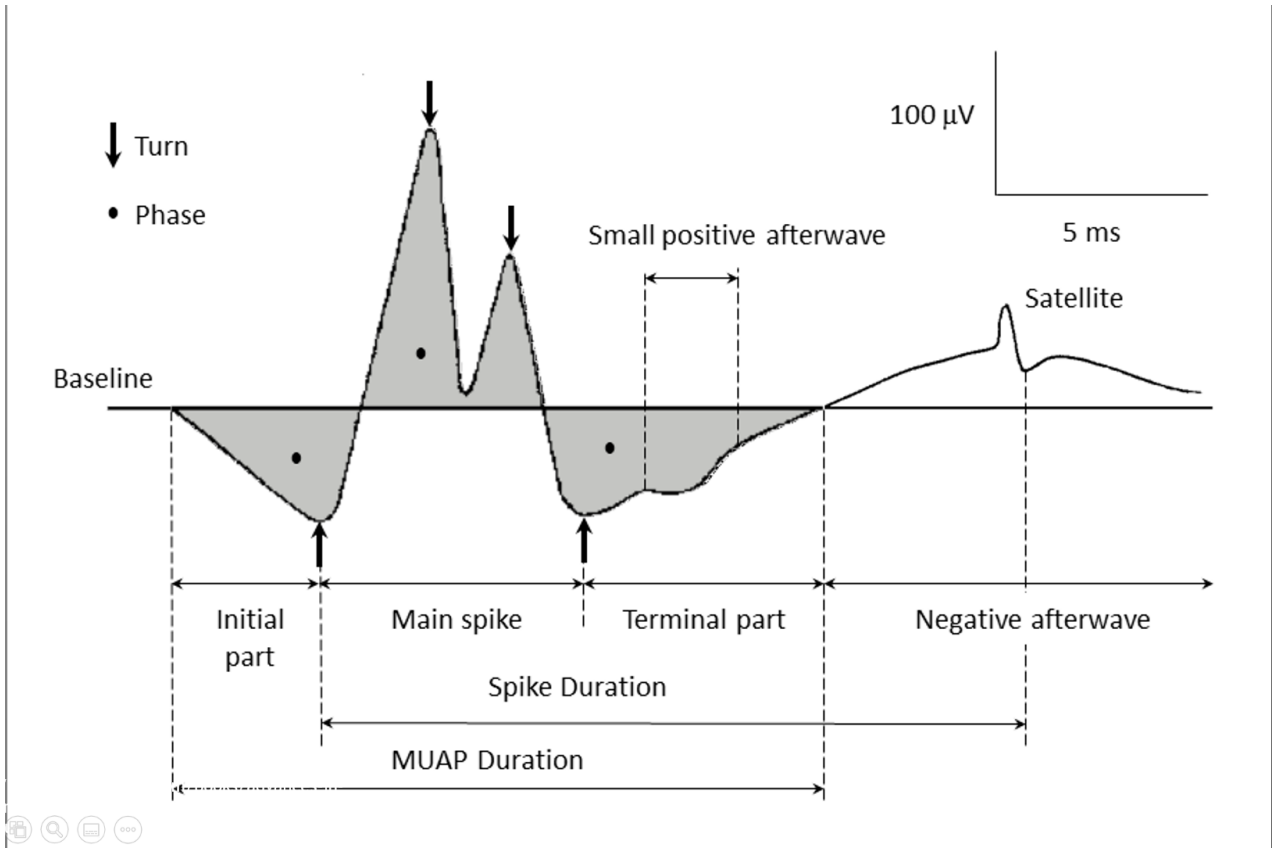
Formation of EMG Signal - MUAPs



The algebraic summation of the action potentials (AP) of all the single fibers present in the recording uptake area of the electrode (AP1+AP2+...+APn) generates the motor unit action potential (MUAP).

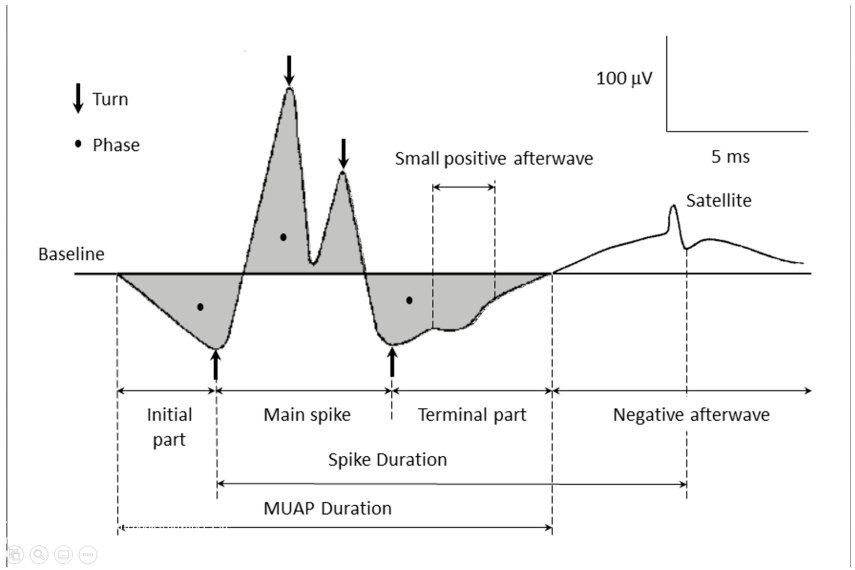
The main parameters of the MUAP waveform are indicated: amp = amplitude; dur = duration; p = phase; t = turn. BL = baseline.

Formation of EMG Signal - MUAPs



Motor Unit Action Potential

- Phase: The part of a MUAP that falls between two baseline (BL) crossings
- Turn: Peak (i.e. a point of directional change) in a MUAP waveform
- Normal MUAPs have simple shapes between two and four phases.
- Polyphasic MUAPs have more than four phases, and those with more than five turns are called polyturn or complex MUAPs.



Types of EMG

- Two main types of EMG exist depending on invasiveness:
  - Surface EMG (sEMG) (non-invasive)
    - Gelled electrodes
    - Dry electrodes
  - Intramuscular EMG (invasive)
    - Needle electrodes
    - Fine-wire electrodes

Types of EMG - Electrode Types

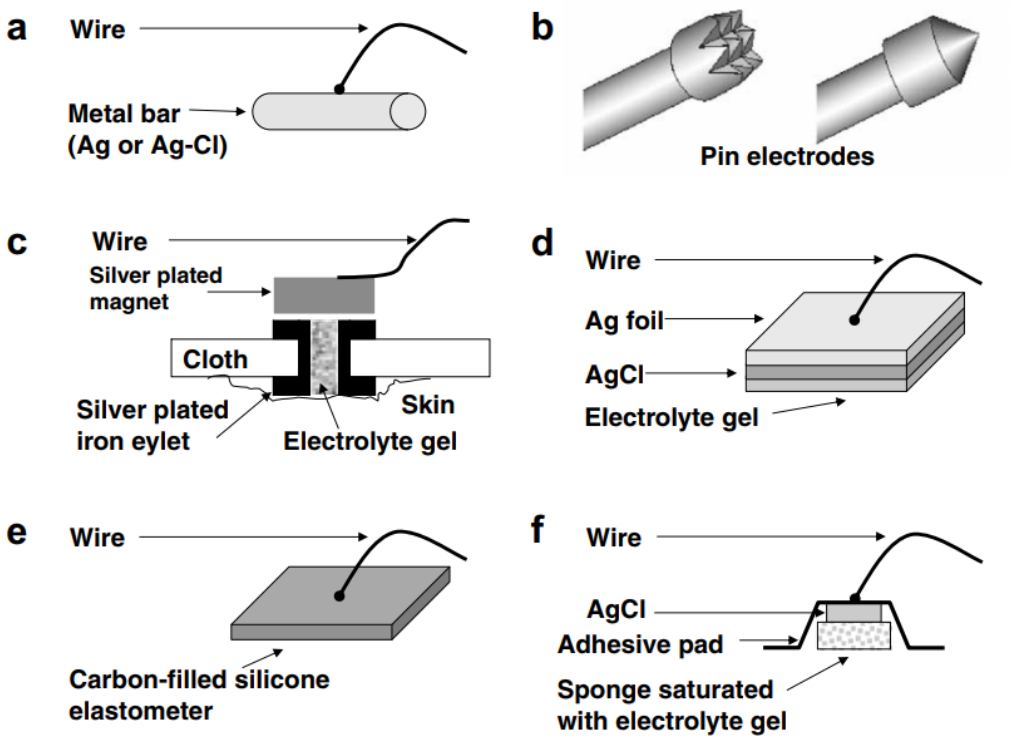


Fig. 1. Examples of surface electrodes for EMG recordings: (a) solid metal bar electrode (dry); (b) pin electrodes (dry); (c) eyelet on cloth with magnetic connector (wet or dry); (d) disposable Ag–AgCl electrode (wet); (e) carbon-filled elastomer electrode (dry); (f) disposable electrode with sponge saturated with an electrolyte gel (wet).

Electrode Impedance, Noise and DC Voltage

- Electrode-skin impedance behavior and properties are addressed in papers dealing with the use of surface electrodes in biopotential recordings:
  - The electrode–skin interface represents the boundary between two media and can be modeled by a non-linear RC circuit
  - Components depend on frequency and current
  - Distinguishing electrode-electrolyte and electrolyte-skin interferance is important.
  - Impedance values depend on:
    - Time
    - Electrode materials
    - Composition of the gel
    - Electrode size
    - Surface structure
    - Skin treatment

Electrode Impedance, Noise and DC Voltage

- In general, a correct procedure of measurement of the electrode–skin impedance should consider the entire sEMG bandwidth (10–500 Hz).
  - Currents in the range of pArms to a few nArms
  - sEMG voltage is in the range of uVrms to a few mVrms
  - Input impedance of the sEMG amplifier is in the range of hundreds of MOhm

Electrode Impedance, Noise and DC Voltage

- Noise level of the electrode is also important.
- The metal–electrolyte interface is intrinsically noisy because of the different charge carriers in the two phases.
- At frequencies above 100 Hz, the surface electrode noise resulted equal to the thermal noise generated by the electrode–skin resistance, whereas at low frequencies (f ¡ 100 Hz) the noise of the skin-electrode interface was significantly greater with respect to the thermal noise
- Spectral characteristics of electrode–skin noise showed a 1/f behavior for very low frequencies (f ¡ 30 Hz), whereas at higher frequencies the sEMG amplifier noise was dominant.

Electrode Impedance, Noise and DC Voltage

- In general, Ag–AgCl electrodes present the lowest noise interface and are recommended for sEMG recording
- Also the level of the electrode–skin noise significantly depended on the skin treatment, so a slight skin abrasion is recommended for decreasing both the noise and the impedance values.
- Usually, noise level of 1–2 uVrms may be attributed to the electronics and 1–4 uVrms to the electrode–skin interferance.
- Contact impedence may range from a few kOhm to a few MOhm. Depends on:
  - Electrode size (larger = lower impedence and noise)
  - Skin condition

