Structure and Function of Skeletal Muscle

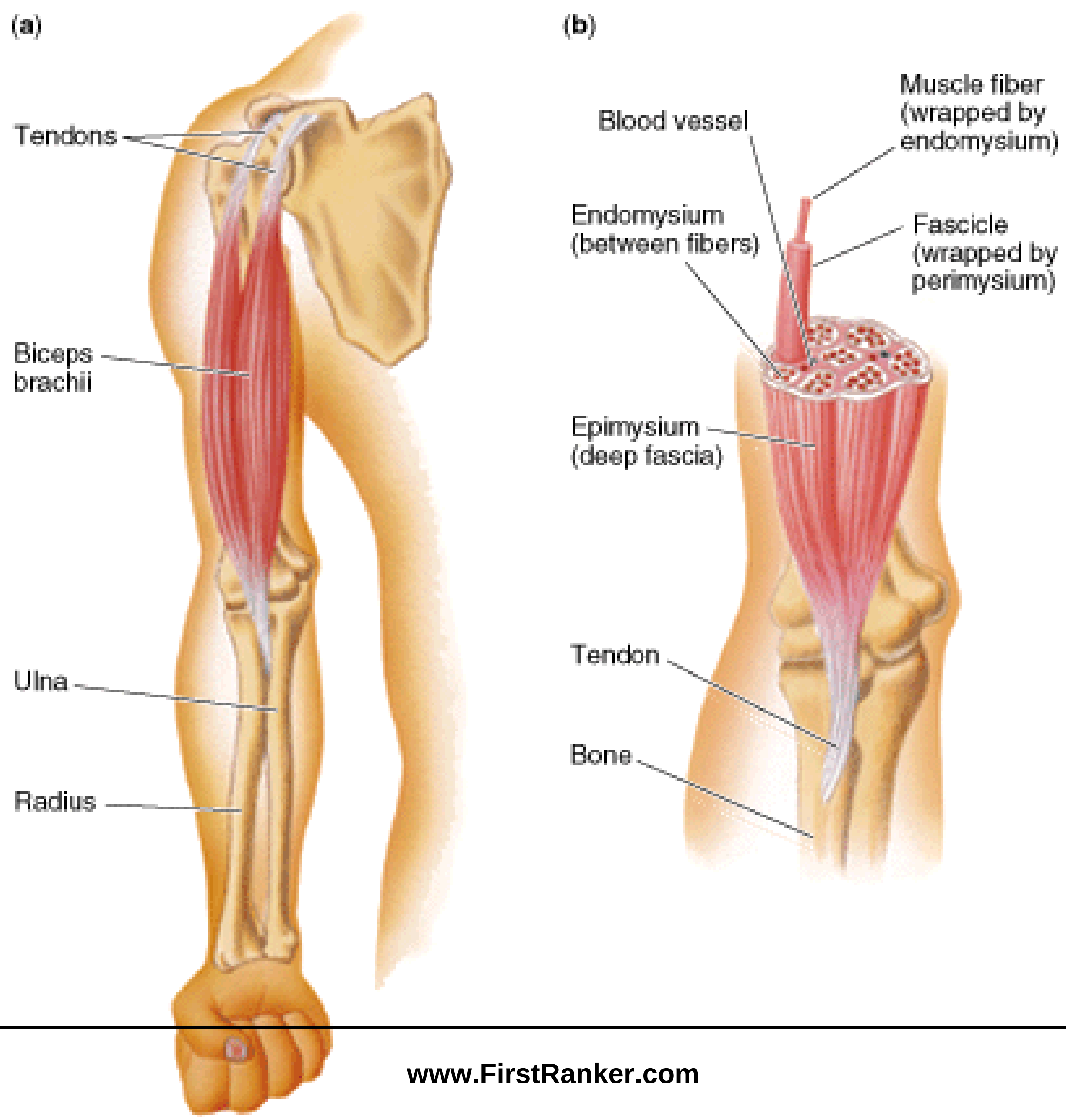
Skeletal Muscle

- Human body contains over 400 skeletal muscles
  - 40-50% of total body weight
- Functions of skeletal muscle
  - Force production for locomotion and breathing
  - Force production for postural support
  - Heat production during cold stress

Structure of Skeletal Muscle: *Connective Tissue Covering*

- Epimysium
  - Surrounds entire muscle
- Perimysium
  - Surrounds bundles of muscle fibers
    - Fascicles
- Endomysium
  - Surrounds individual muscle fibers

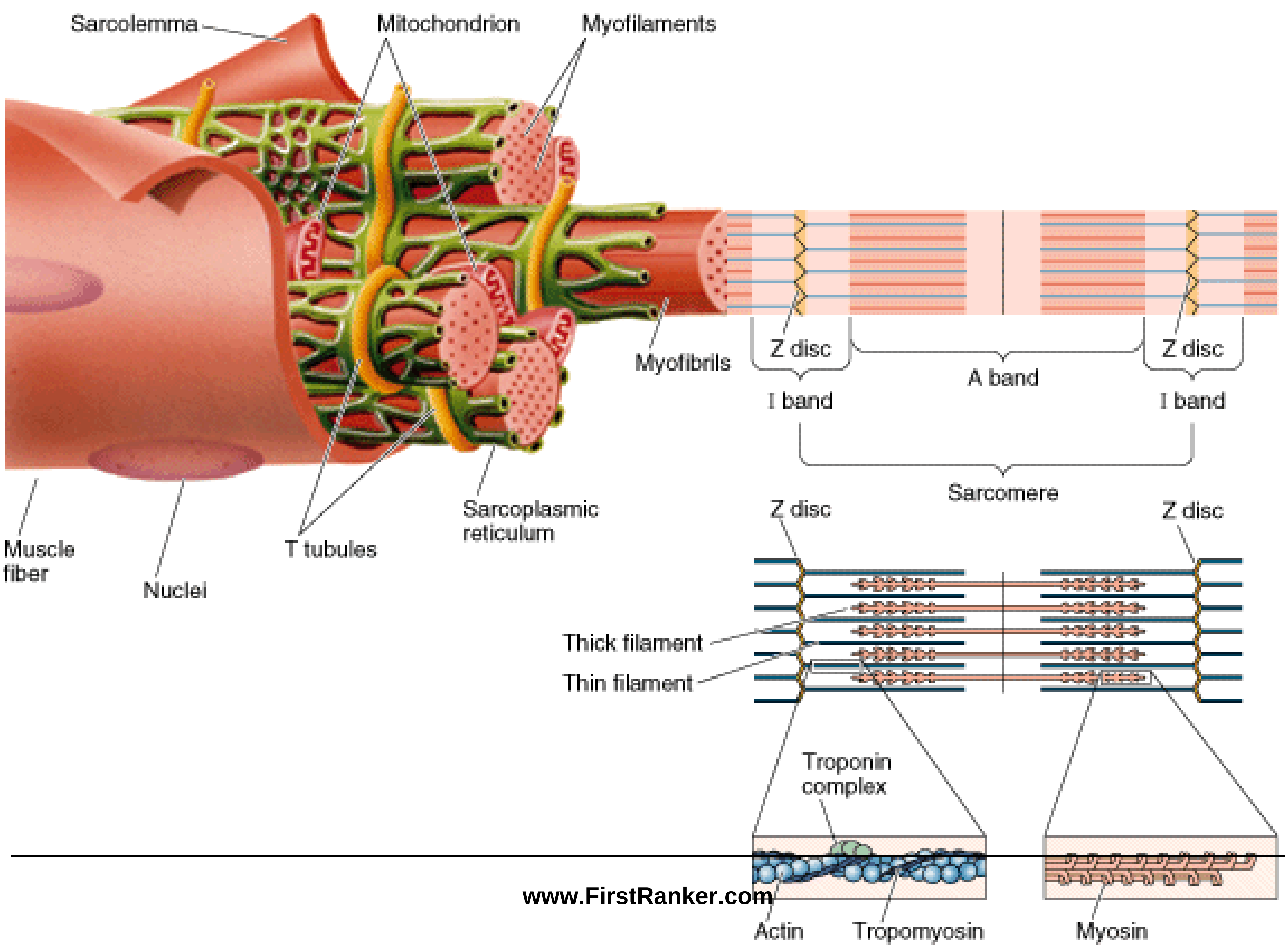
► **Organization of Skeletal Tissue**



Structure of Skeletal Muscle: *Microstructure*

- Sarcolemma
  - Muscle cell membrane
- Myofibrils
  - Threadlike strands within muscle fibers
  - Actin (thin filament)
    - Troponin
    - Tropomyosin
  - Myosin (thick filament)

