Νευροφυσιολογία και Αισθήσεις

Διάλεξη 13

Κίνηση από τον Νωτιαίο Μυελό

(Spinal Control of Movement)

Biomedical Imaging & Applied Optics
University of Cyprus

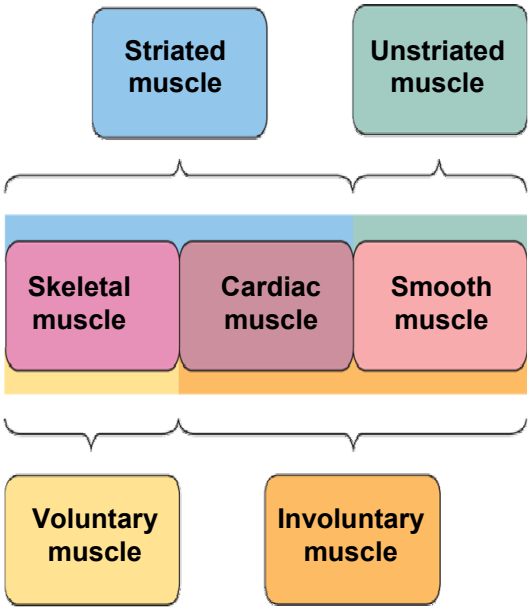
Introduction

- **Motor Programs**
  - Motor system: Muscles and neurons that control muscles
  - Role: Generation of coordinated movements
  - Parts of motor control
    - Spinal cord→ coordinated muscle contraction
    - Brain→ motor programs in spinal cord

Add toxins!!!!

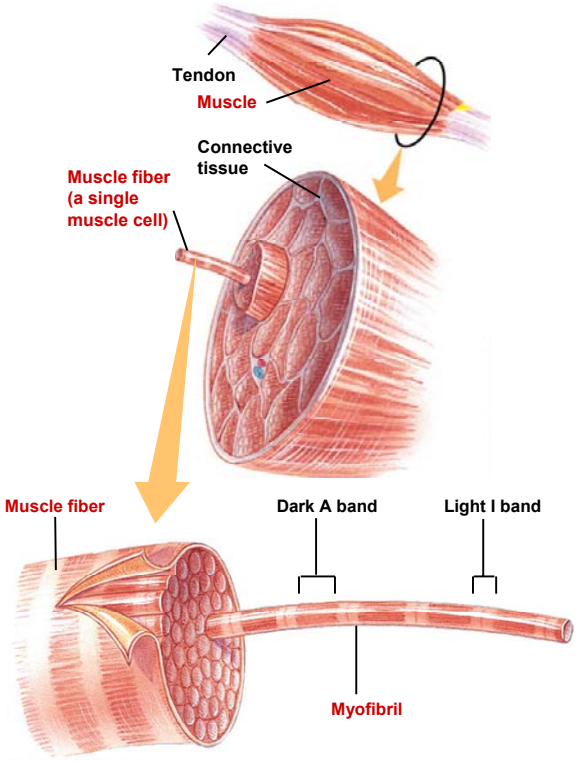
Muscle

- **Comprises largest group of tissues in body**
  - Skeletal (30-40% BW), smooth and cardiac (10% BW)
- **Controlled muscle contraction allows**
  - Purposeful movement of the whole body or parts of the body
  - Manipulation of external objects
  - Propulsion of contents through various hollow internal organs
  - Emptying of contents of certain organs to external environment
- **Three types of muscle**
  - Skeletal muscle
    - Make up muscular system
  - Cardiac muscle
    - Found only in the heart
  - Smooth muscle
    - Appears throughout the body systems as components of hollow organs and tubes
- **Classified in two different ways**
  - Striated or unstriated
  - Voluntary or involuntary



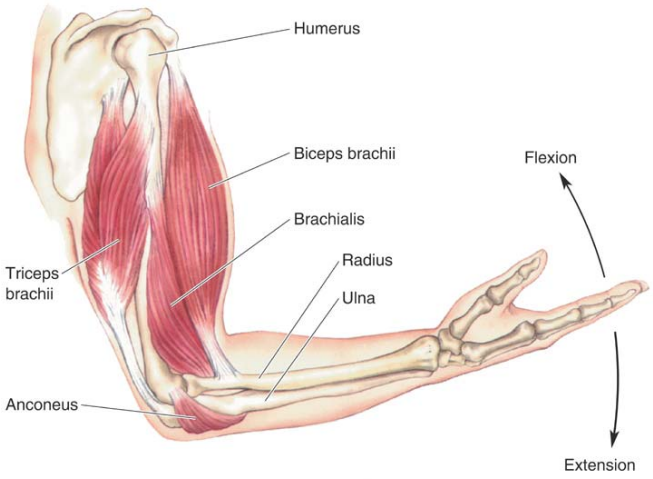
The Somatic Motor System

- **Muscle consists a number of muscle fibers lying parallel to one another and held together by connective tissue**
- **Single skeletal muscle cell is known as a muscle fiber**
  - Multinucleated
  - Large, elongated, and cylindrically shaped
  - Fibers usually extend entire length of muscle
  - Many Myofibrils



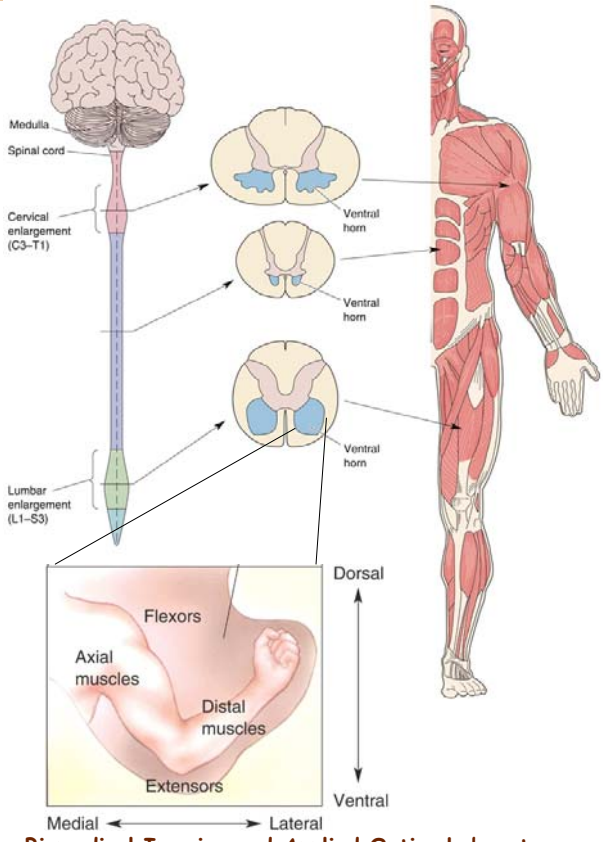
The Somatic Motor System

- **Somatic Musculature**
  - Axial muscles: Trunk movement
  - Proximal muscles: Shoulder, elbow, pelvis, knee movement
  - Distal muscles: Hands, feet, digits (fingers and toes) movement
- **Movement**
  - Flexion
  - Extension
  - Abduction
  - Adduction