Models of Impedance

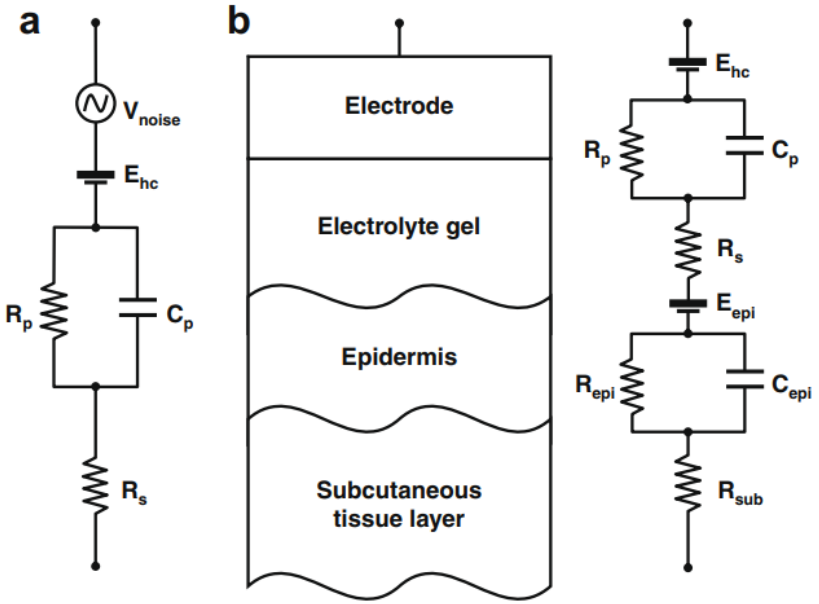
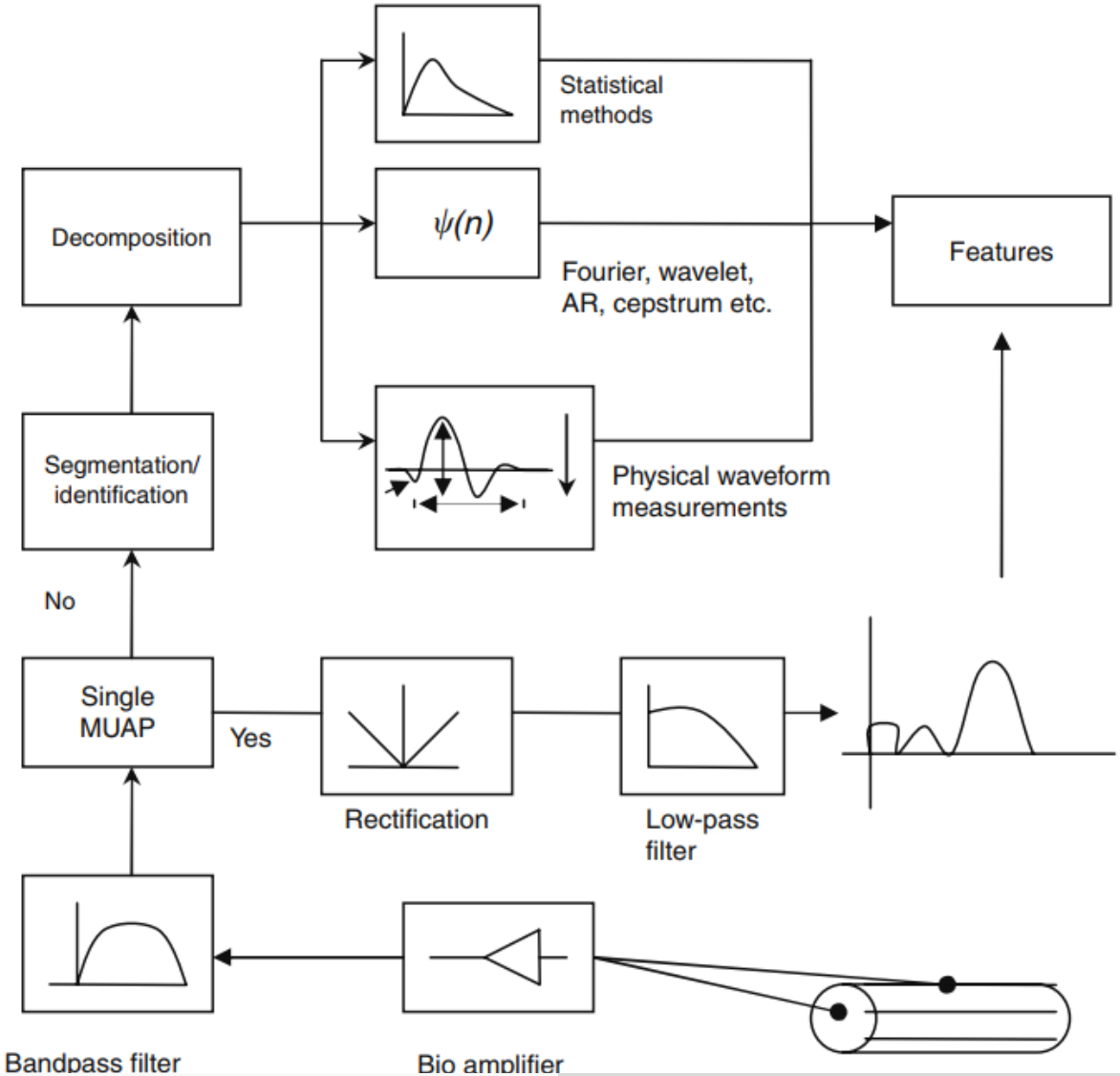


Fig. 2. Models of the electrode–skin impedance: (a) simplified electrical model of the electrode–gel interface: E_{hc} is the half-cell potential at the metal–electrolyte junction, the parallel R_pC_p takes into account the polarizability and the capacitive behavior of the junction, R_s describes the resistive behavior of the electrolyte gel, V_{noise} is the associated noise component; (b) generalized model of the electrode–skin interface. The electrode–electrolyte junction described in (a) is expanded in order to take into account the effect of the conductive gel (R_p, C_p, and R_s) and the electrolyte-skin interface. E_{epi} is the half-cell potential due to differences in the ionic concentrations between the gel and the superficial layer of the skin, the parallel $R_{epi}C_{epi}$ characterizes the skin impedance, and R_{sub} is the resistive component associated to the subcutaneous tissue layer. Equivalent noise generators are not indicated for simplicity but are present at all interfaces. Redrawn and adapted from Neuman (1998a).

EMG Signal Acquisition

- EMG signals are recorded via electrodes.
- For diagnosis, suspected area of disorder is chosen.
- EMG signals are recorded, amplified, filtered and finally digitized.
  - Electrode size (larger = lower impedence and noise)
  - Skin condition

EMG Signal Acquisition



EMG Signal Acquisition

- The recording is made as close as possible to the source of the action potential.
- The amplitude of the recording depends on the electrode proximity to the target muscle group and also the distance between the recording electrodes
- The recording can be influenced by other volume-conducted near-field potentials such as compound MUAPs and sensory nerve action potentials.

EMG Signal Acquisition

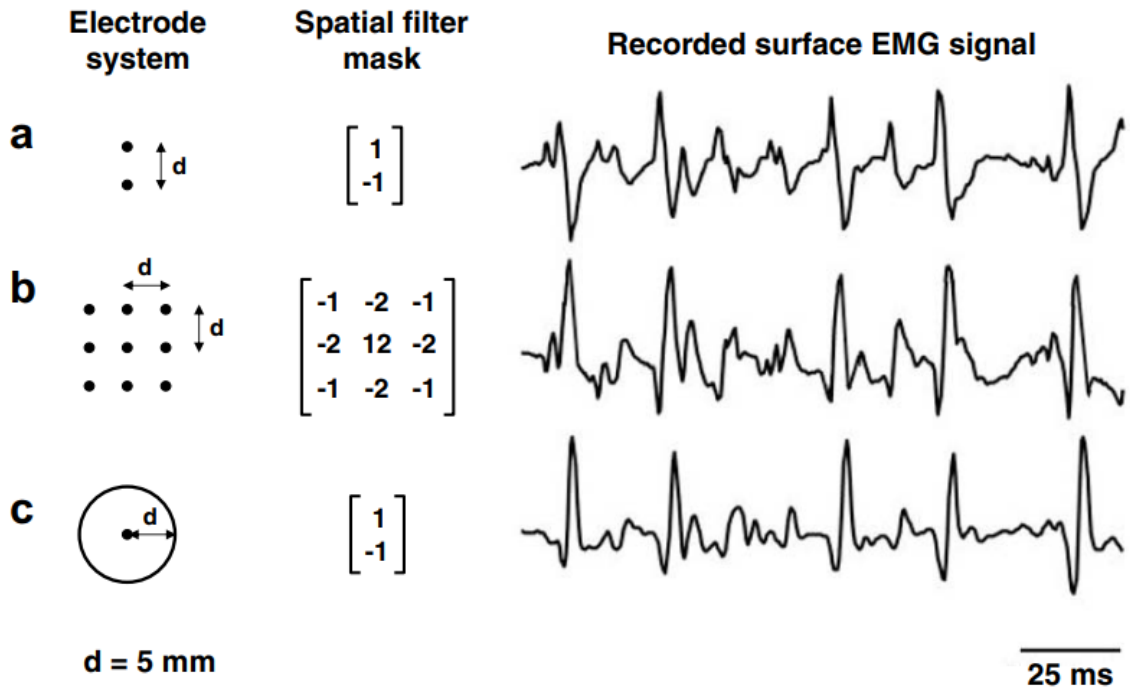
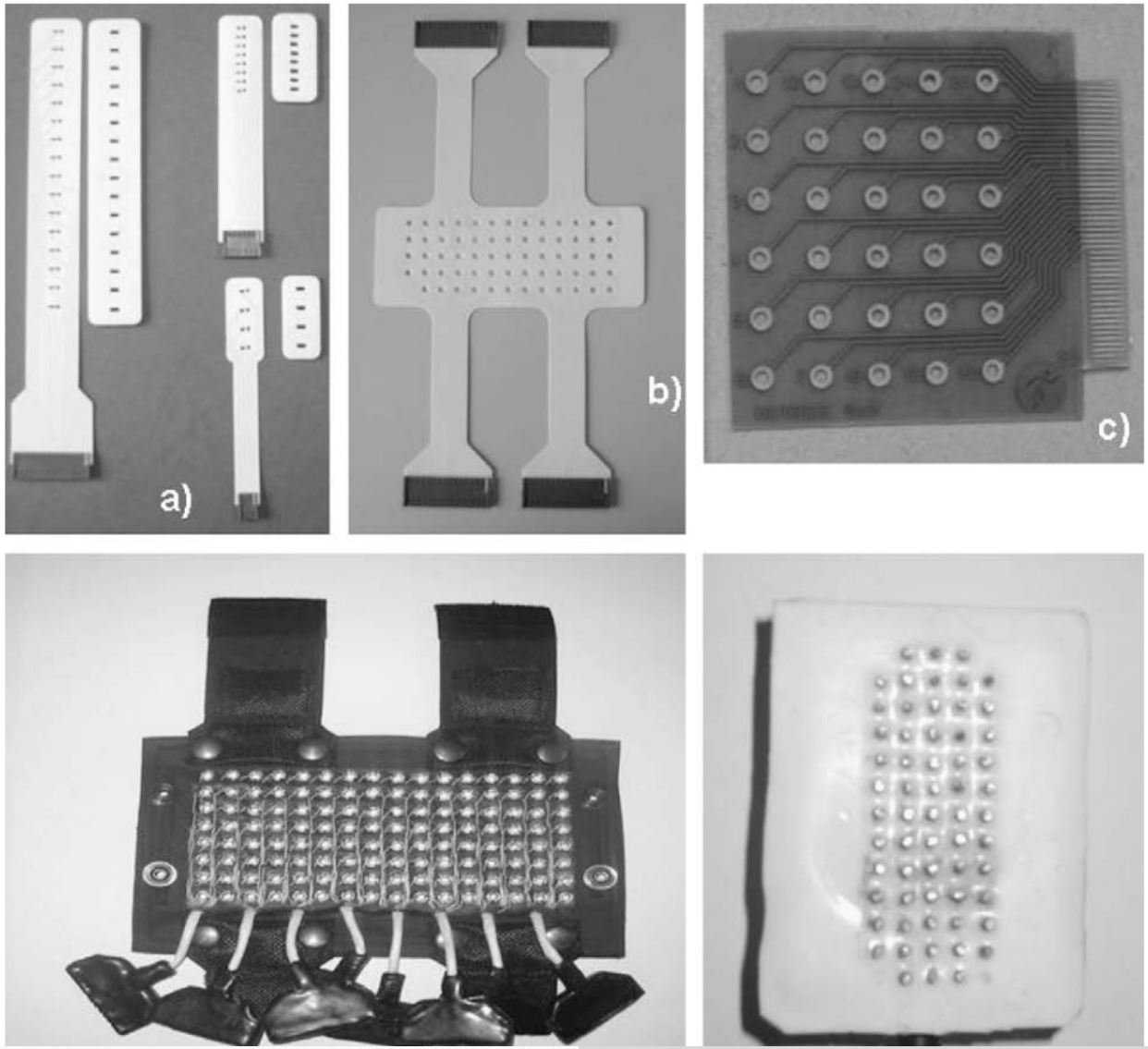


Fig. 4. Examples of sEMG signal recorded, during the same contraction, with different spatial filter configurations: (a) single differential system; (b) inverse binomial f the second order (IB^2); (c) single ring concentric electrode system. In all cases, the interelectrode distance was 5 mm. The greater spatial selectivity of the concentric ele system with respect to the other systems is evident. Redrawn and adapted from Farina and Cescon (2001).