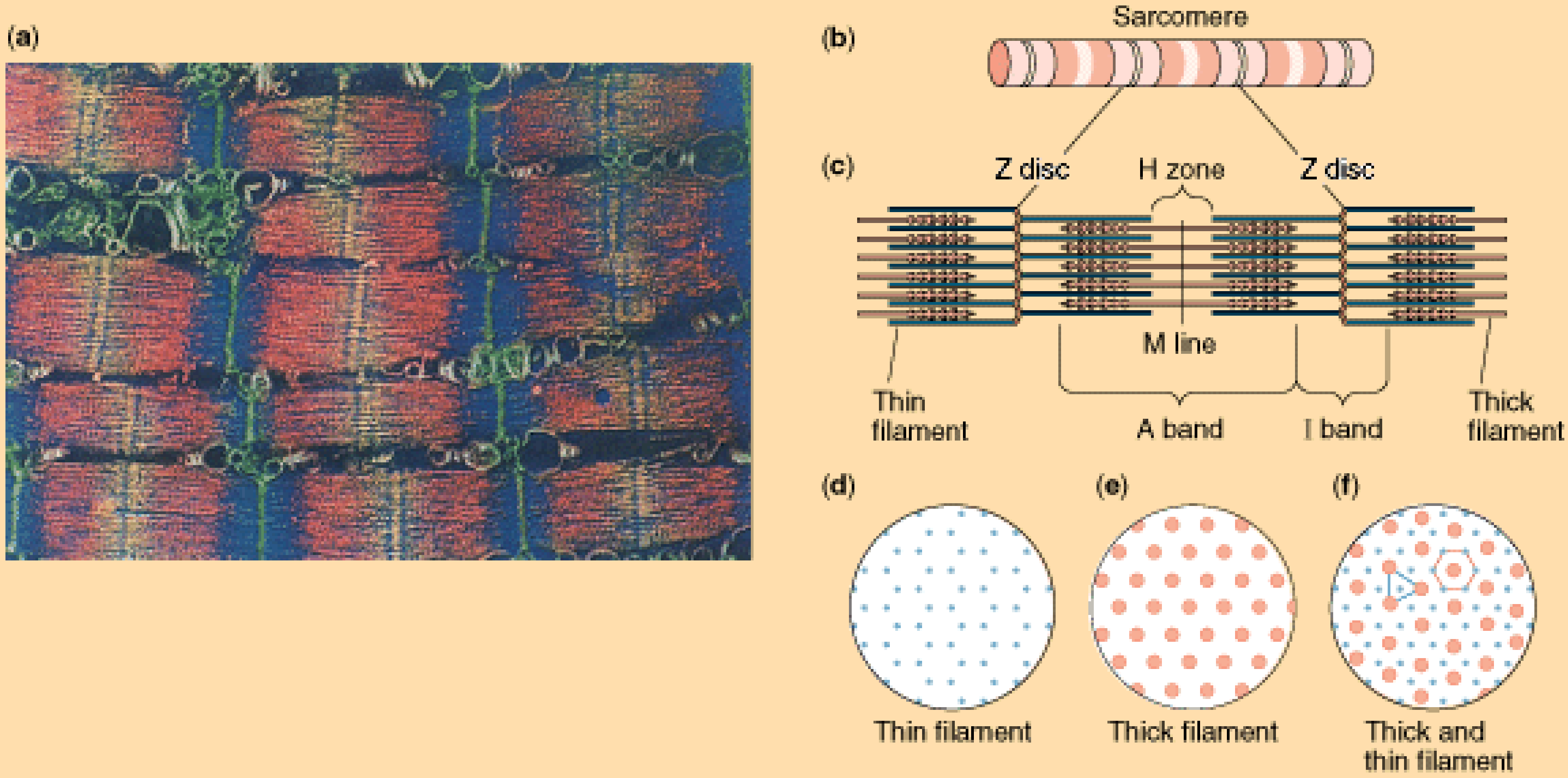
► **Organization of a Muscle Fiber**



Structure of Skeletal Muscle: *The Sarcomere*

- Further divisions of myofibrils
  - Z-line
  - A-band
  - I-band
- Within the sarcoplasm
  - Sarcoplasmic reticulum
    - Storage sites for calcium
  - Transverse tubules
  - Terminal cisternae

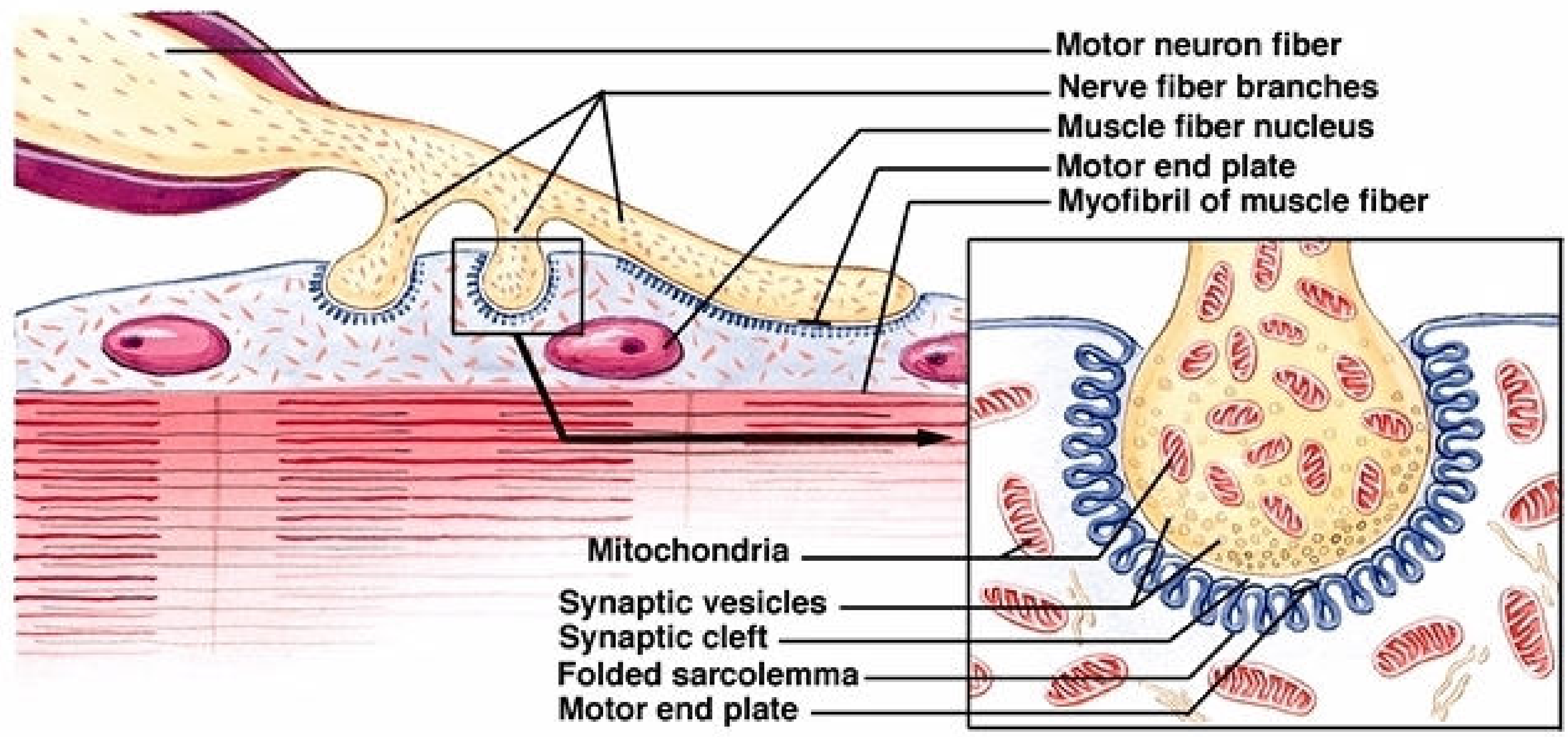
► **Arrangements of Myofilaments in a Sarcomere**