The Somatic Motor System

- **Upper motor neurons**
  - Supply input to the spinal cord
- **Lower motor neurons**
  - Innervated by ventral horn of spinal cord
  - Begin in ventral hornVentral horn distribution
  - Two lower motor neurons
    - Alpha
    - Gamma



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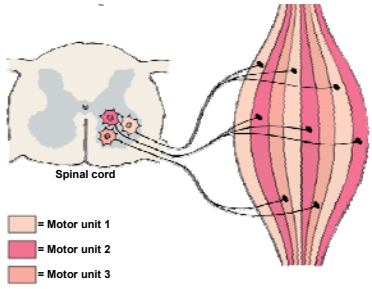
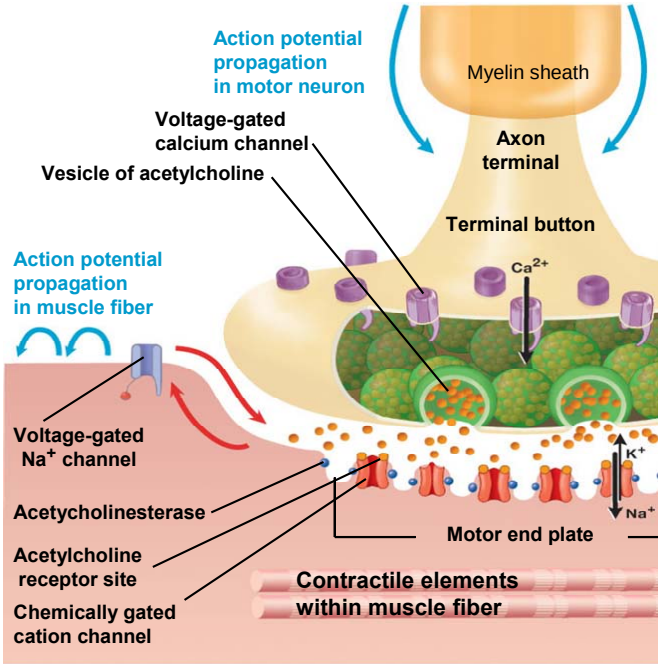
The Somatic Motor System

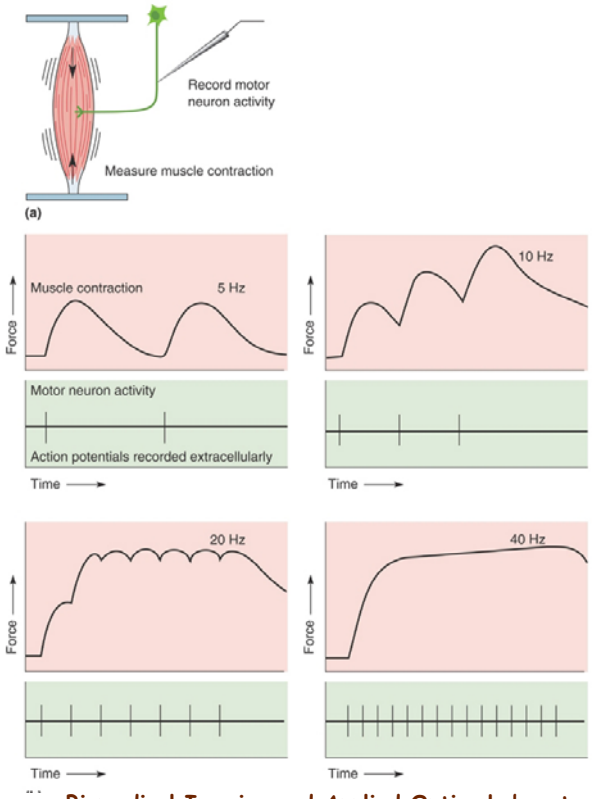
- **Alpha Motor Neurons synapse with muscle**
  - AP reaches terminal
  - ACh released
  - Nicotinic receptors on endplate
  - Create EPSPs (aka endplate potentials)
  - Voltage-gated Na+ channels → AP
  - Contraction
  - Acetylcholinestarase degrades ACh
- **Motor Unit**
  - Alpha motor neuron and all the muscle fibers it innervates





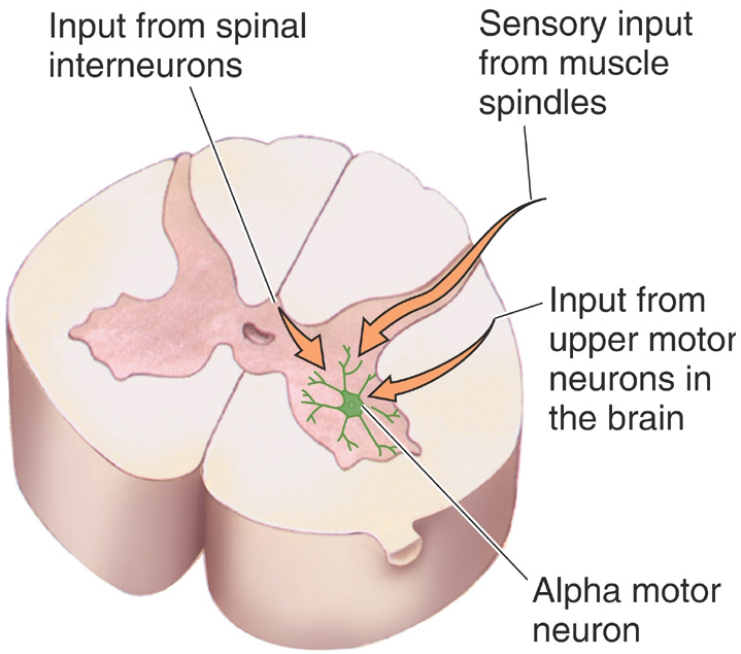
The Somatic Motor System

- **Graded Control of Muscle Contraction by Alpha Motor Neurons**
  - Varying firing rate of motor neurons
  - Recruit additional synergistic motor units
    - Smaller first, largest last
- **Tetanus**
  - Muscle fiber stimulated so rapidly that it does not have a chance to relax
  - Contraction usually 3-4x stronger than a single twitch
  - Do not confuse with the disease!