EMG Signal Acquisition



EMG Signal Acquisition

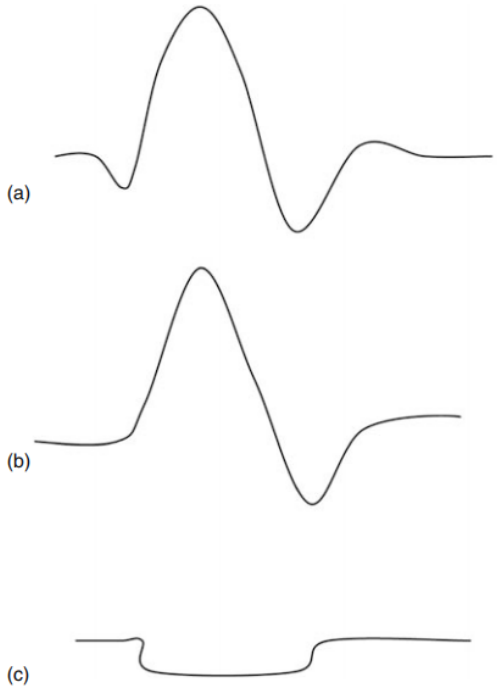


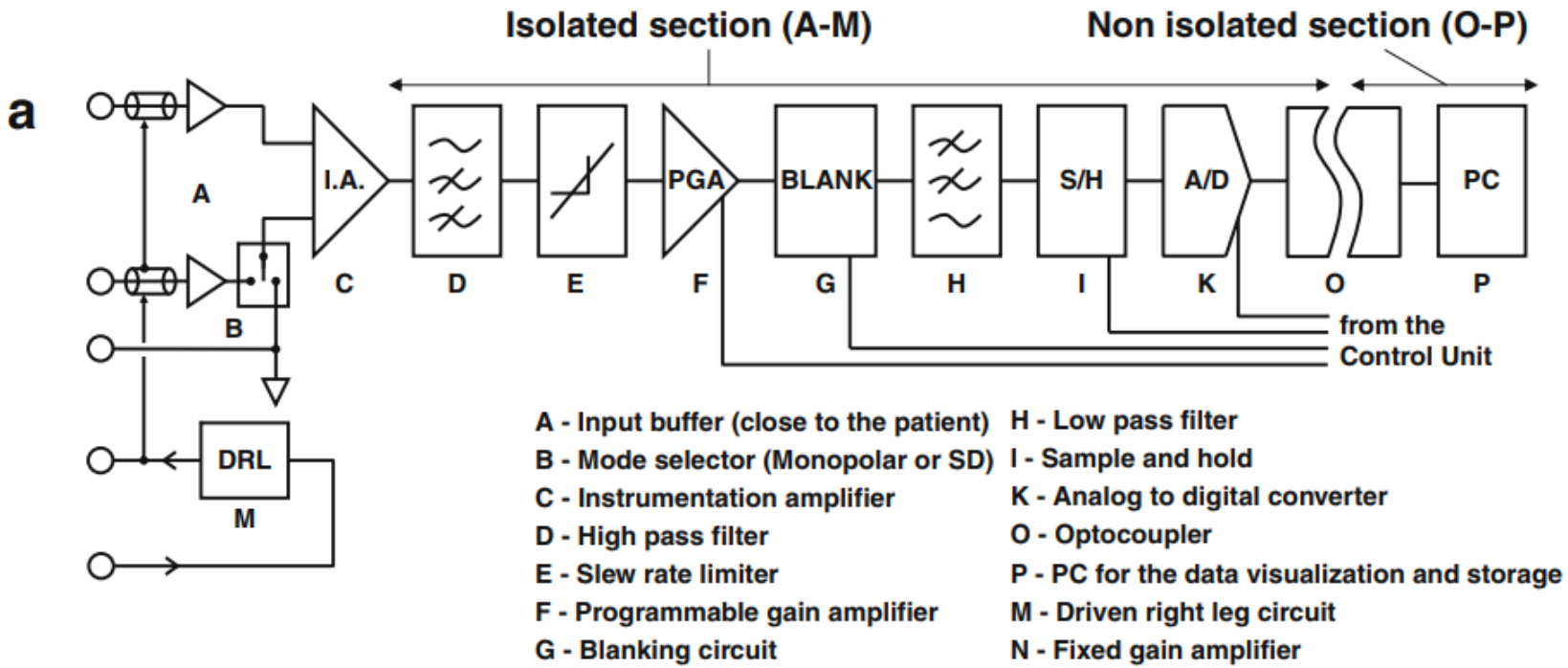
FIGURE 5.19
(a) Waveform morphology for a triphasic action potential. Initially a small positive phase is observed as the action potential approaches, followed by a negative spike when the potential is beneath the electrode. Lastly, a small positive spike signals the wave travelling away from the measuring area. (b) Waveform morphology for a biphasic action potential. The negative spike is observed first because the measuring electrode is directly over the source of the action potential. (c) Waveform morphology for action potential that is far away (far-field wave). EMG records a small positive deflection.

EMG Signal Acquisition

Various info can be gathered from EMG recordings:

- Insertional activity: (1-3) ms, 0.3 mV amplitude. Occurs while initial insertion and movement of needle electrodes
- Spontaneous activity: Abnormal or spontaneous depolarization of muscles without impulse activation.
- MUAP morphology and stability: The shape of the individual MUAPs can provide clues as to the etiology of the disorder
- MUAP recruitment: The number of motor units recruited can measure physical strength and it's useful for detection of neuromuscular disorders.

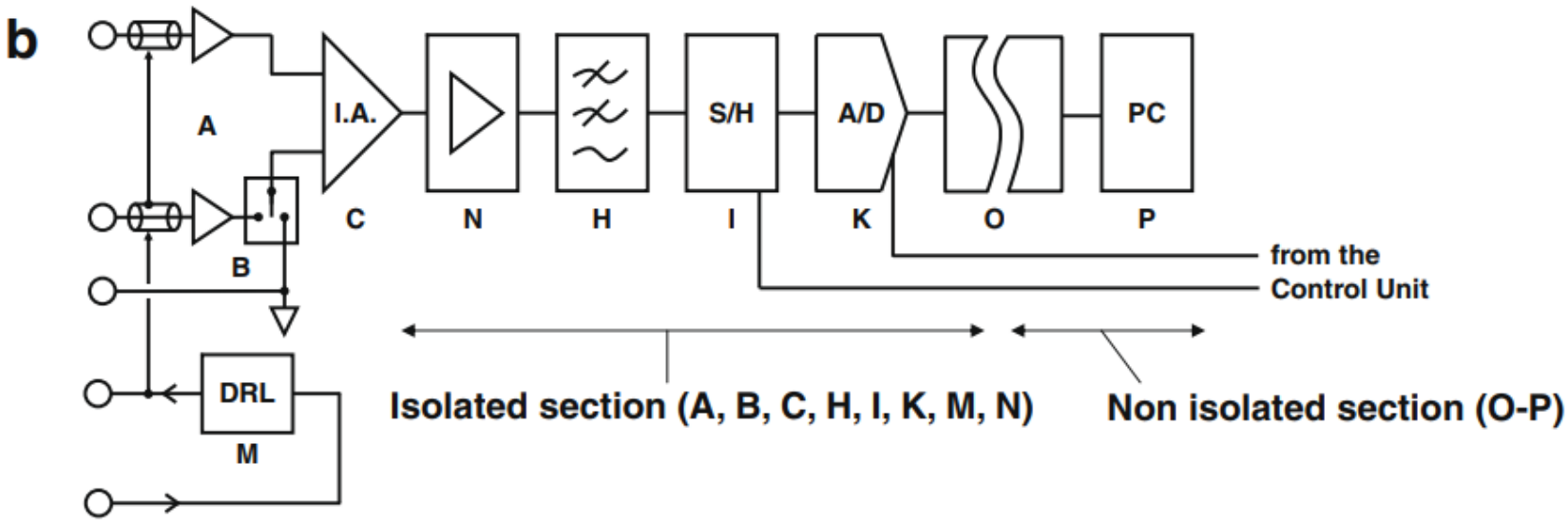
EMG Signal Amplification



EMG Signal Amplification

- Blanking circuit: Forces the detected signal to zero in a time window in which the stimulation is present.

EMG Signal Amplification



EMG Signal Filtering

The signal is first bandpass filtered, sampled, and then low-pass filtered again.

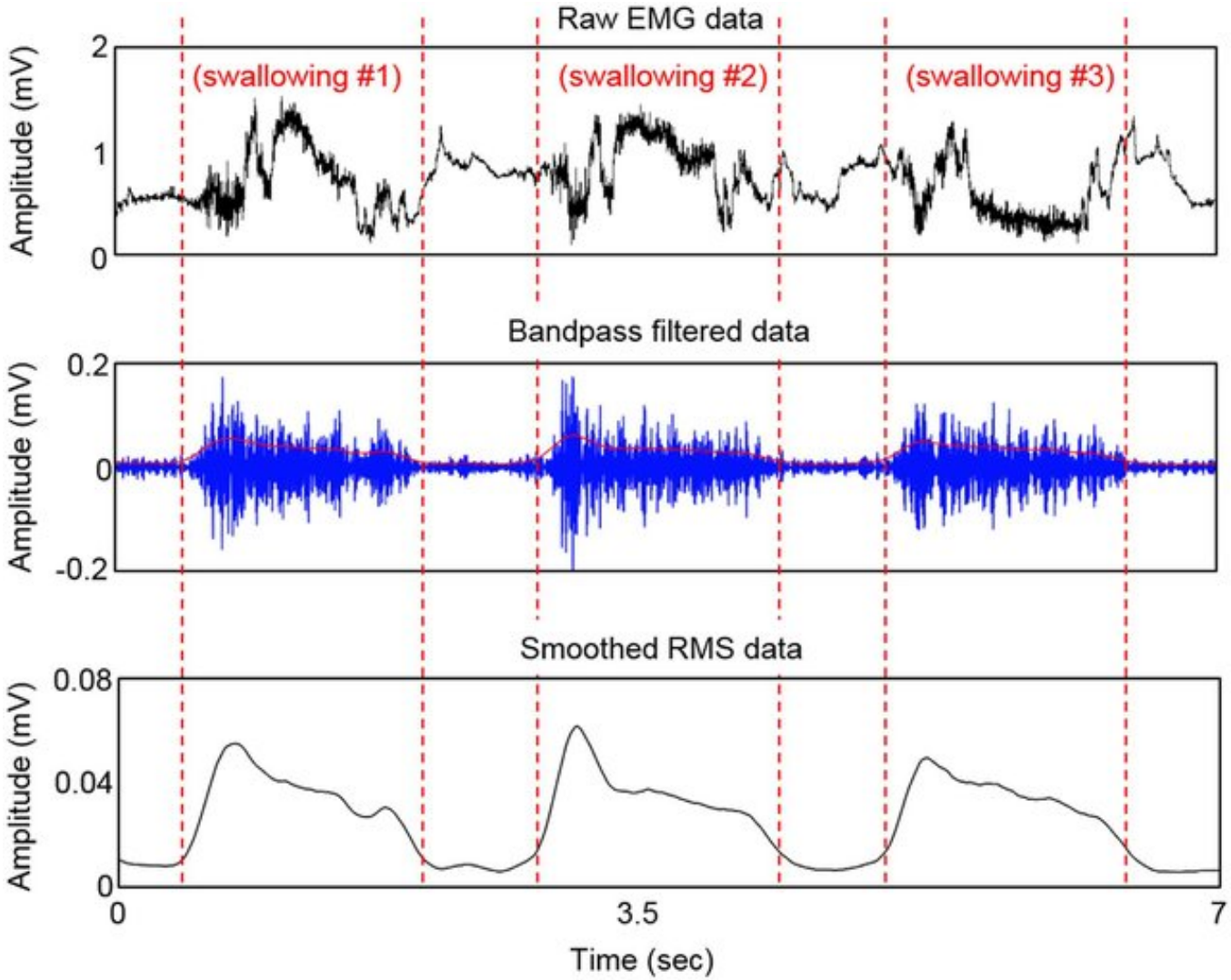
- Butterworth or Chebyshev filters are usually implemented in the instrumentation and there is seldom the need to specify the cutoff or bandpass frequencies.
- Some international journals such as the IEEE Transactions on Biomedical Engineering or the Journal of Electromyography and Kinesiology are, however, strict about the type of filtering and require that these values be reported

EMG Signal Filtering

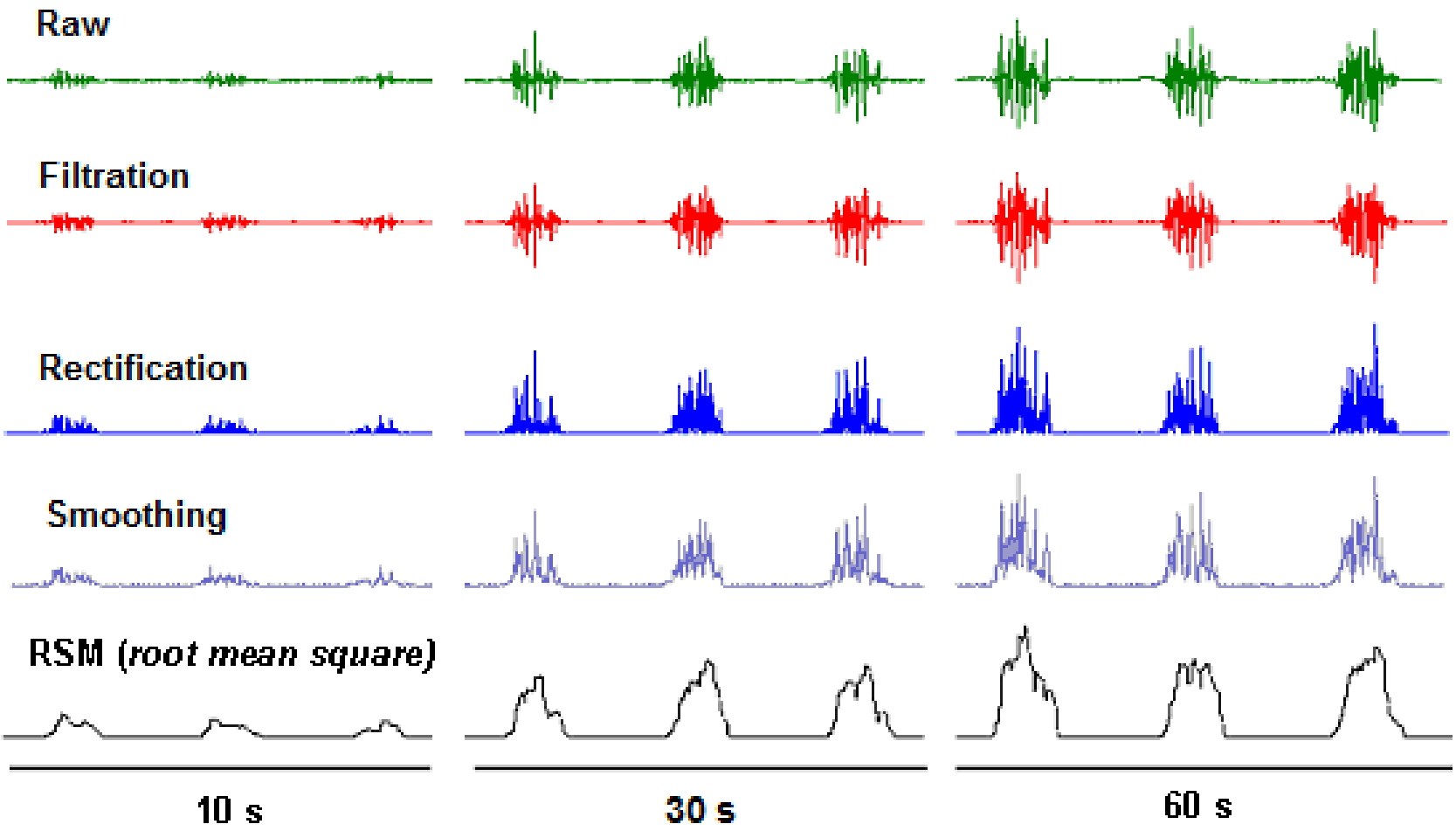
A major portion of power in the EMG signal is known to be contained in the 5–500 Hz frequency range of the power density spectra.