The Neuromuscular Junction

- Site where motor neuron meets the muscle fiber
  - Separated by gap called the neuromuscular cleft
- Motor end plate
  - Pocket formed around motor neuron by sarcolemma
- Acetylcholine is released from the motor neuron
  - Causes an end-plate potential (EPP)
    - Depolarization of muscle fiber

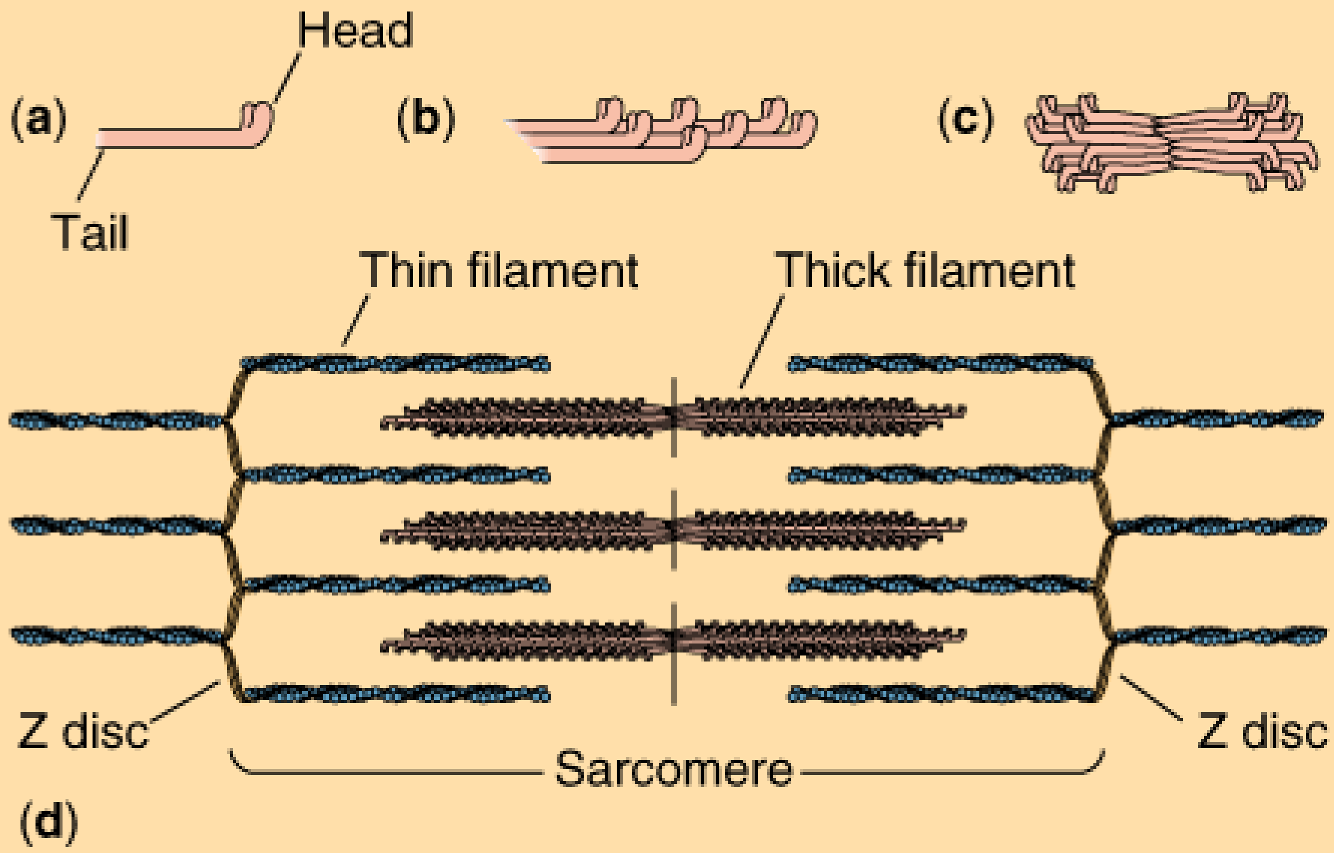
Illustration of the Neuromuscular Junction



Motor Unit

- Single motorneuron & muscle fibers it innervates
- Eye muscles – 1:1 muscle/nerve ratio
- Hamstrings – 300:1 muscle/nerve ratio

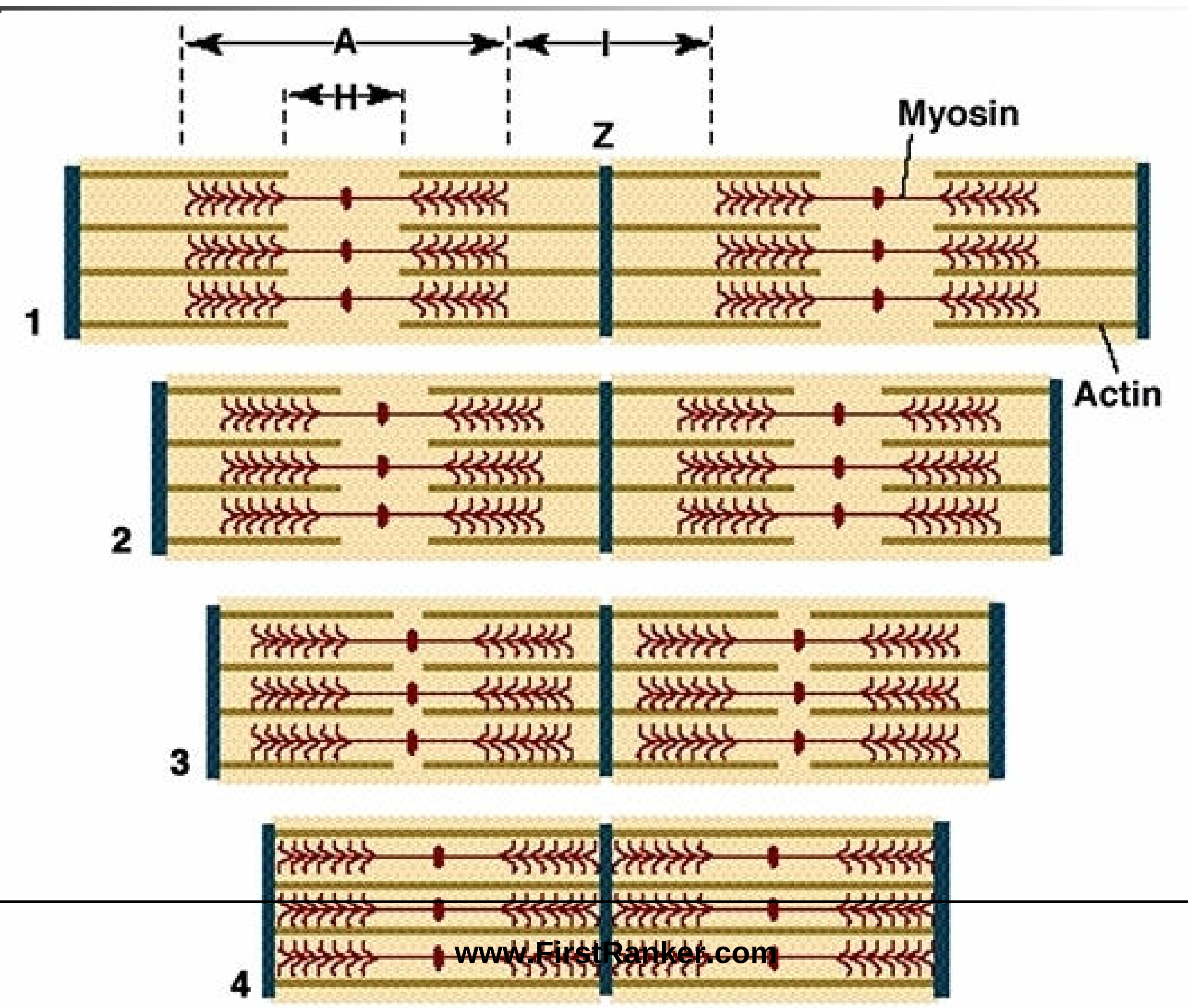
► **Molecular Organization of Thick Filaments**