The Somatic Motor System

- **Inputs to Alpha Motor Neurons**

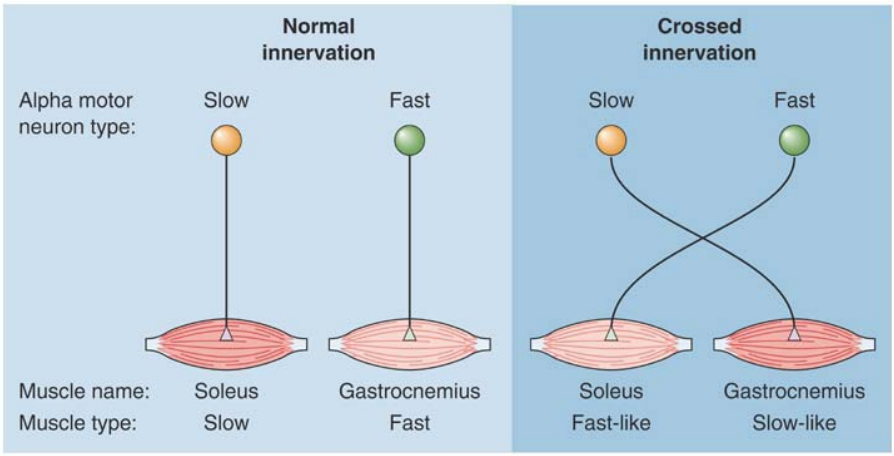


The Somatic Motor System

- **Types of Motor Units**
  - Red muscle fibers
    - Large number of mitochondria and enzymes
    - Slow to contract, can sustain contraction
  - White muscle fibers
    - Few mitochondria, anaerobic metabolism
    - Contract and fatigue rapidly
  - Fast motor units
    - Larger diameter, faster conducting neurons
    - Rapidly fatiguing white fibers
  - Slow motor units
    - Smaller diameter, slower conducting neurons
    - Slowly fatiguing red fibers

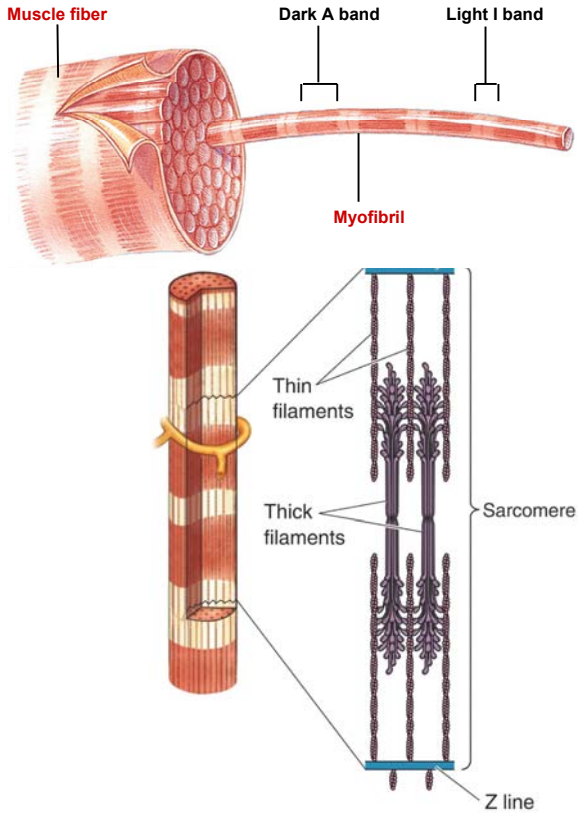
The Somatic Motor System

- **Neuromuscular Matchmaking**
  - Are muscle properties due to innervating nerve characteristics?
  - Alternate nerve input
    - Switch in muscle phenotype (physical characteristics)
- **Muscles change due to change in activity**
  - Hypertrophy: Exaggerated growth of muscle fibers
  - Atrophy: Degeneration of muscle fibers



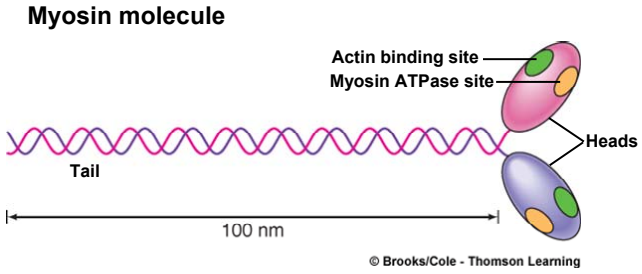
Excitation-Contraction Coupling

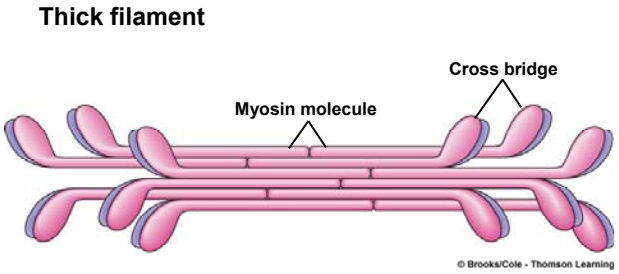
- **Muscle fiber (cell)**
  - Many myofibrils
- **Myofibrils**
  - Contractile elements of muscle fiber
  - Viewed microscopically they display alternating dark (the A bands) and light bands (the I bands) giving appearance of striations
  - Regular arrangement of thick and thin filaments
    - Thick filaments – myosin (protein)
    - Thin filaments – actin (protein)
- **Sarcomere**
  - Functional unit of skeletal muscle
  - Found between two Z lines
    - Z lines connect thin filaments of two adjoining sarcomeres