- Surface EMG recordings are preferred to be in the 10–350 Hz band
- Filtering within 10–150 Hz or 50–350 Hz, for example, is not favorable because portions of the signal's power above 150 Hz and below 50 Hz are eliminated.
- Intramuscular recording should be made with the appropriate increase of the high frequency cut-off to a minimum 450 Hz or by applying a bandpass filter of 10–450 Hz.

EMG Signal Filtering



EMG Signal Filtering



EMG Signal Digitization

After the analog signal is collected, amplified, and bandpass filtered, it is digitized and stored on a computer for further processing.

- Sampling is done at the Nyquist rate, which is at least twice the highest frequency cutoff of the bandpass filter.
- For example, if a bandpass filter of 10–350 Hz is used, the minimum sampling rate should be 700 Hz (350 2) or preferably higher to improve accuracy and resolution.
- In some cases, a low-pass filter is used to first smooth the EMG signal such that a lower-sampling rate (50–100 Hz) can be used for digitization
- The raw unfiltered EMG signal can also be stored in the computer using a sampling rate greater than 2.5 kHz.
- The conversion of the analog EMG signal to digital signal can be done by an A/D converter, with a resolution of min. 8 bits.

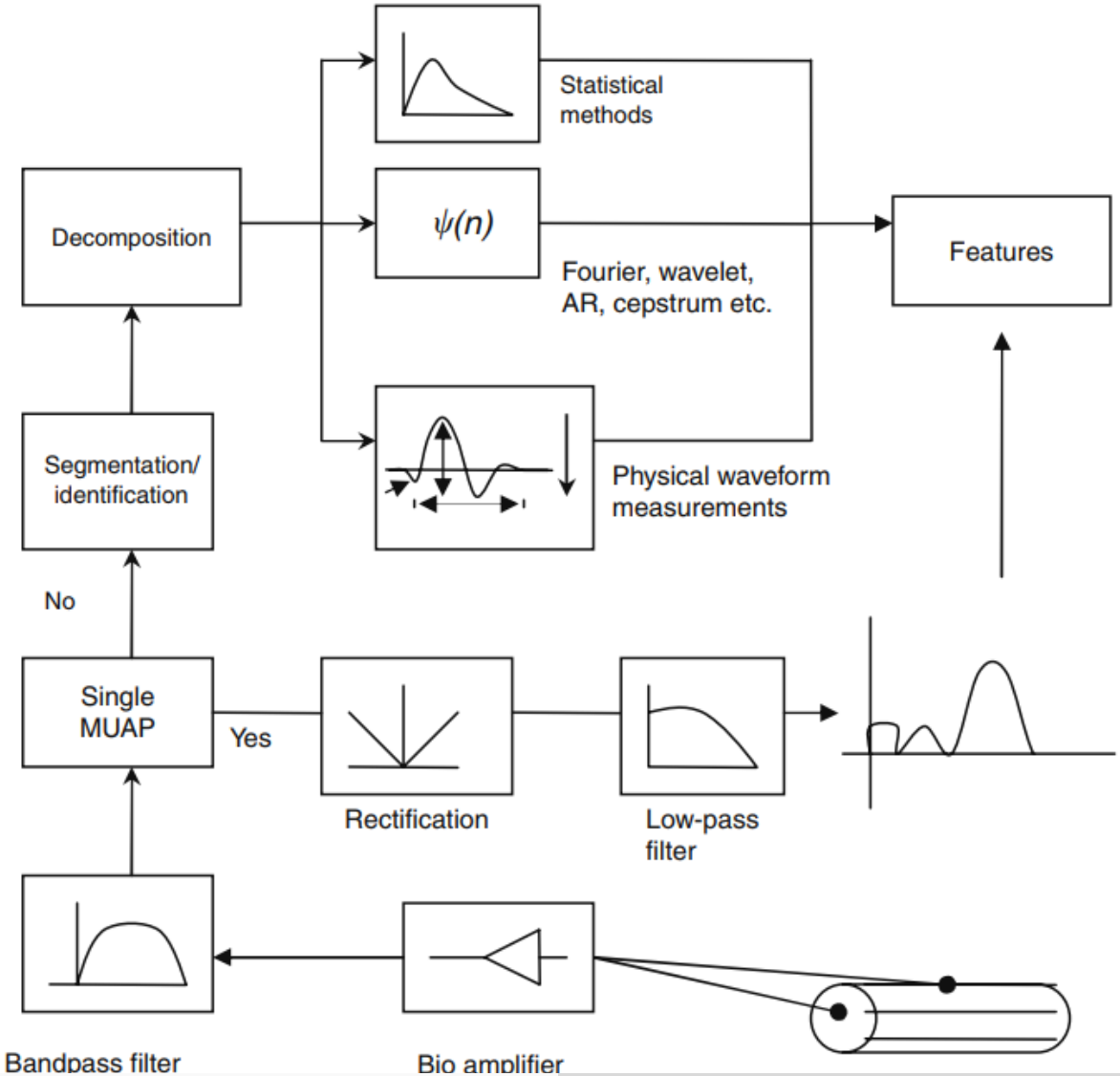
EMG Signal Processing

- Studied since 1950s
- Initially based on analysis of stochastic temporal characteristics and frequency domain power spectra
- Prior to that, traditional methods were used with quantitative analysis performed manually by the physician or electromyographer.

EMG Signal Processing

- The objective is to extract characteristic information from the waveform that may be indicative of a particular muscle action.
- Highlighting special characteristics can infer neuromuscular disorders, muscle strength, and nerve health.
- There are three steps in preprocessing EMG signals to extract important features:
  - Segmentation
  - Decomposition of MUAPs
  - Extraction of waveform characteristics

EMG Signal Acquisition



EMG Signal Processing - Segmentation

- MUAPs occur in fixed intervals during muscle contraction.
- Area of interest in the signal should be located. (Preprocessing)
- This preprocessing reduces the amount of data and noise needs to be processed.
- Noise is everything else except the wanted EMG signal.

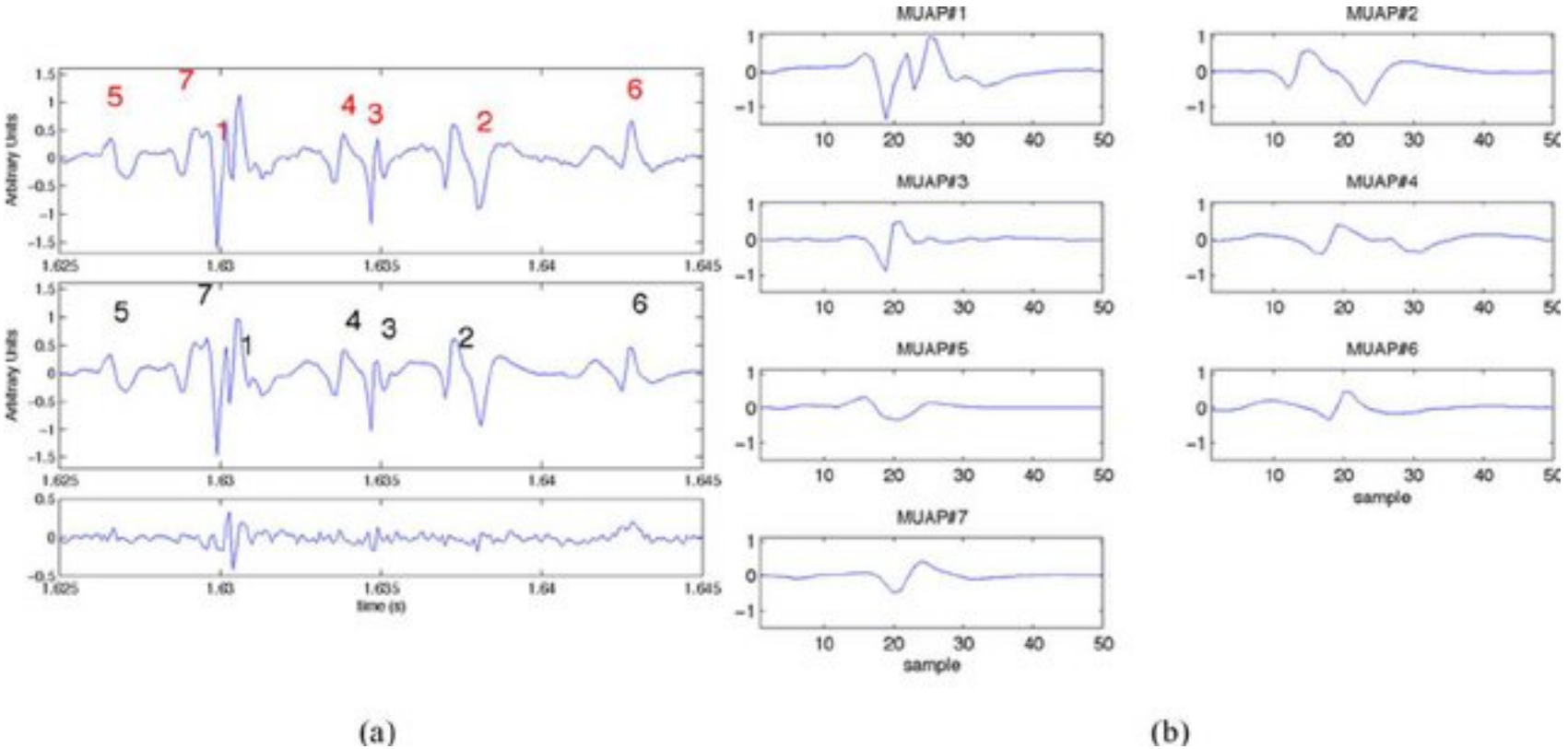
EMG Signal Processing - Segmentation

- First, the signal is usually amplified by a factor of 1000.
- Characteristics of the amplification (type of amplifier, CMRR, SNR) must be noted since the remaining processing steps may require this information.

EMG Signal Processing - Decomposition and Identification of MUAPs

- Complex signal is seperated into individual action potentials.
- This step is usually required in sEMG because of complexity of the MUAPTs originating from effects of adjoining muscles.
- The objective of decomposition is to determine the EMG signals at all levels of contraction, separate reliably and accurately all MUAPs, and to provide an acceptable level of decomposition in the presence of noise.

EMG Signal Processing - Decomposition



(a) (b)