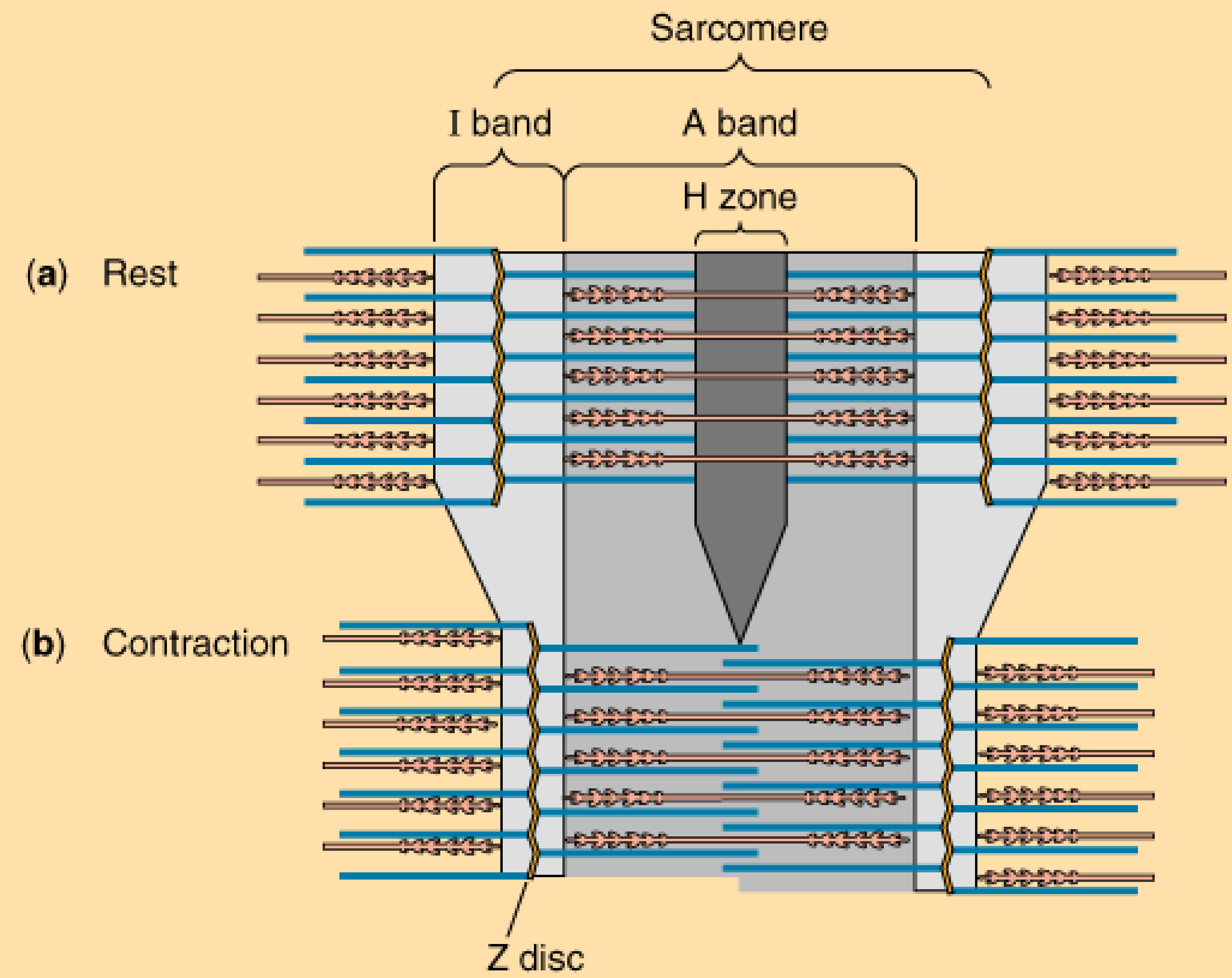
Muscular Contraction

- The sliding filament model
  - Muscle shortening occurs due to the movement of the actin filament over the myosin filament
  - Formation of cross-bridges between actin and myosin filaments
  - Reduction in the distance between Z-lines of the sarcomere

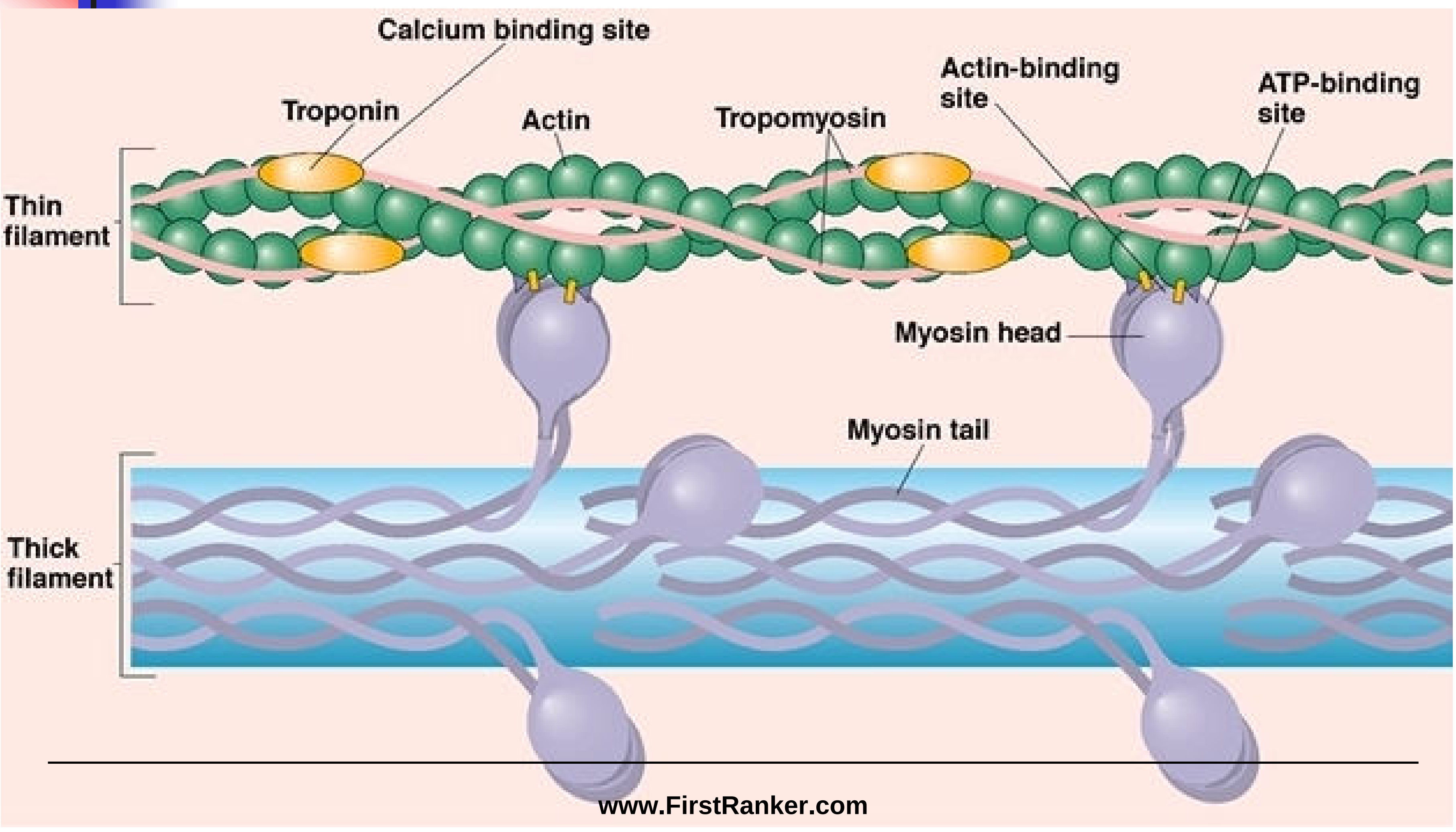
The Sliding Filament Model of Muscle Contraction



▶ **Changes in a Sarcomere During Contraction**



Cross-Bridge Formation in Muscle Contraction



Sliding Filament Theory

- Rest – uncharged ATP cross-bridge complex
- Excitation-coupling – charged ATP cross-bridge complex, "turned on"
- Contraction – actomyosin – ATP > ADP & Pi + energy
- Recharging – reload cross-bridge with ATP
- Relaxation – cross-bridges "turned off"