Excitation-Contraction Coupling

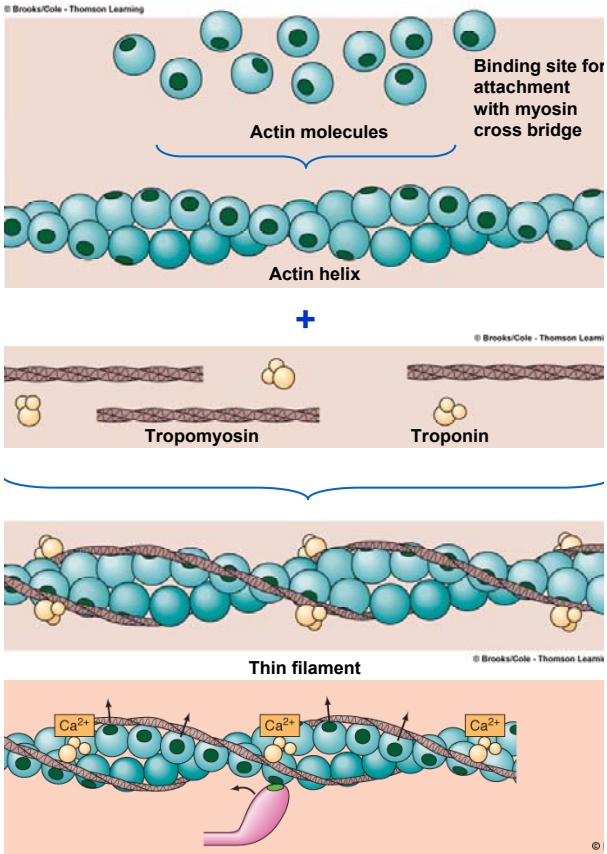
- **Thick filaments**
  - Myosin
  - Several hundred of them
  - Heads form cross bridges between thick and thin filaments
    - Cross bridge has two important sites critical to contractile process
      - An actin-binding site
      - A myosin ATPase (ATP-splitting) site





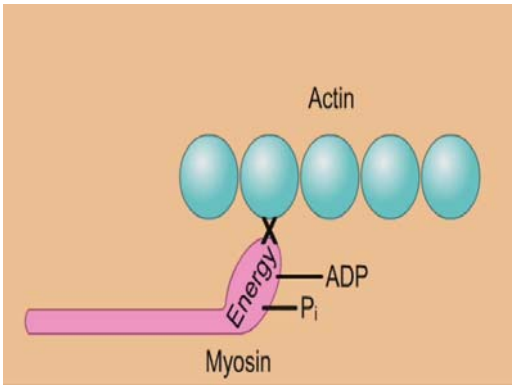
Excitation-Contraction Coupling

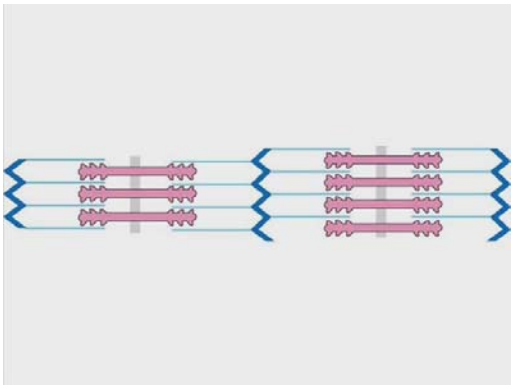
- **Thin filaments**
  - Actin
    - Primary structural component of thin filaments
    - Each actin molecule has special binding site for attachment with myosin cross bridge
  - Tropomyosin
    - Thread-like molecules that covers actin sites blocking interaction with thick filaments
  - Troponin
    - Made of three polypeptide units
      - One binds to tropomyosin
      - One binds to actin
      - One can bind with Ca^{2+}
  - When Ca^{2+} binds to troponin
    - Tropomyosin moves away from blocking position
    - Cross bridges can form



Excitation-Contraction Coupling

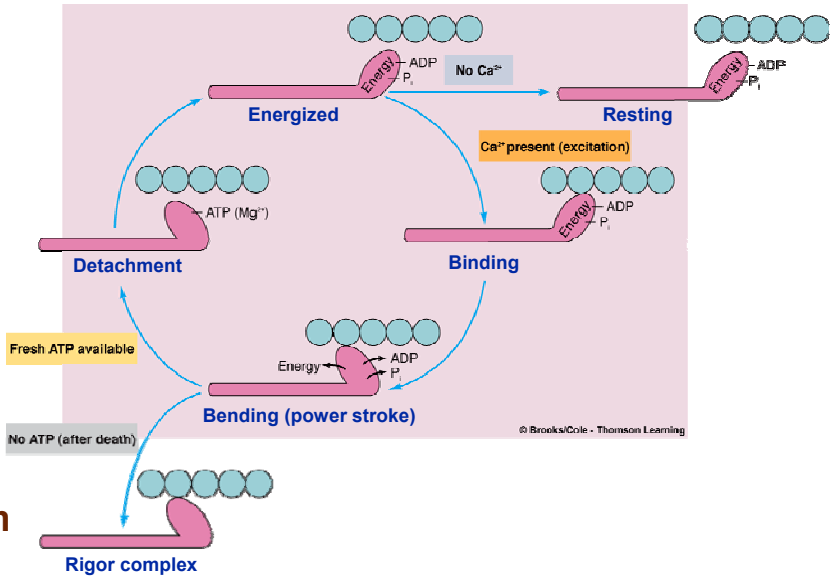
- **Power Stroke**
  - Ca^{2+} released into sarcoplasm
  - Myosin heads bind to actin, binding sides exposed
  - Myosin heads swivel toward center of sarcomere (***power stroke***)
  - ADP released
  - ATP binds to myosin head and detaches it from actin
  - Hydrolysis of ATP transfers energy to myosin head and reorients it