EMG Signal Processing - Decomposition-ICA

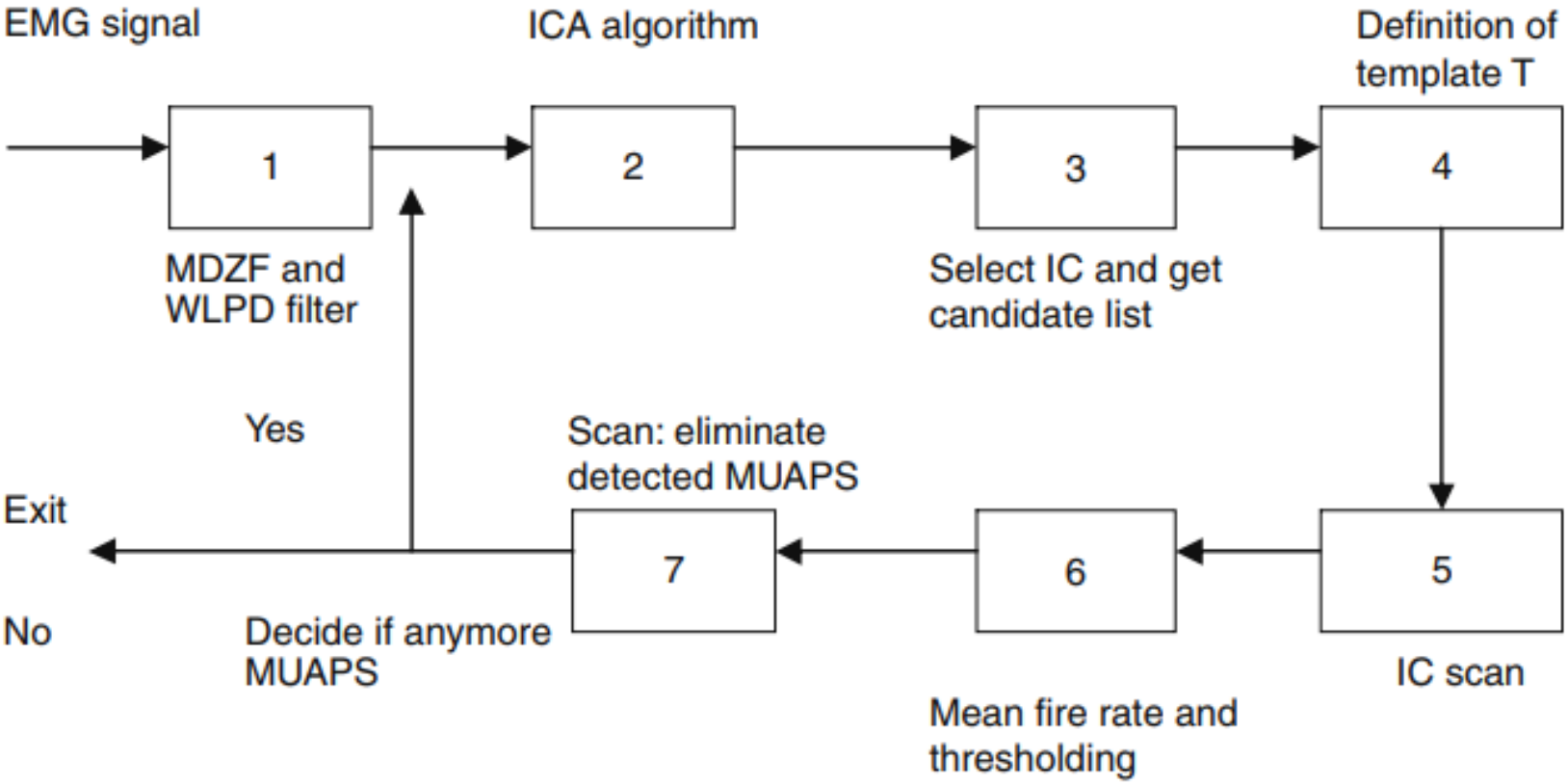
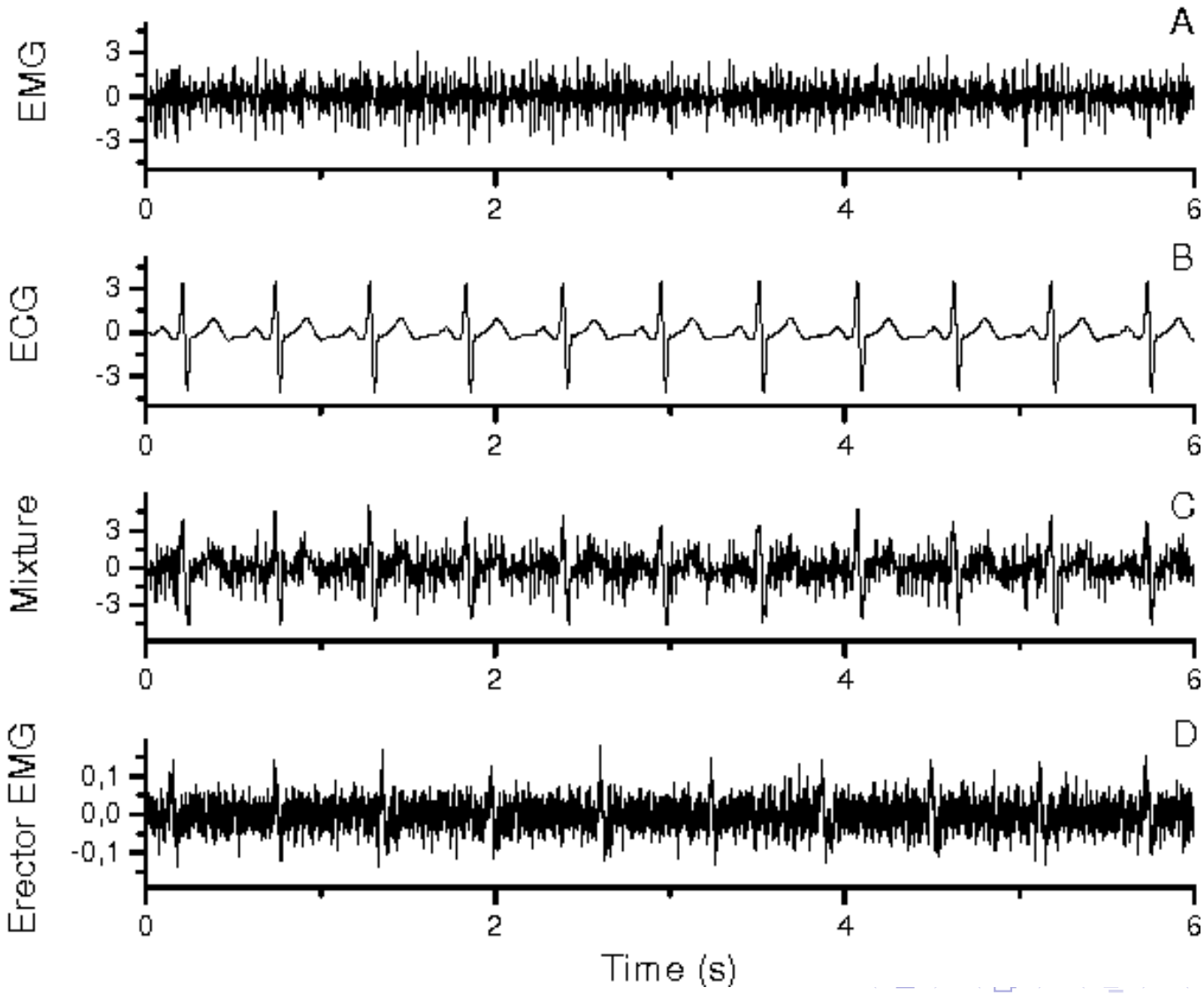


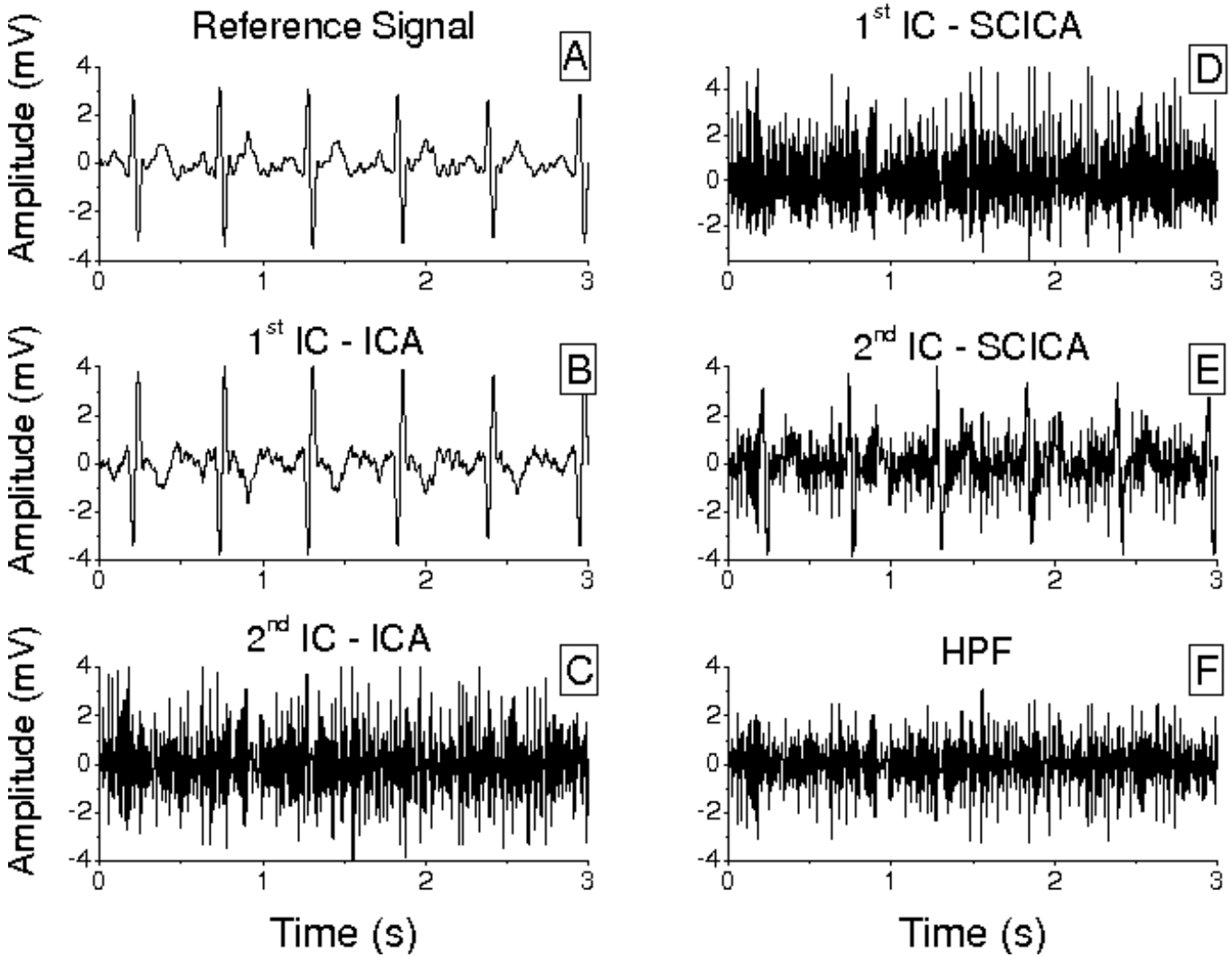
FIGURE 5.21

Example of an sEMG waveform decomposition system (Garcia et al., 2002) consisting of signal processing (1), signal decomposition (2), template matching (3–5), and postprocessing (6–7).

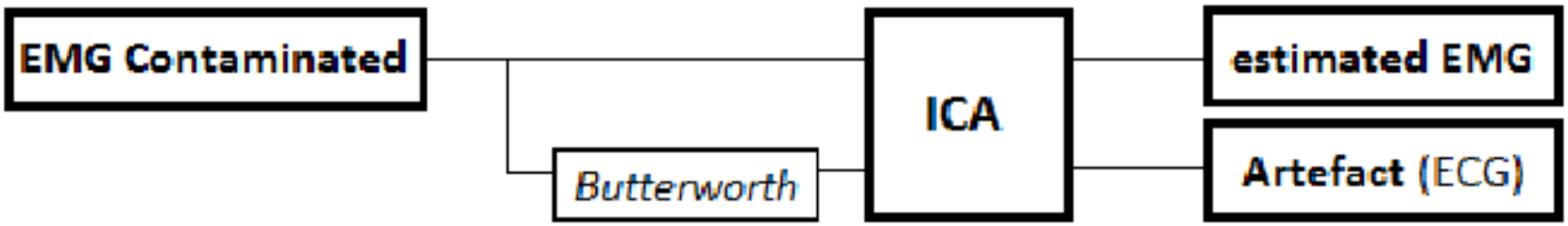
EMG Signal Processing - Decomposition-ICA



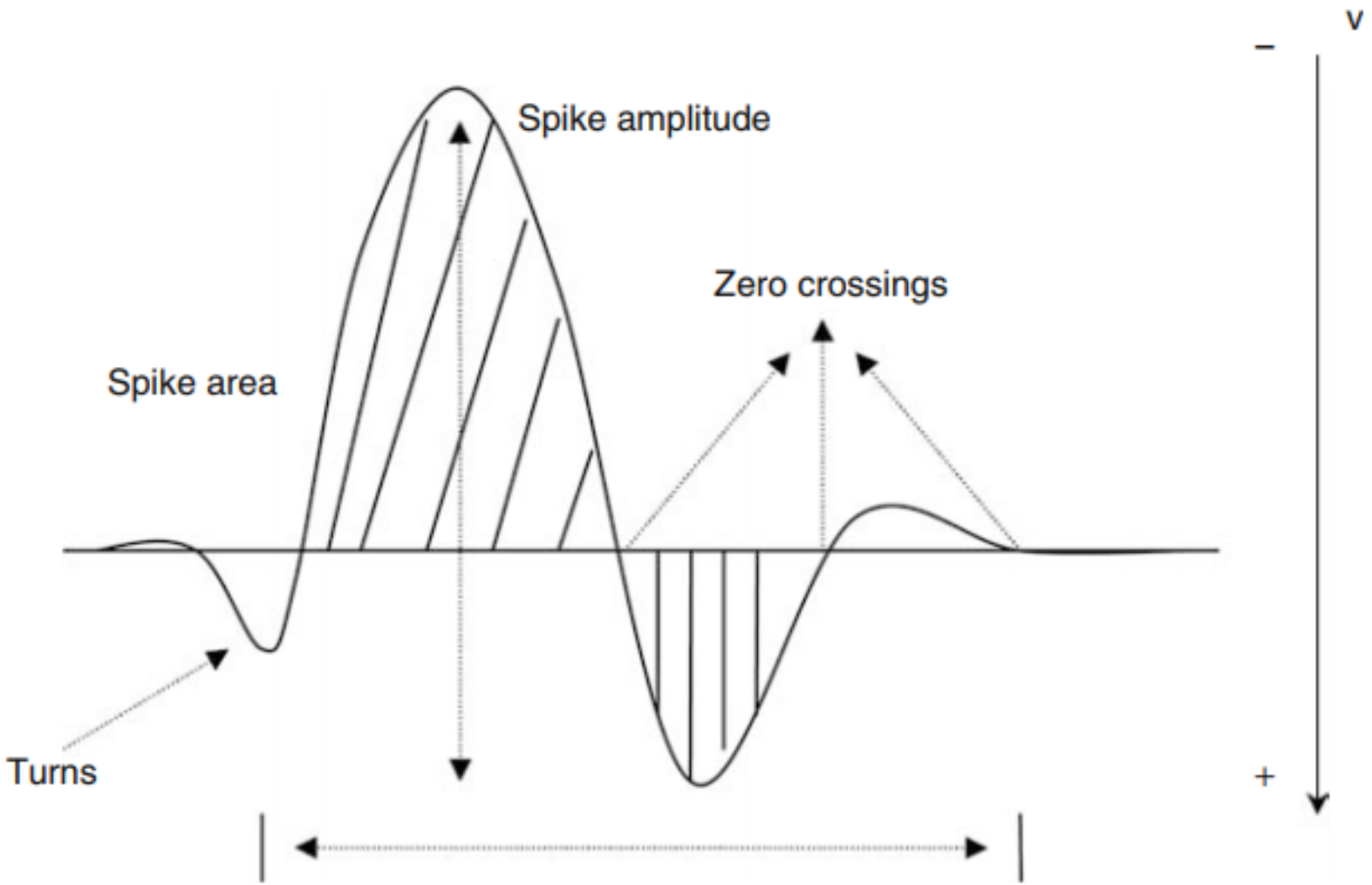
EMG Signal Processing - Decomposition-ICA



EMG Signal Processing - Decomposition-ICA



EMG Signal Processing - Pyhsical Decomposition of MUAPs



EMG Signal Processing - Feature Extraction

After processing the raw EMG waveforms, further information can be extracted from the physical measurements of the waveform, statistical quantities of the signal, time- and frequency-domain characteristics, and coefficients of theoretical EMG waveform models.