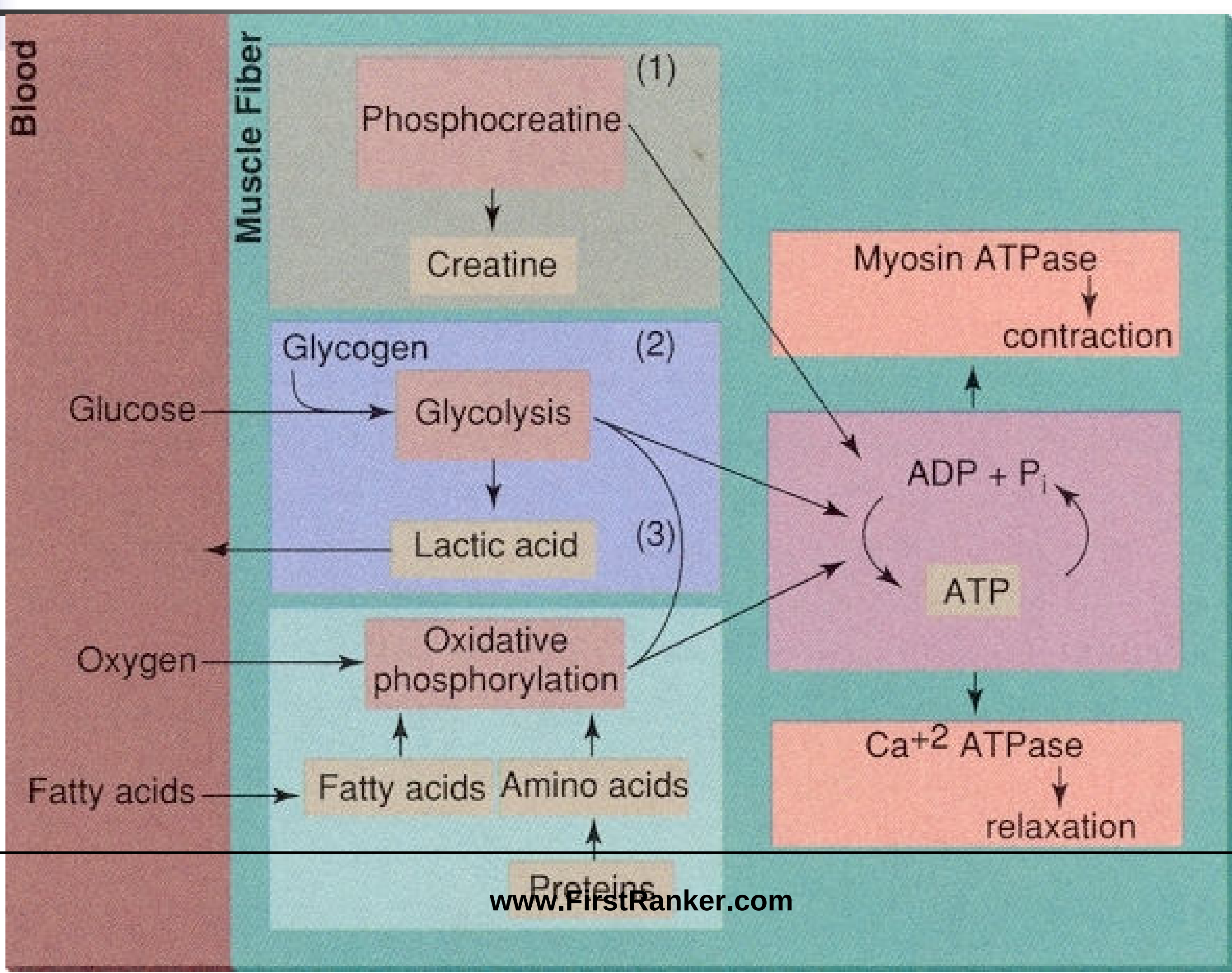
Muscle Function

- All or none law – fiber contracts completely or not at all
- Muscle strength gradation
  - Multiple motor unit summation – more motor units per unit of time
  - Wave summation – vary frequency of contraction of individual motor units

Energy for Muscle Contraction

- ATP is required for muscle contraction
  - Myosin ATPase breaks down ATP as fiber contracts
- Sources of ATP
  - Phosphocreatine (PC)
  - Glycolysis
  - Oxidative phosphorylation

Sources of ATP for Muscle Contraction



Properties of Muscle Fibers

- Biochemical properties
  - Oxidative capacity
  - Type of ATPase
- Contractile properties
  - Maximal force production
  - Speed of contraction
  - Muscle fiber efficiency

Individual Fiber Types

<u>Fast fibers</u>

- Type IIb fibers
  - Fast-twitch fibers
  - Fast-glycolytic fibers
- Type IIa fibers
  - Intermediate fibers
  - Fast-oxidative glycolytic fibers