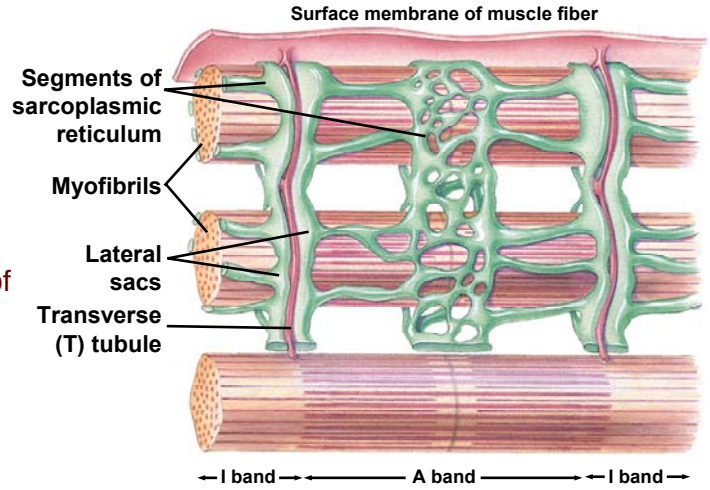
Excitation-Contraction Coupling

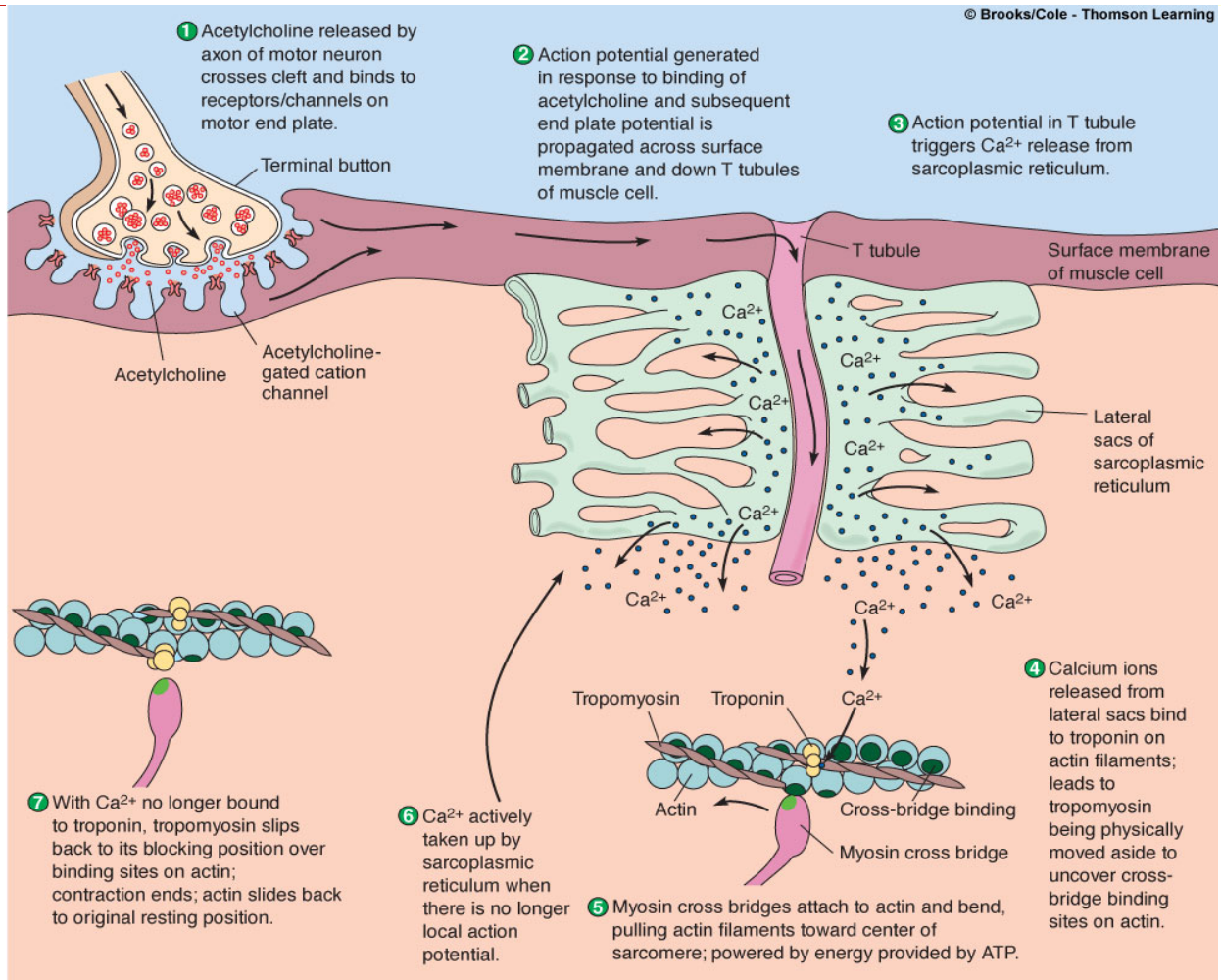
- **Contraction continues if ATP is available and Ca^{2+} level in sarcoplasm is high**
- **Myosin head remains attached until ATP binds → rigor mortis**
  - Ca^{2+} released
  - ATP quickly depleted
  - Onset in a few hours
  - Can last 1-2 days
- **Ca^{2+} stores are in the sarcoplasmic reticulum**