EMG Signal Processing - Feature Extraction

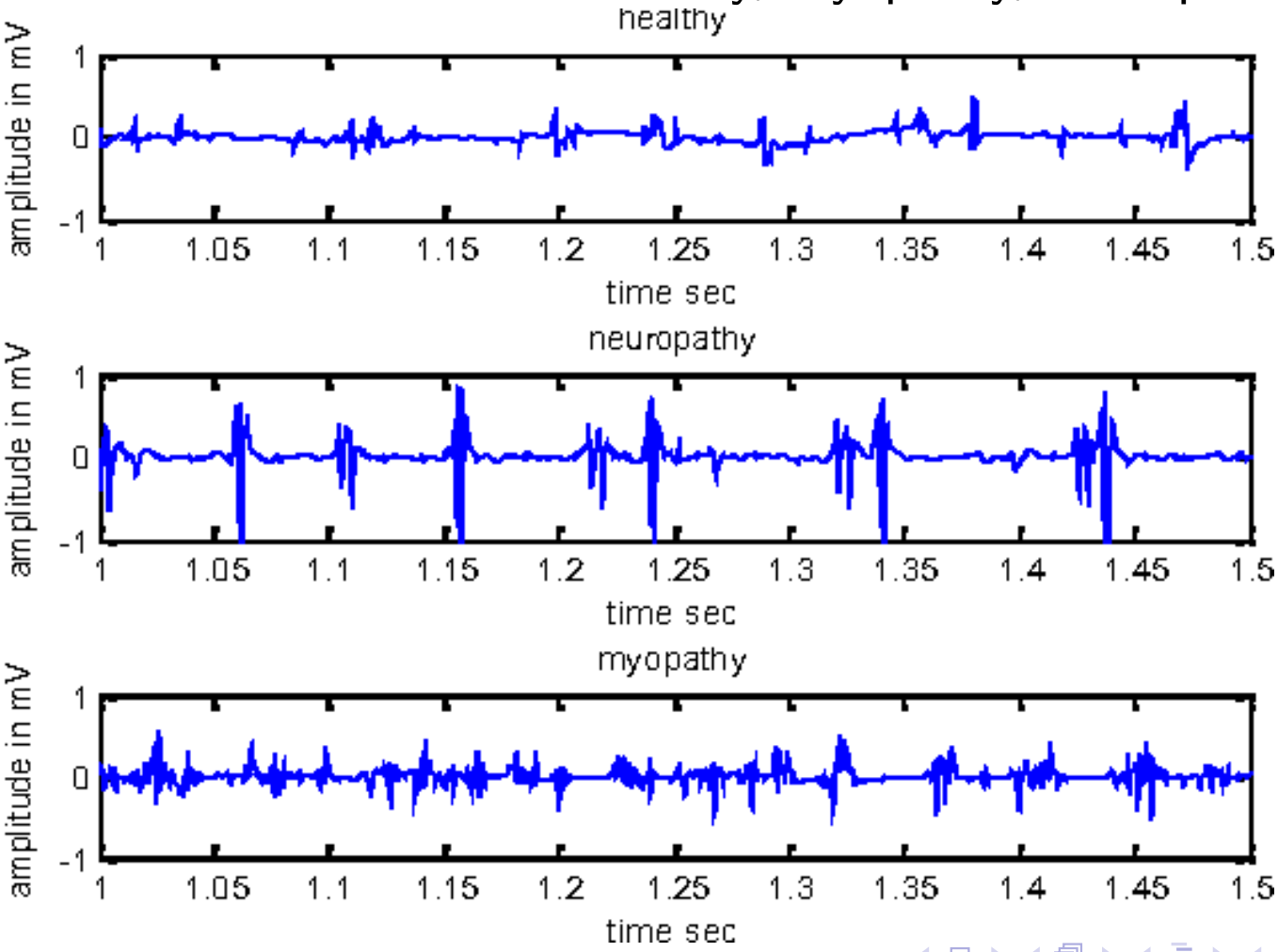
- Duration (DUR): The time between the beginning and end of a MUAP determined using a sliding window. For example, a window with length 3 ms and 40uV
- Spike duration (SPDUR): The time between the first and the last positive spike.
- Amplitude (AMP): The difference between the largest positive peak and the most negative peak gives the peak-to-peak amplitude.
- Area: The area of the MUAP waveform, either the entire waveform or the rectified version of the waveform.

EMG Signal Processing - Feature Extraction

- Spike area: This is similar to the area but it is the area under the spikes and calculated only over the spike duration.
- Phases: The number of baseline crossings that exceeds a certain voltage threshold, for example, 25 V.
- Turns. The number of positive and negative peaks separated by a specified threshold voltage, for example, 25 uV.
- Willison amplitude (WAMP). The number of counts for a change of signal in the EMG amplitude above a predefined threshold.

EMG Signal Processing - Feature Extraction

Three Muscle conditions: healthy, myopathy, neuropathy



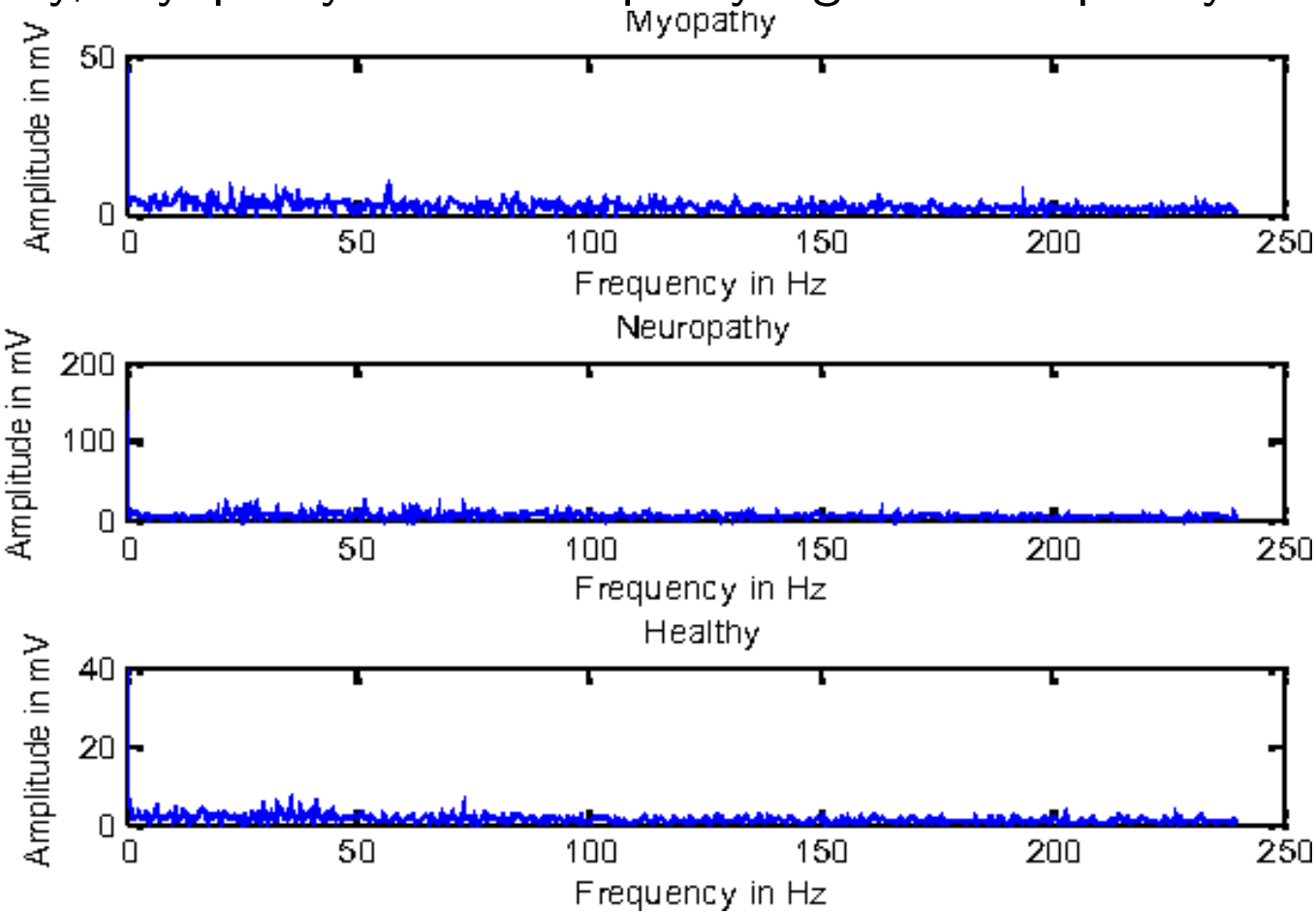
EMG Signal Processing - Feature Extraction

Raw EMG Signal for healthy, myopathy and neuropathy muscle conditions

Feature (Average of 20 Samples)	Myopathy	Neuropathy	Healthy
Mean Amplitude in time domain (mV)	14.61	53.6	18.39
Integration in time domain(mV)	14030	52809	17660
RMS amplitude in time domain(mV)	0.4389	0.8673	0.5763
Variance in time domain	477.49	4403.69	254.8
No of peaks in time domain	22.2	36.875	47.857
Mean Amplitude in frequency domain (mV)	1.04669	3.67	0.96
Variance in frequency domain	2.41276	29.8	3.249
No of peaks in frequency domain	79.6	111.25	111.71

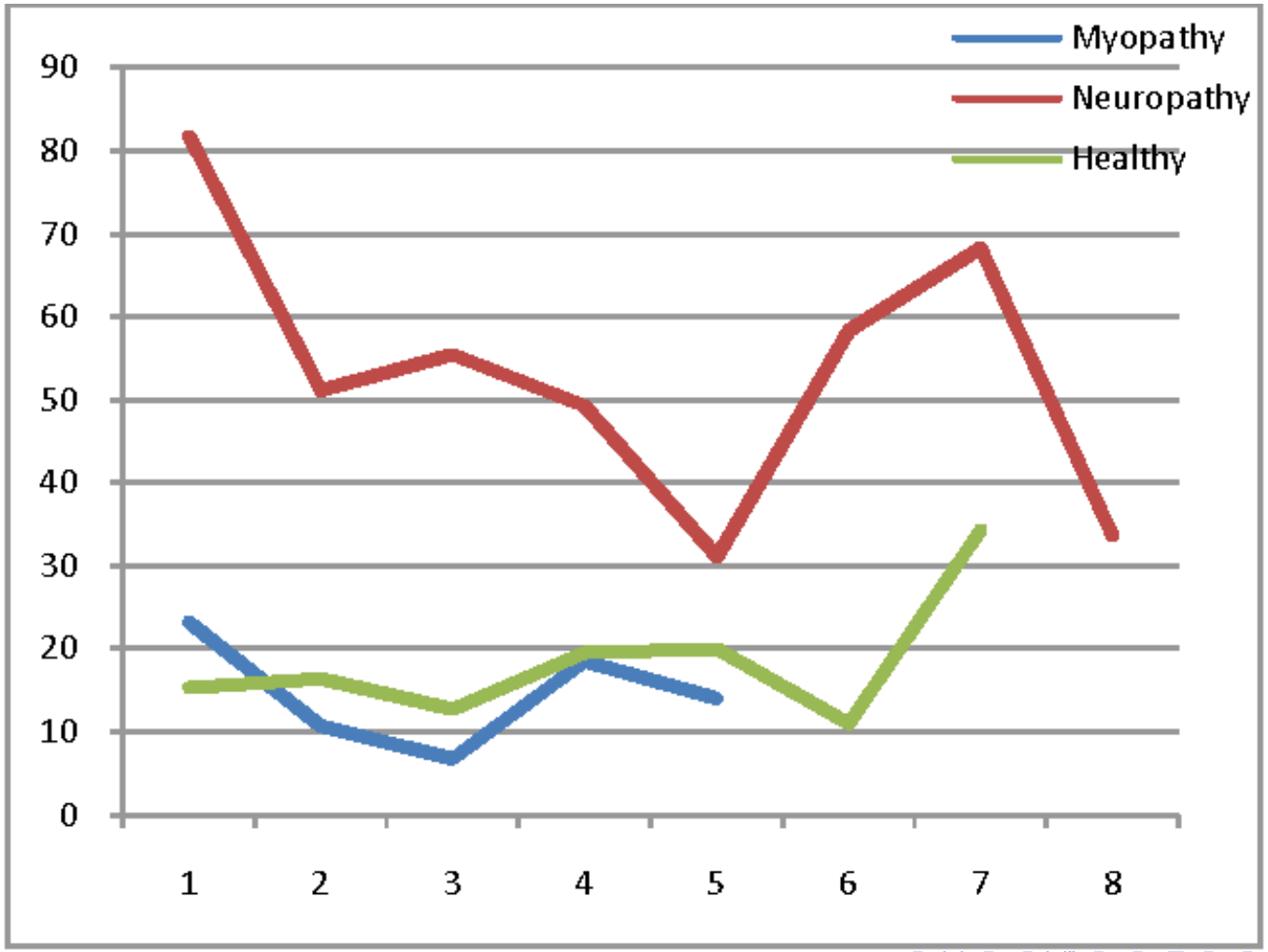
EMG Signal Processing - Feature Extraction