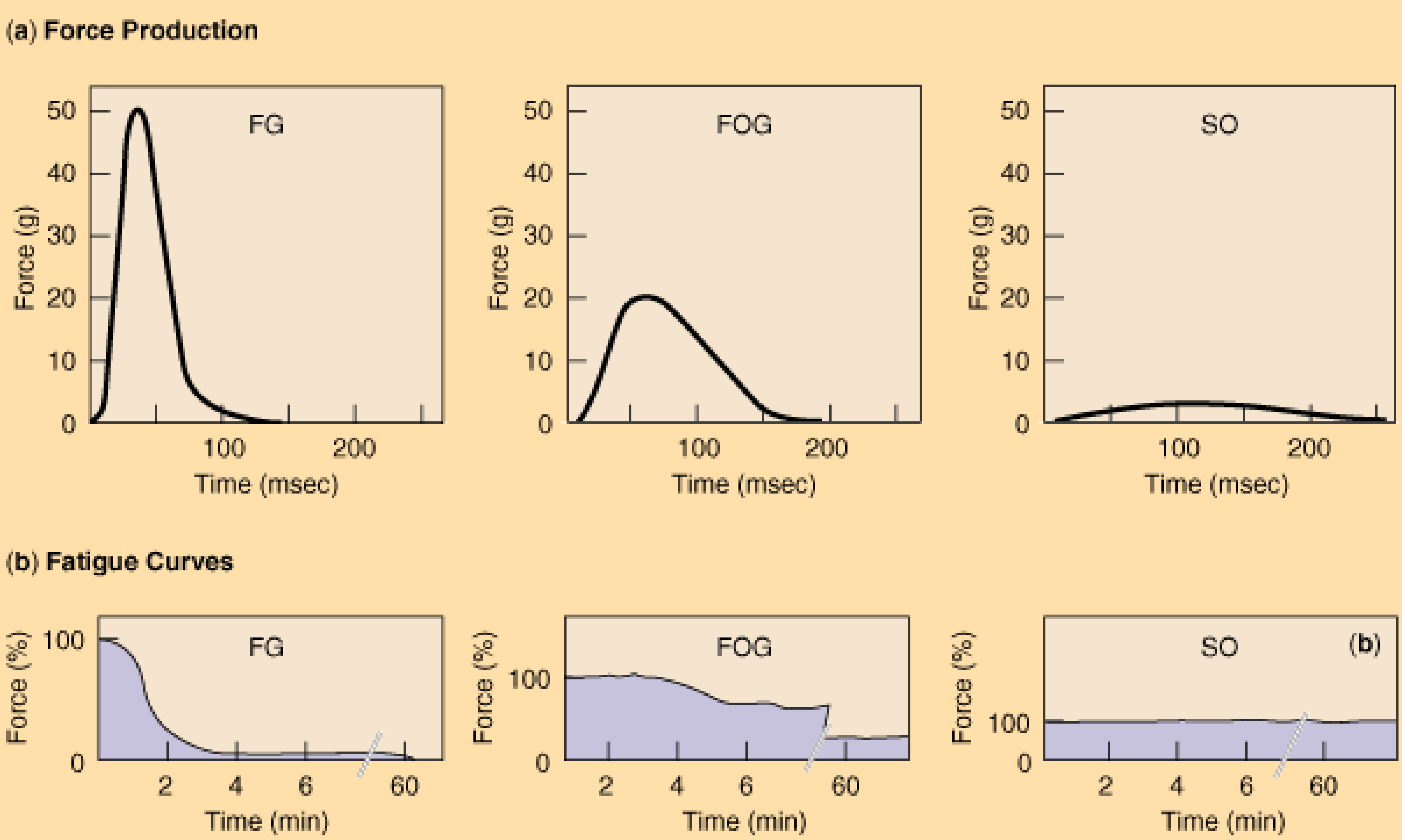
<u>Slow fibers</u>

- Type I fibers
  - Slow-twitch fibers
  - Slow-oxidative fibers

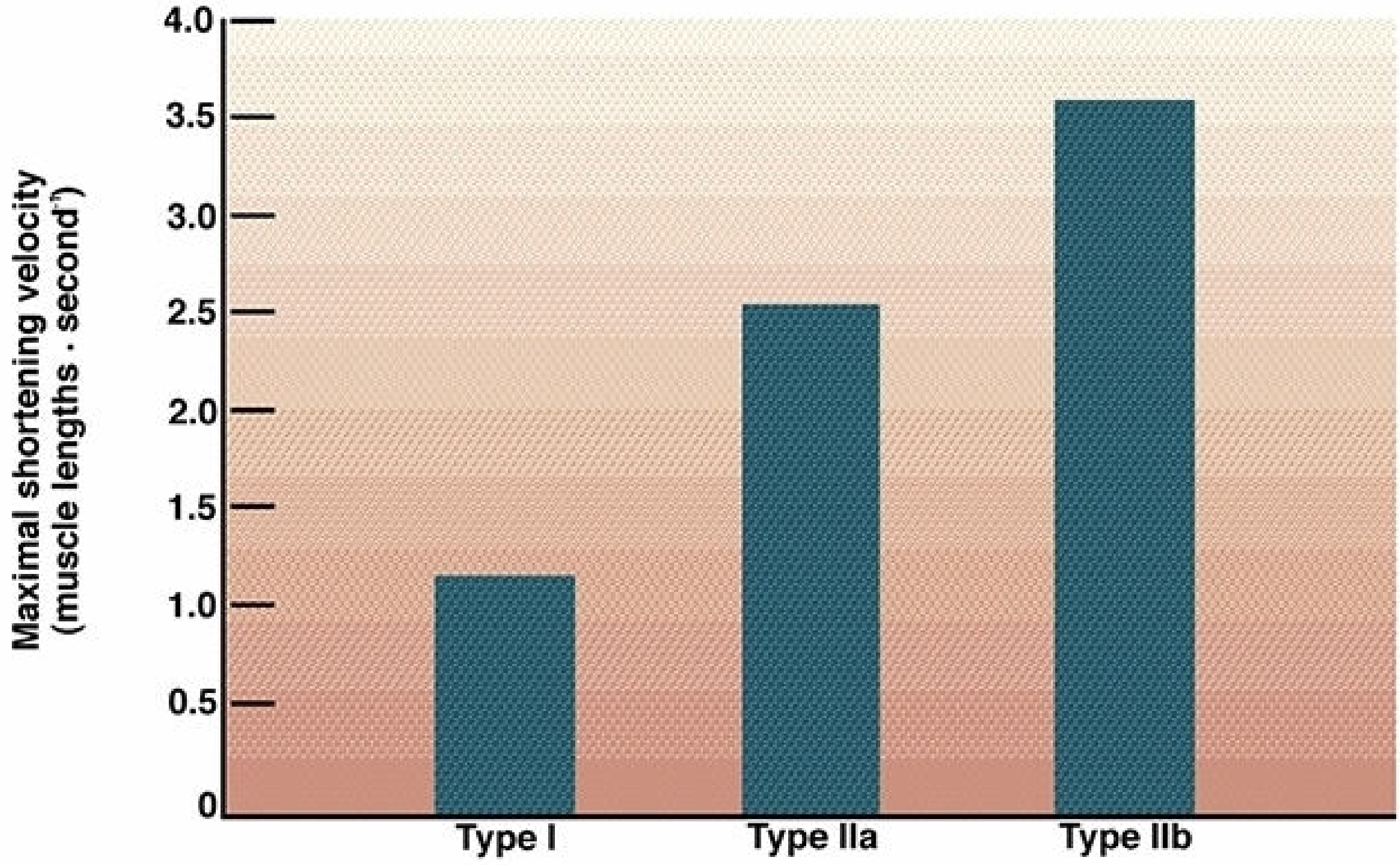
▶ Properties of Motor Units

Muscle Fibers			
Twitch properties	Slow	Fast	
Metabolic properties	Oxidative	Oxidative/ glycolytic	Glycolytic
Name based on twitch and metabolic properties	SO	FOG	FG
Other nomenclature	ST, Type I	FTa, FTA, Type IIA	FTb, FTB, Type IIB
Motor Neurons			
Neuron type	α_2	α_1	α_1
Neuron size	Small	Large	Large
Conduction velocity	Slow	Fast	Fast
Recruitment threshold	Low	High	High

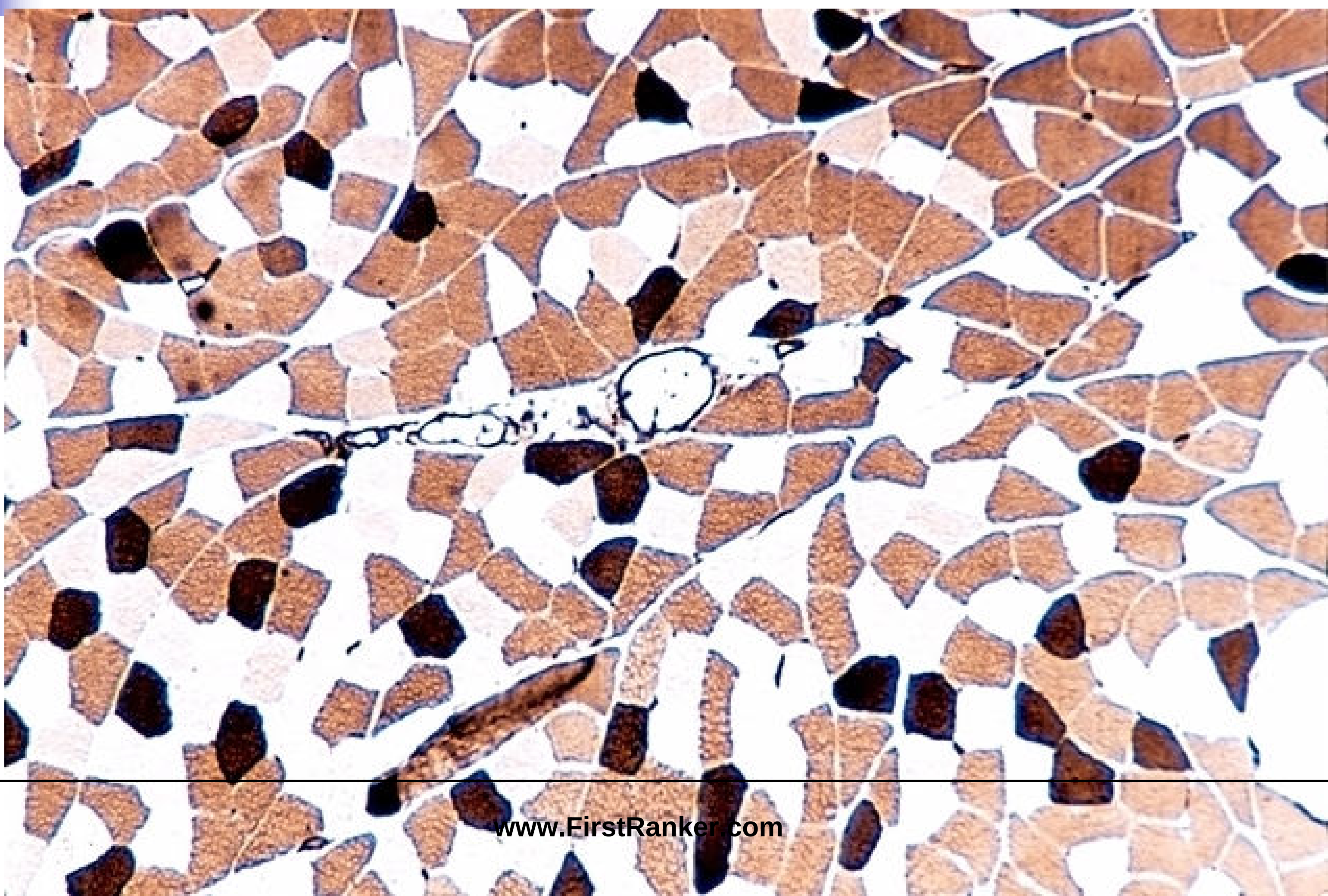
▶ Force Production and Fatigue Curves of Fiber Types