Excitation-Contraction Coupling

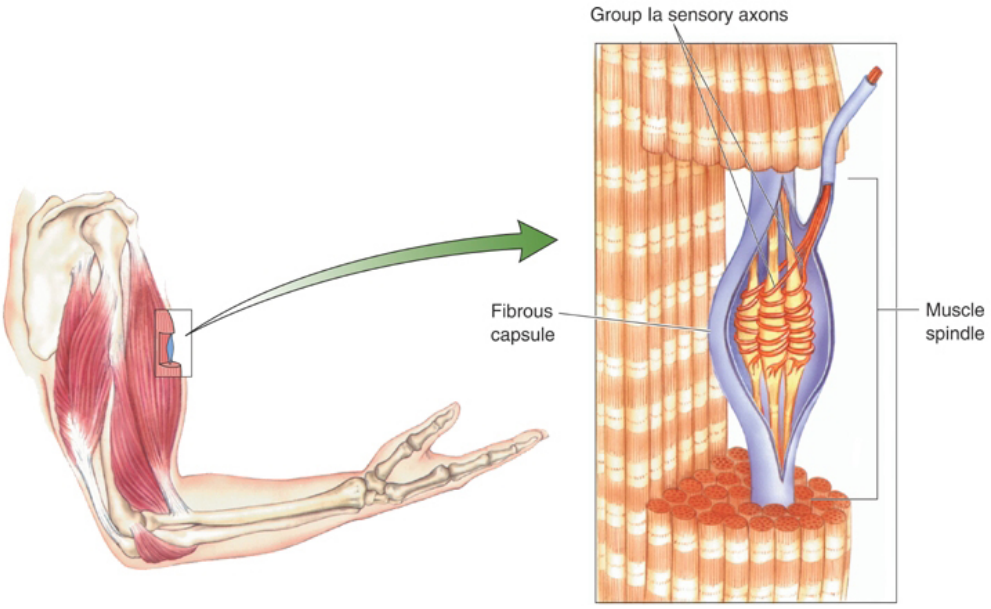
- **Sarcoplasmic Reticulum (SR)**
  - Modified endoplasmic reticulum
  - A fine network of interconnected compartments that surround each myofibril
  - Not continuous but encircles myofibril throughout its length
- **T tubules**
  - Run perpendicularly from surface of muscle cell membrane into central portions of the muscle fiber
  - T tubule membrane is continuous with surface membrane → action potential on surface membrane spreads down into T-tubule
  - Spread of action potential triggers release of Ca^{2+} from SR into cytosol





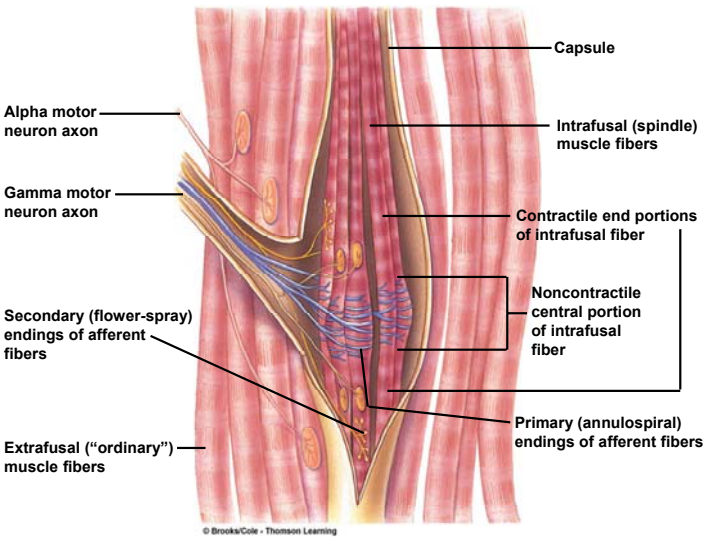
Spinal Control of Motor Units

- **Sensory feedback from muscle**
  - Proprioception



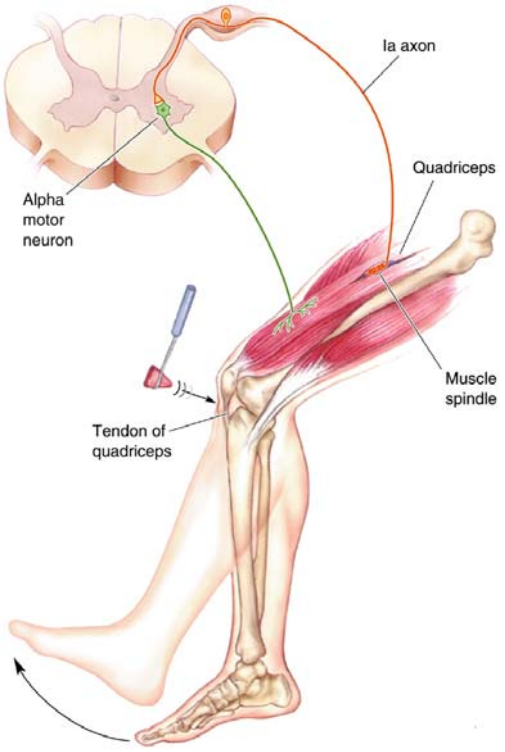
Spinal Control of Motor Units

- **Muscle Spindles**
  - Parallel with muscle
  - Monitor muscle length
  - Collections of specialized muscle fibers known as intrafusal fibers
    - Lie within spindle-shaped connective tissue capsules parallel to extrafusal fibers
    - Have contractile ends and a non-contractile central portion
  - Each spindle has its own nerve supply
    - Plays key role in stretch reflex
    - Efferent
      - Gamma motor neurons
    - Afferent (Ia)



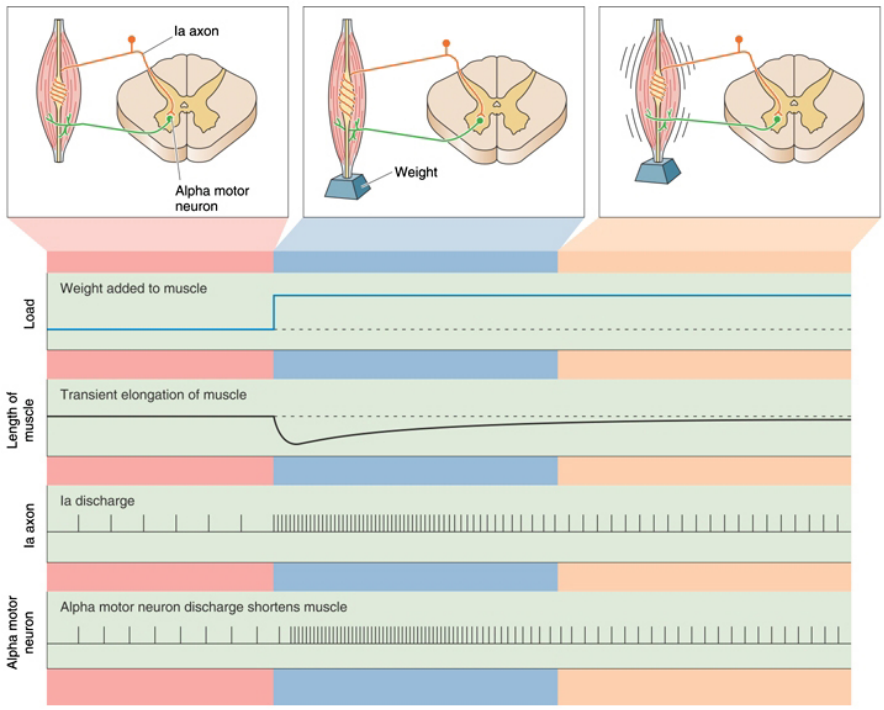
Spinal Control of Motor Units

- **The Myotatic Reflex**
  - Stretch reflex: Muscle pulled→ tendency to pull back
  - Feedback loop
  - Discharge rate of sensory axons: Related to muscle length
  - Monosynaptic
  - Example: knee-jerk reflex