Healthy, Myopathy and Neuropathy signal in frequency domain



EMG Signal Processing - Feature Extraction

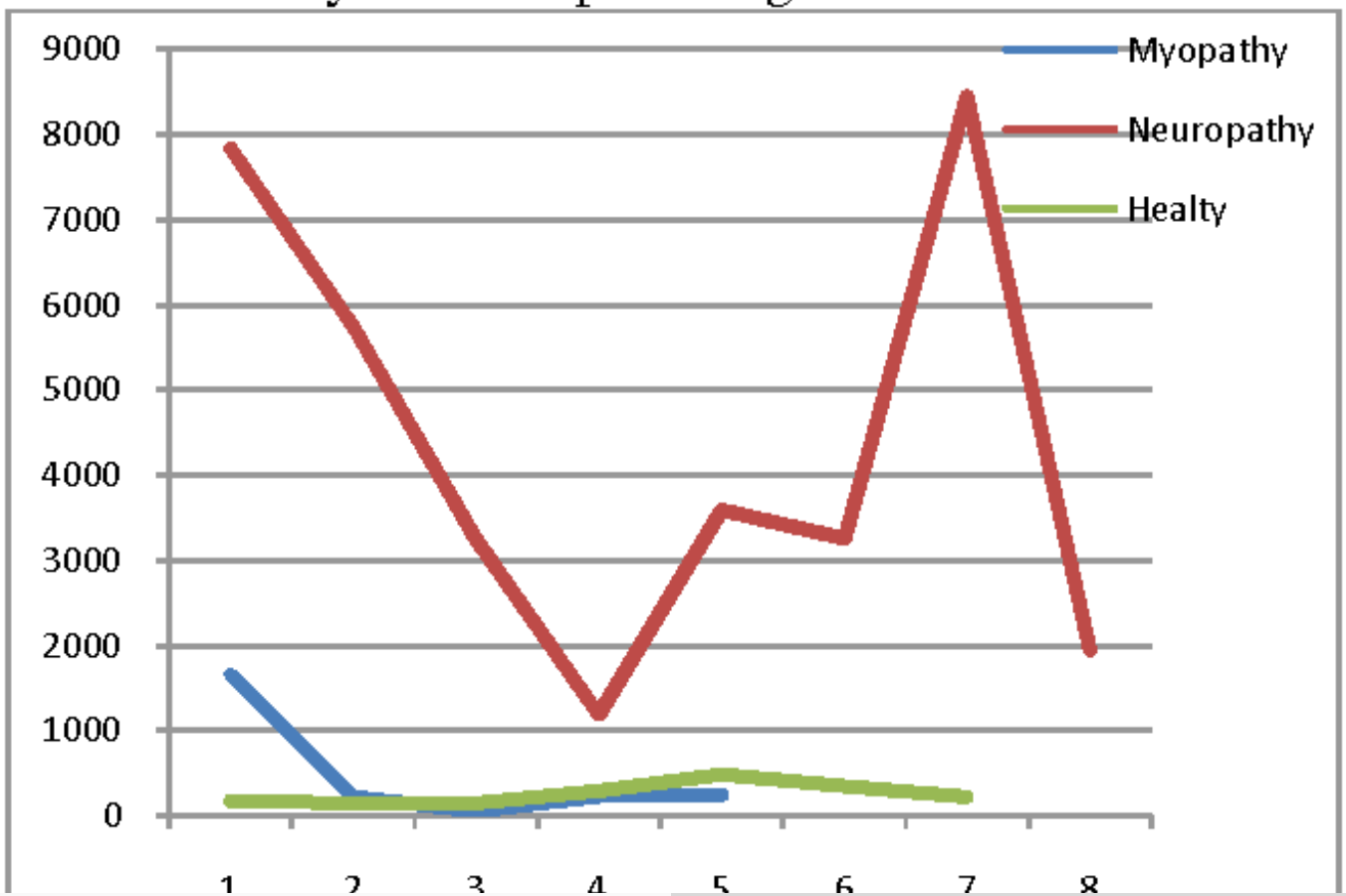
Mean amplitude for healthy, myopathy and neuropathy conditions



EMG Signal Processing - Feature Extraction

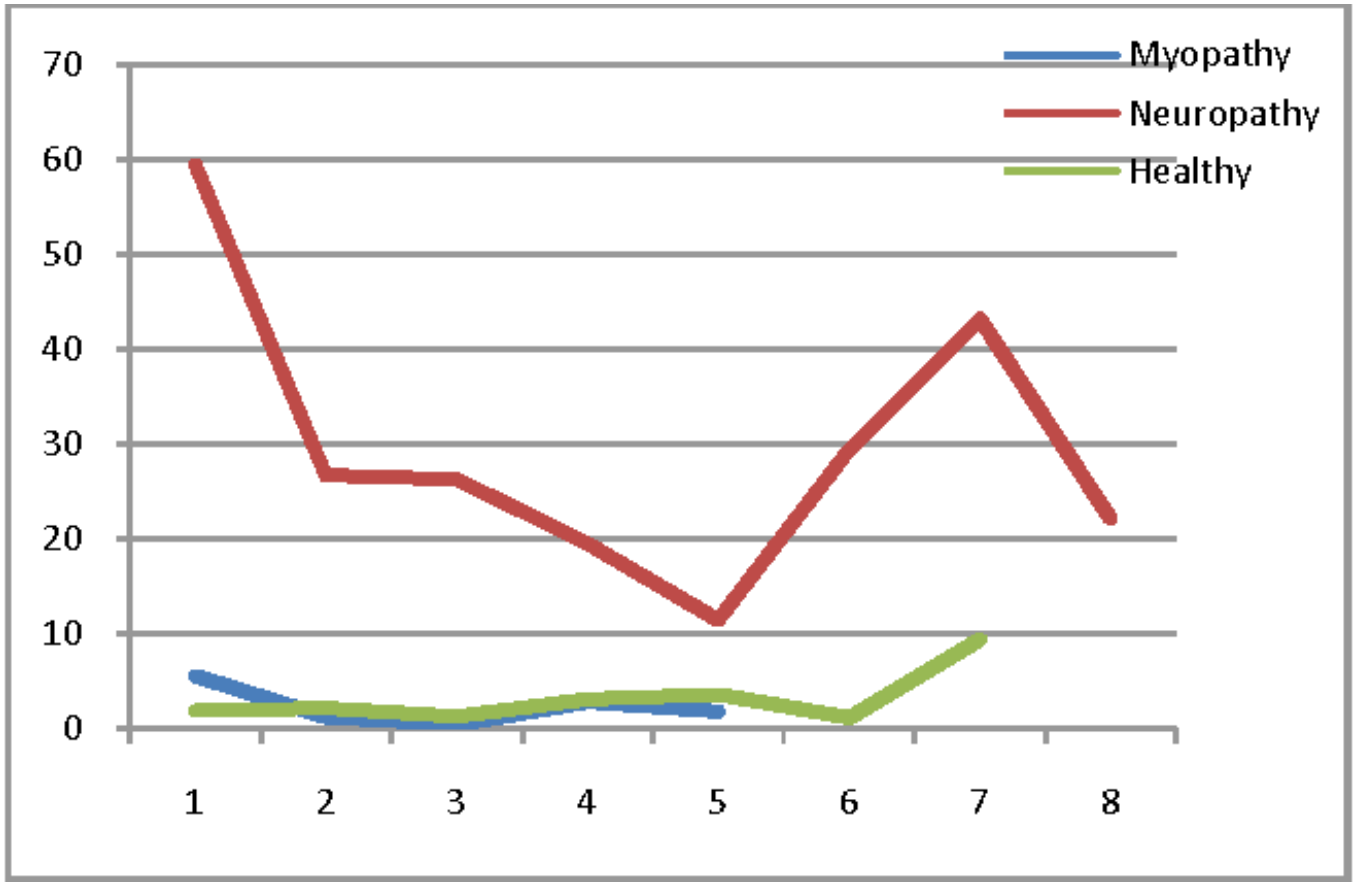
Variance in amplitude for healthy, myopathy and neuropathy conditions when EMG is analysed in time domain

domain activity for neuropathic signals.



EMG Signal Processing - Feature Extraction

Variance at amplitude for healthy, myopathy and neuropathy conditions when EMG is analysed in the frequency domain



EMG Signal Processing - Feature Extraction

Total peaks in the frequency domain for healthy, myopathy and neuropathy conditions

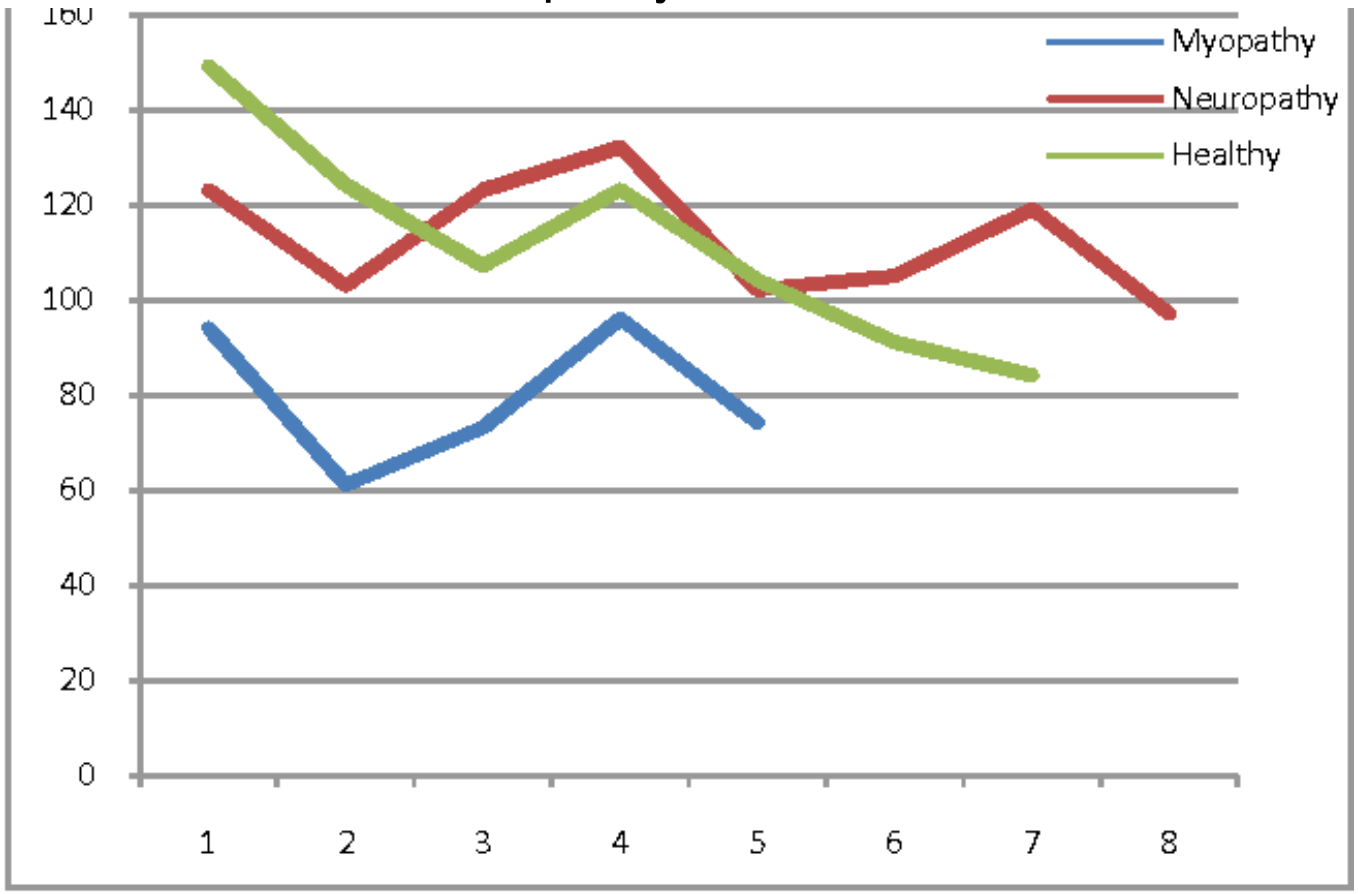


Figure 7: Total peaks in the frequency domain for

Classification of Neuromuscular Diseases - ANN

- In ANN, the popular MLP network has been applied for classification in several research ventures.

Classification of Neuromuscular Diseases - ANN

TABLE 5.2
Comparison of Classification Accuracies of Myopathy, Motor Neuron Disease, and Normal Subjects

Method	Acc. (%)	Feature Set
BP–NN (Pattichis et al., 1995)	80.0	MUAP time domain
NN-majority vote (Pattichis et al., 1995)	80.0	AR, cepstrum, time domain
SOM	80.0	MUAP time domain
SVM (Xie et al., 2003)	82.40	MUAP time domain
Neurofuzzy hybrid (Christodoulou and Pattichis, 1999)	88.58	AR, cepstrum, time domain
Hybrid SOM (Christodoulou and Pattichis, 1999)	94.81	MUAP time domain
Statistical (Christodoulou and Pattichis, 1999)	95.30	MUAP time domain
Hybrid SOM–LVQ (Christodoulou and Pattichis, 1999)	97.61	MUAP time domain
Genetics-based machine learning (Pattichis and Schizas, 1996)	$\leq$95	MUAP time domain

Note: The data sets used are not the same, hence the results are just a general indication of the potential of these techniques.