Comparison of Maximal Shortening Velocities Between Fiber Types



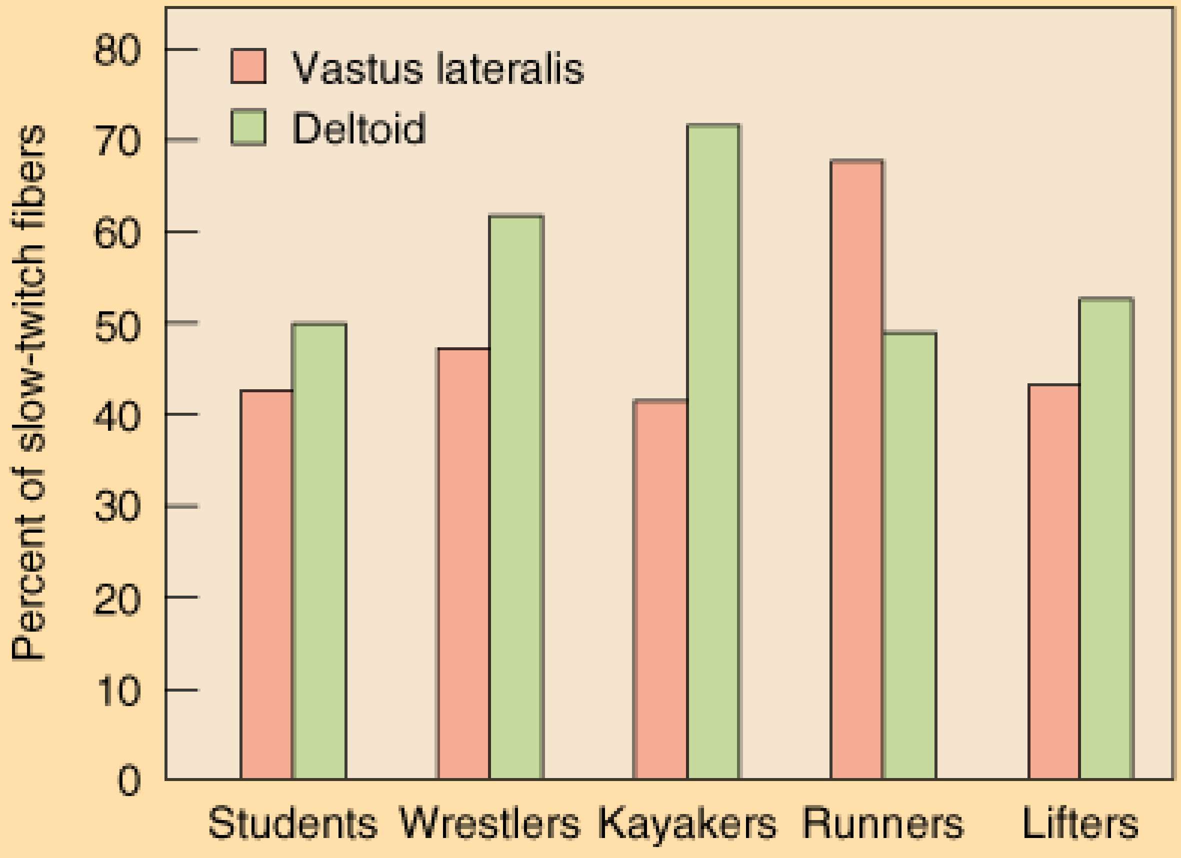
Histochemical Staining of Fiber Type



Fiber Types and Performance

- Power athletes
  - Sprinters
  - Possess high percentage of fast fibers
- Endurance athletes
  - Distance runners
  - Have high percentage of slow fibers
- Others
  - Weight lifters and nonathletes
  - Have about 50% slow and 50% fast fibers

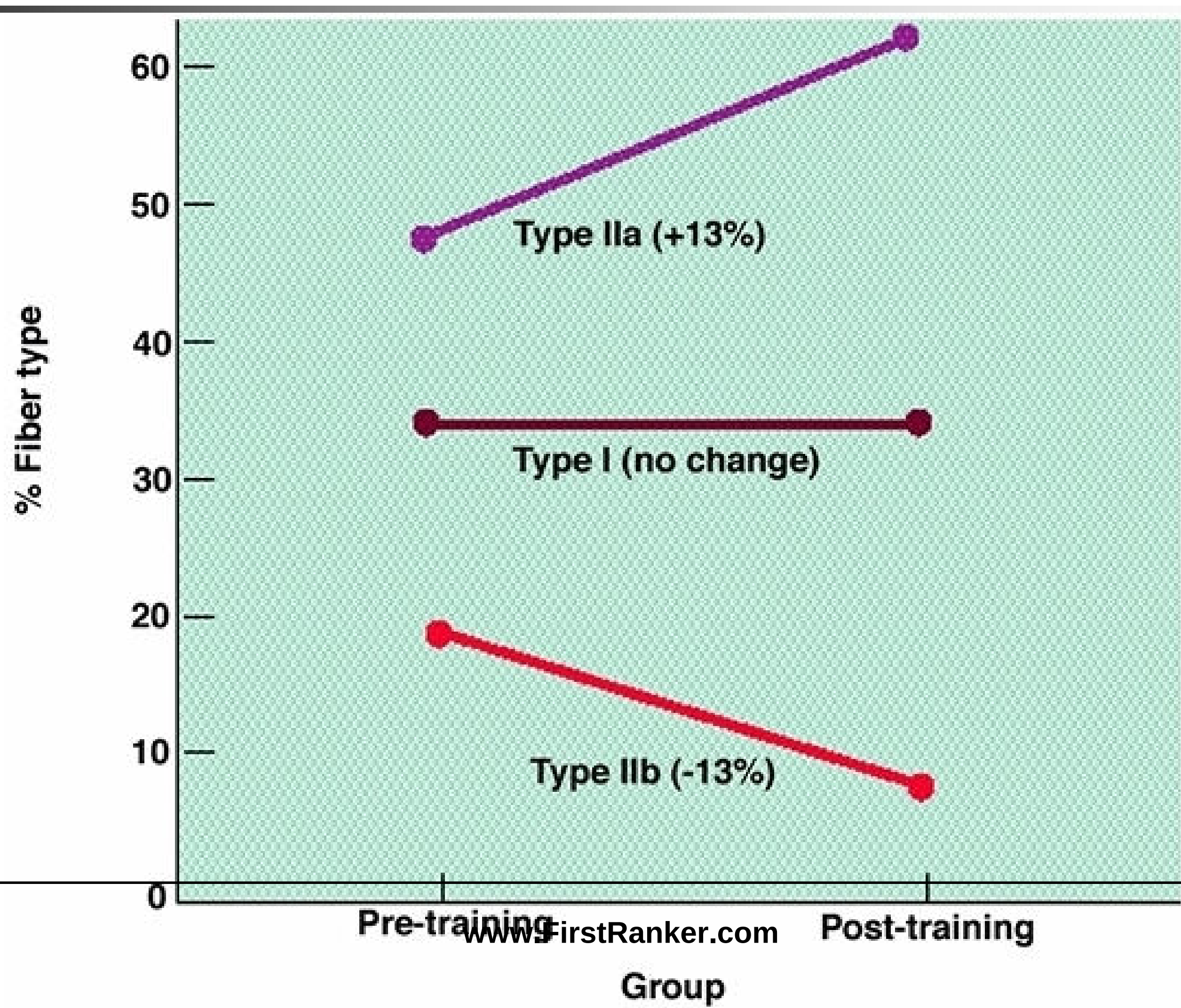
► **Fiber Type Distribution of Different Muscle Groups Among Athletes**



Alteration of Fiber Type by Training

- Endurance and resistance training
  - Cannot change fast fibers to slow fibers
  - Can result in shift from Type IIb to IIa fibers
    - Toward more oxidative properties