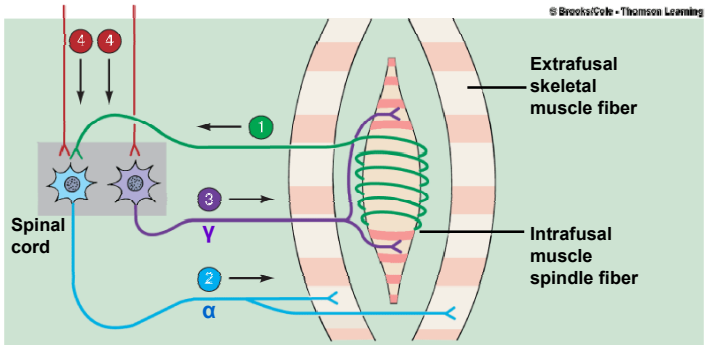
Spinal Control of Motor Units

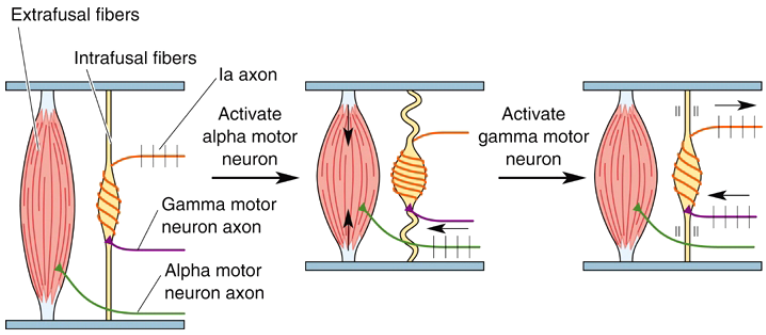
- **The Myotatic Reflex**



Spinal Control of Motor Units

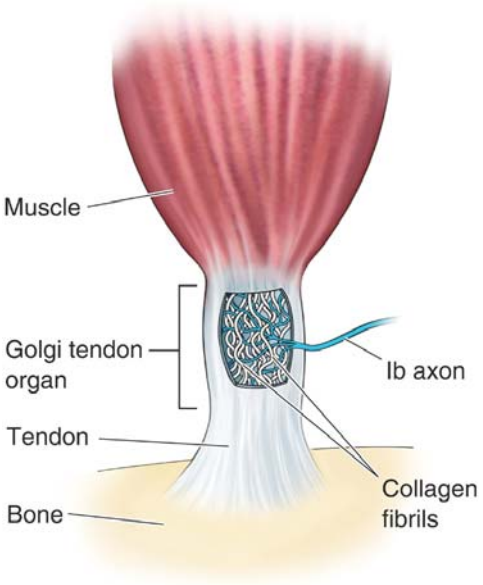
- **Coactivation of alpha and gamma motor neurons**
  - Spindle coactivation during muscle contraction
  - Spindle contracted to reduce length
    - With no coactivation
      - Slackened spindle
      - Not sensitive to stretch
  - Adjustment to keep muscle spindles sensitive to stretch





Spinal Control of Motor Units

- **Gogli Tendon Organs**
  - In series with muscle
    - Specialized nerve fibers embedded in the tendons (Ib)
  - Provide necessary feedback for overall muscle tension
    - Integrates all factors which influence tension
  - Stretch of tendons exerts force on nerve endings
    - Increase firing rate
    - Reverse myotatic reflex
  - Part of this information reaches conscious awareness
    - We are aware of tension (but not of length) of muscles



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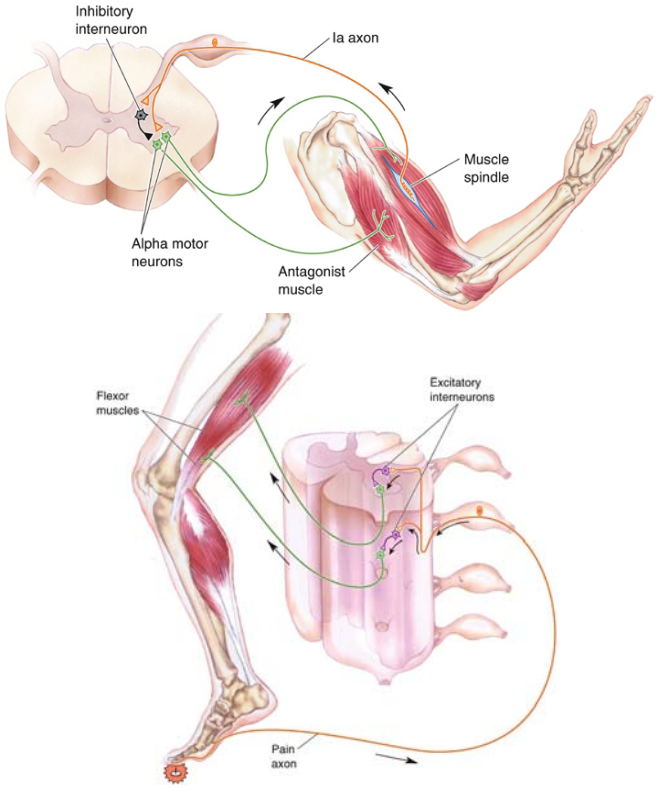
Spinal Control of Motor Units