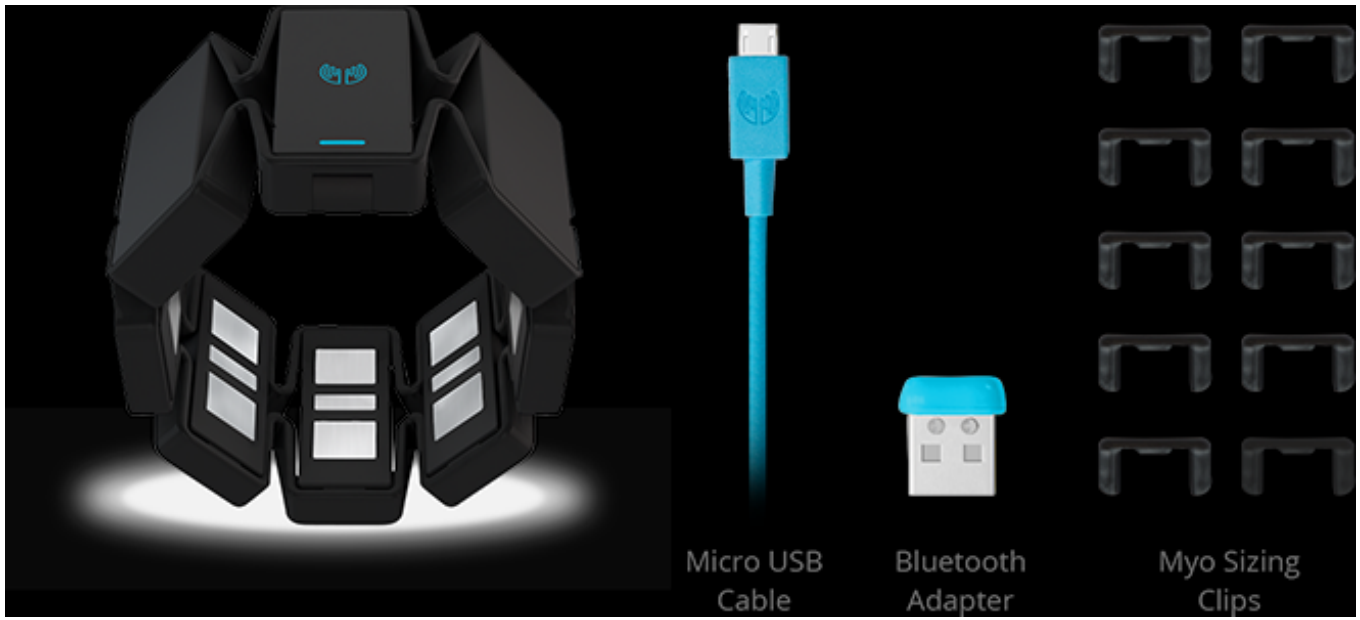
Classification of Neuromuscular Diseases - SVM

- The SVM classifier has also been applied to EMG signals for diagnosis of neuromuscular disorders

Classification of Neuromuscular Diseases - Fuzzy and Knowledge Based Systems

- Fuzzy techniques have also been employed for automated diagnosis of disease under the assumption that fuzzification of features will allow improved classification of differential diagnosis for certain neuromuscular diseases.
- In other applications, neurofuzzy controllers have been built to control the medicine dispensing and monitoring during surgery.

Commercial Applications of EMG - Myo Gesture Control



Commercial Applications of EMG - Myo Gesture Control

Myo Gesture Control features:

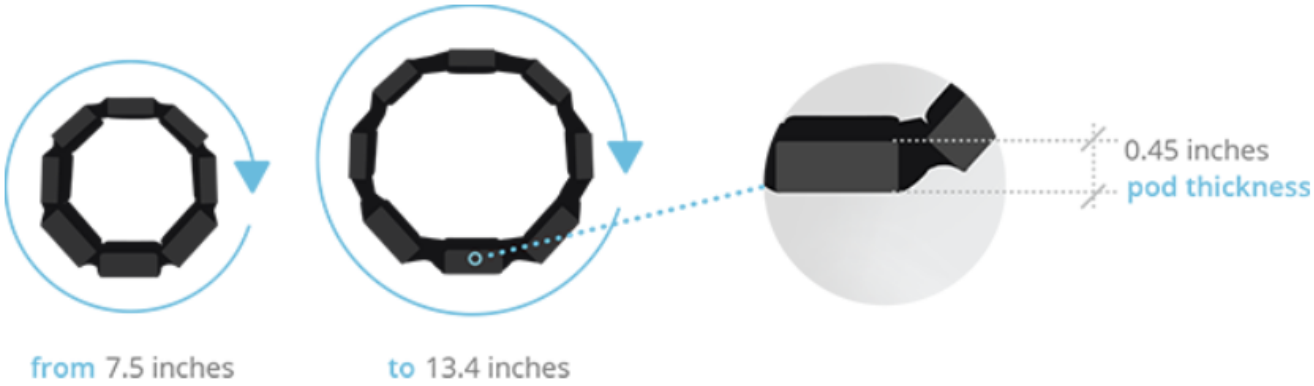
- 8 EMG electrodes
- 9-axis IMU
- Transmission unit

The EMG electrodes detect the signals related to muscles activity of the user's forearm and the IMU detects the forearm movements in the three-dimensional space.
The acquired data are sent via the Bluetooth Low Energy (BLE) module embedded into the armband, to other electronic devices

Commercial Applications of EMG - Myo Gesture Control

Sizing, weight, and dimensions

Arm size	Expandable between 7.5-13 inches (19-34 centimetres) forearm circumference
Weight	93 grams
Thickness	0.45 inches (1.14 centimetres)



Commercial Applications of EMG - Myo Gesture Control

Gestures and motion

Hand gestures detected by proprietary **EMG muscles sensors**

Highly sensitive **motion sensor**

Commercial Applications of EMG - Myo Gesture Control

Hardware

Sensors	• Medical grade stainless steel EMG sensors • Highly sensitive nine-axis IMU containing three-axis gyroscope, three-axis accelerometer, three-axis magnetometer
LEDs	Dual indicator LEDs
Processor	ARM Cortex M4 processor
Haptic Feedback	Short, medium, long vibrations

Commercial Applications of EMG - Myo Gesture Control

Communication

Bluetooth Smart

Power and battery

Charging	Micro-USB
Battery	Built-in rechargeable lithium ion battery
Performance	One full day of use in a single charge

Commercial Applications of EMG - Myo Gesture Control

Figure 1: By analyzing electrical activities of forearm muscles, the MYO armband detects hand movements in each direction (Myo Armband web site). Copyright © Thalmic Labs Inc. 2013–2016.

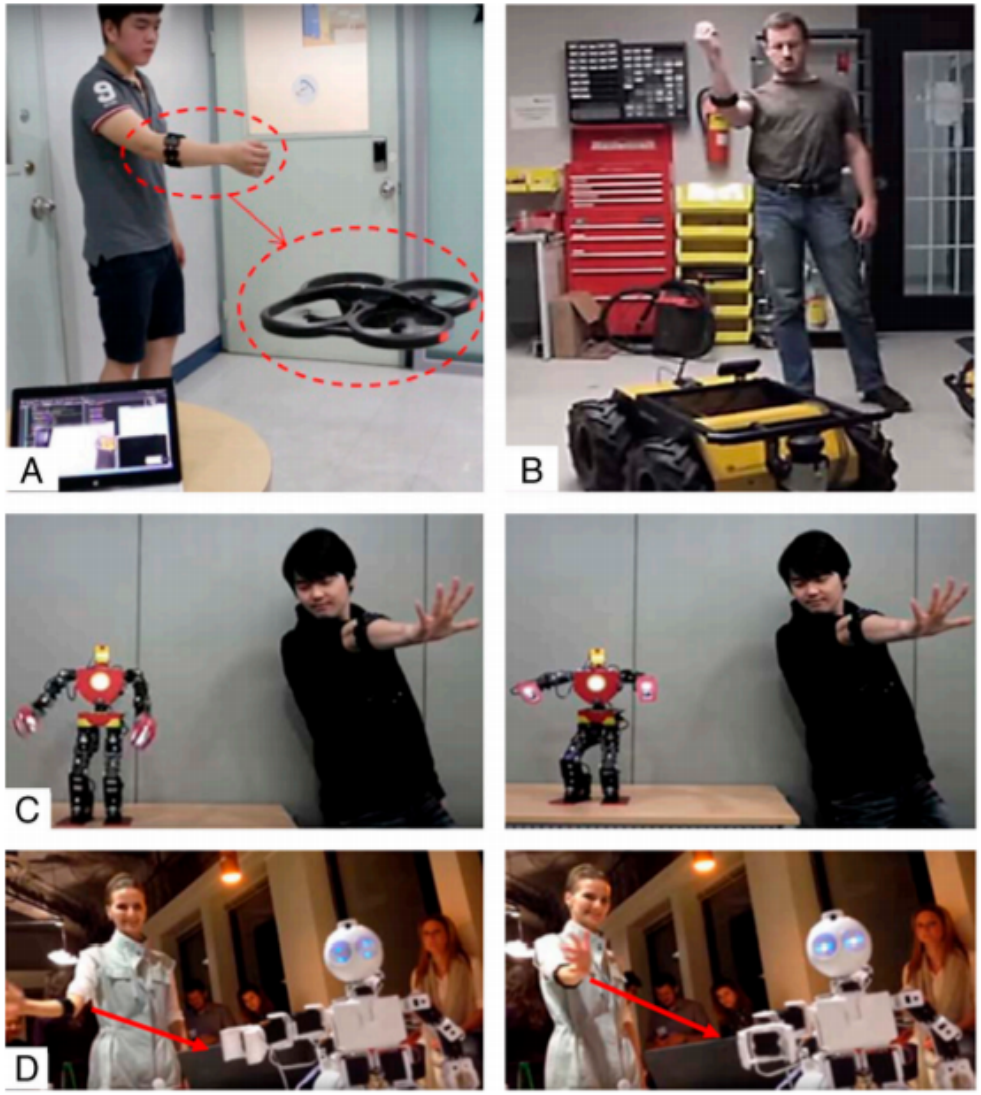
Commercial Applications of EMG - Myo Gesture Control

Figure 2: Myo armband allows to play several games by detecting the gestures performed by the user wearing it and sending the related signals to a PC/TV provided of Bluetooth connection. Copyright © Thalmic Labs Inc. 2013–2016.

Commercial Applications of EMG - Myo Gesture Control

Figure 3: In this game, two players wearing Myo armband must paint as fast as possible a whiteboard; the player who in a given time fills a larger area of the board wins.

Commercial Applications of EMG - Myo Gesture Control



Commercial Applications of EMG - Myo Gesture Control

Figure 8: Myo armband used in a surgery room for controlling a camera to visualize the examined body part, without having to physically touch a controller or medical instrument and thus improving user safety and reducing infections risk.

Commercial Applications of EMG - Myo Gesture Control

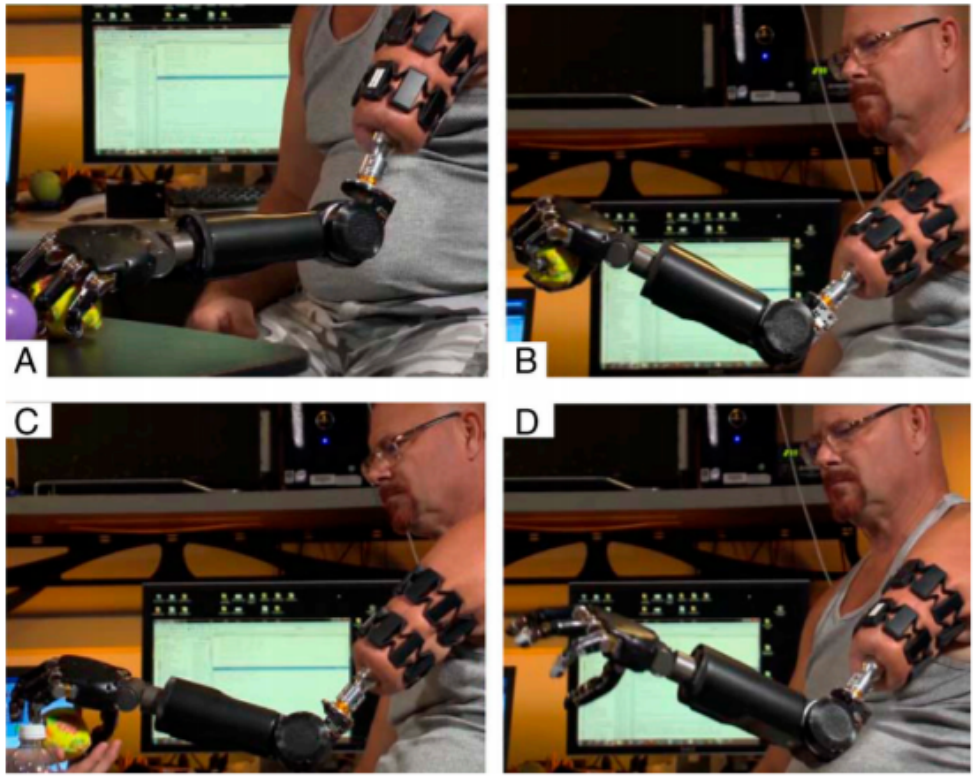


Figure 9: Two Myo armbands used to control the movements of a trans-humeral prosthesis; in this specific experimental test, the patient first grabs and then releases a tennis ball. Copyright© Thalmic Labs Inc. 2013–2016.

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