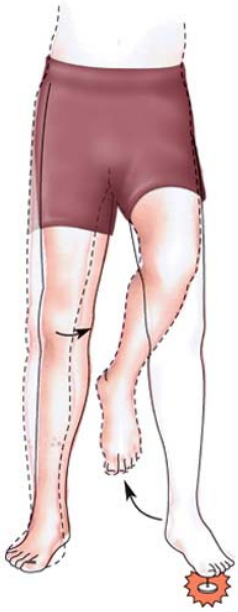
- **Proprioception from the joints**
  - Proprioceptive axons in collective joint tissues
  - Respond to angle, direction and velocity of movement in a joint
  - Information from joint receptors
    - Combined with muscle spindle, Golgi tendon organs, skin receptors

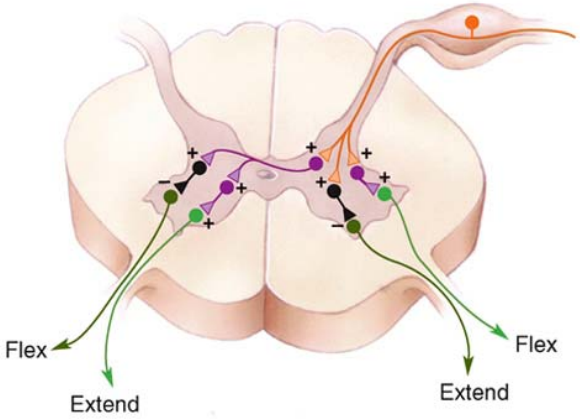
Spinal Interneurons

- **Synaptic inputs**
  - Primary sensory axons
  - Descending axons from brain
  - Collaterals of lower motor neuron axons
- **Inhibitory Interneurons**
  - Reciprocal inhibition: Contraction of one muscle set accompanied by relaxation of antagonist muscle
    - Example: Myotatic reflex
- **Excitatory Input**
  - Flexor reflex: Complex reflex arc used to withdraw limb from aversive stimulus
  - Crossed-extensor reflex: Activation of extensor muscles and inhibition of flexors on opposite side



Spinal Interneurons



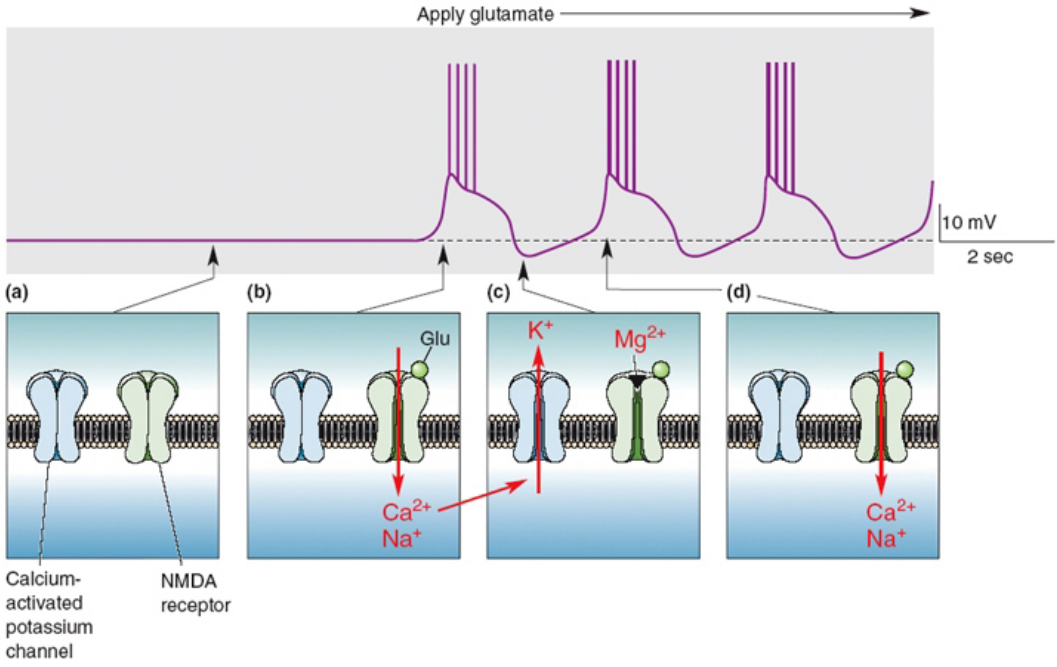


Spinal Motor Programs for Walking

- **Spinal Motor Programs for Walking**
  - Why do headless chickens still run?
  - (so do headless cats to some extend)

Spinal Motor Programs for Walking

- The Generation of Spinal Motor Programs for Walking



Spinal Motor Programs for Walking

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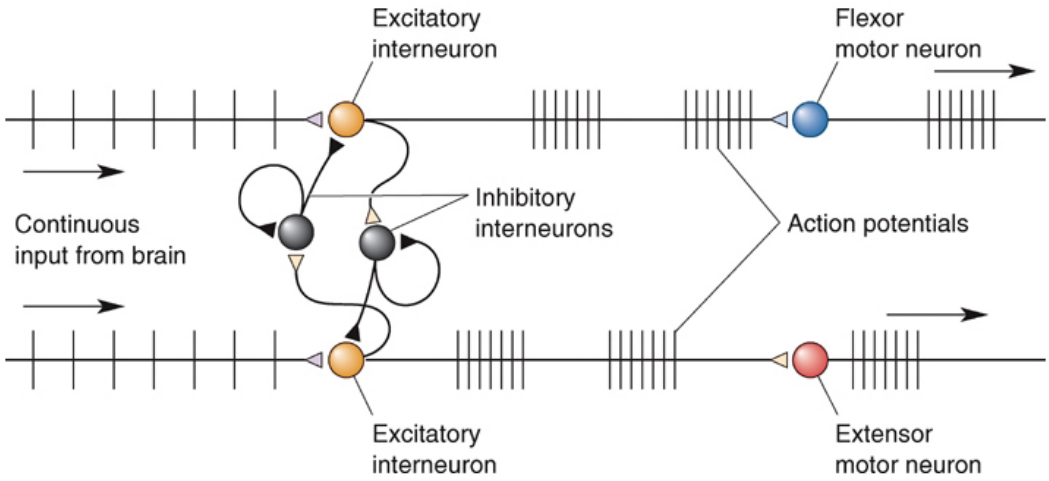

Επόμενη Διάλεξη …

Διάλεξη 14

Κίνηση από το ΚΝΣ

(CNS Control of Movement)