Training-Induced Changes in Muscle Fiber Type



Hypertrophy and Hyperplasia

- Increase in size
- Increase in number

Age-Related Changes in Skeletal Muscle

- Aging is associated with a loss of muscle mass
  - Rate increases after 50 years of age
- Regular exercise training can improve strength and endurance
  - Cannot completely eliminate the age-related loss in muscle mass

Types of Muscle Contraction

- Isometric
  - Muscle exerts force without changing length
  - Pulling against immovable object
  - Postural muscles
- Isotonic (dynamic)
  - Concentric
    - Muscle shortens during force production
  - Eccentric
    - Muscle produces force but length increases

Isotonic and Isometric Contractions

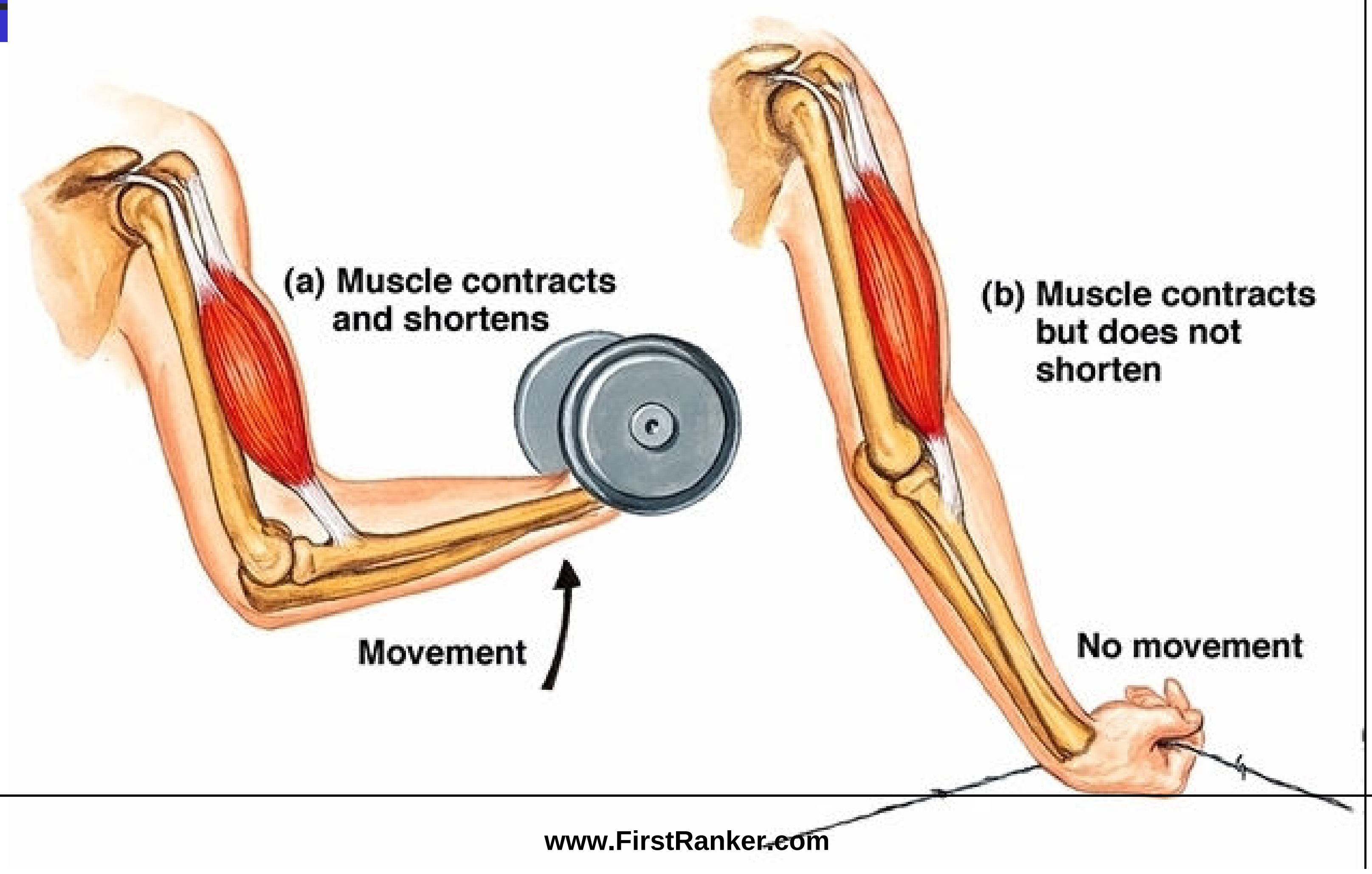
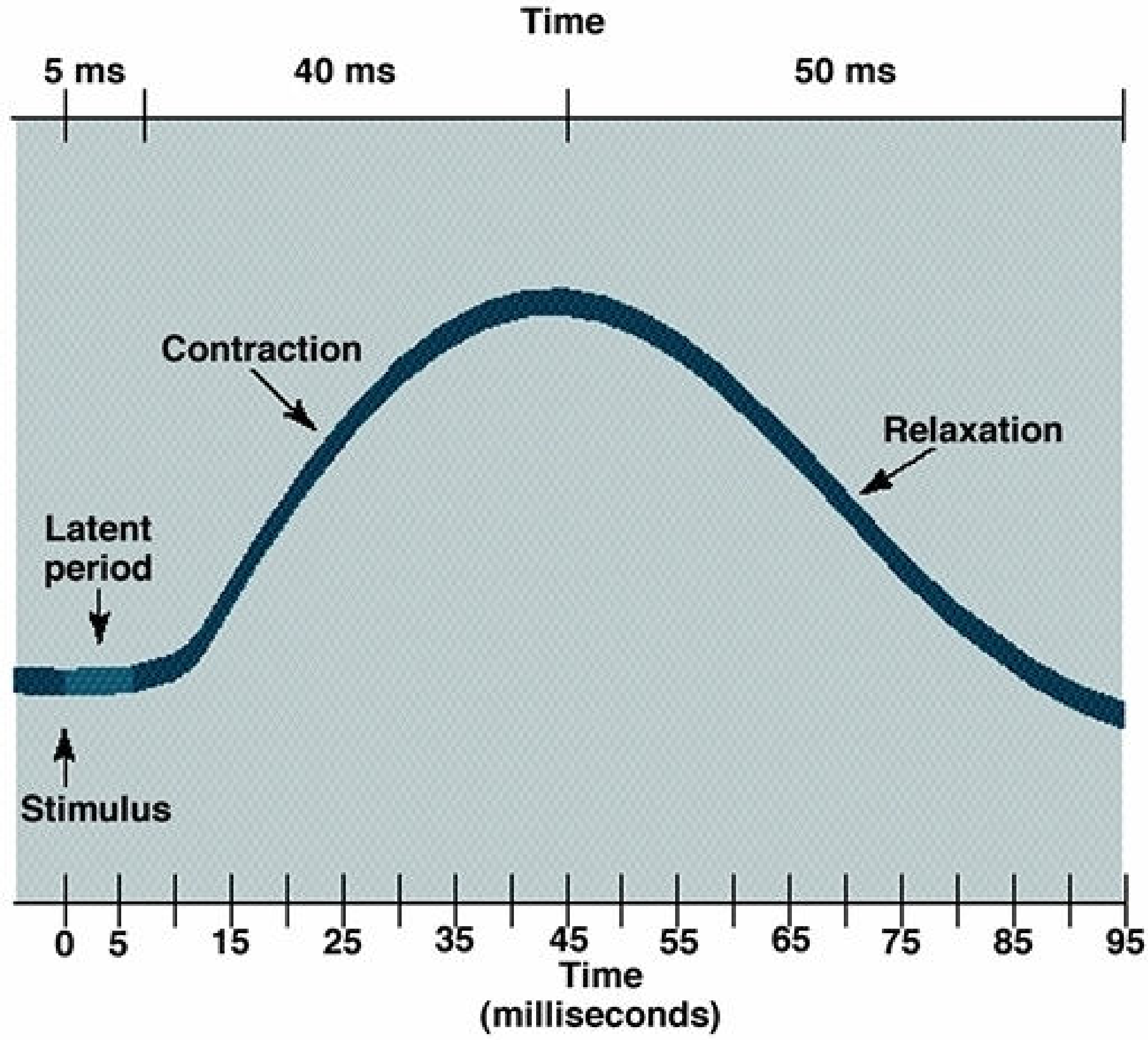


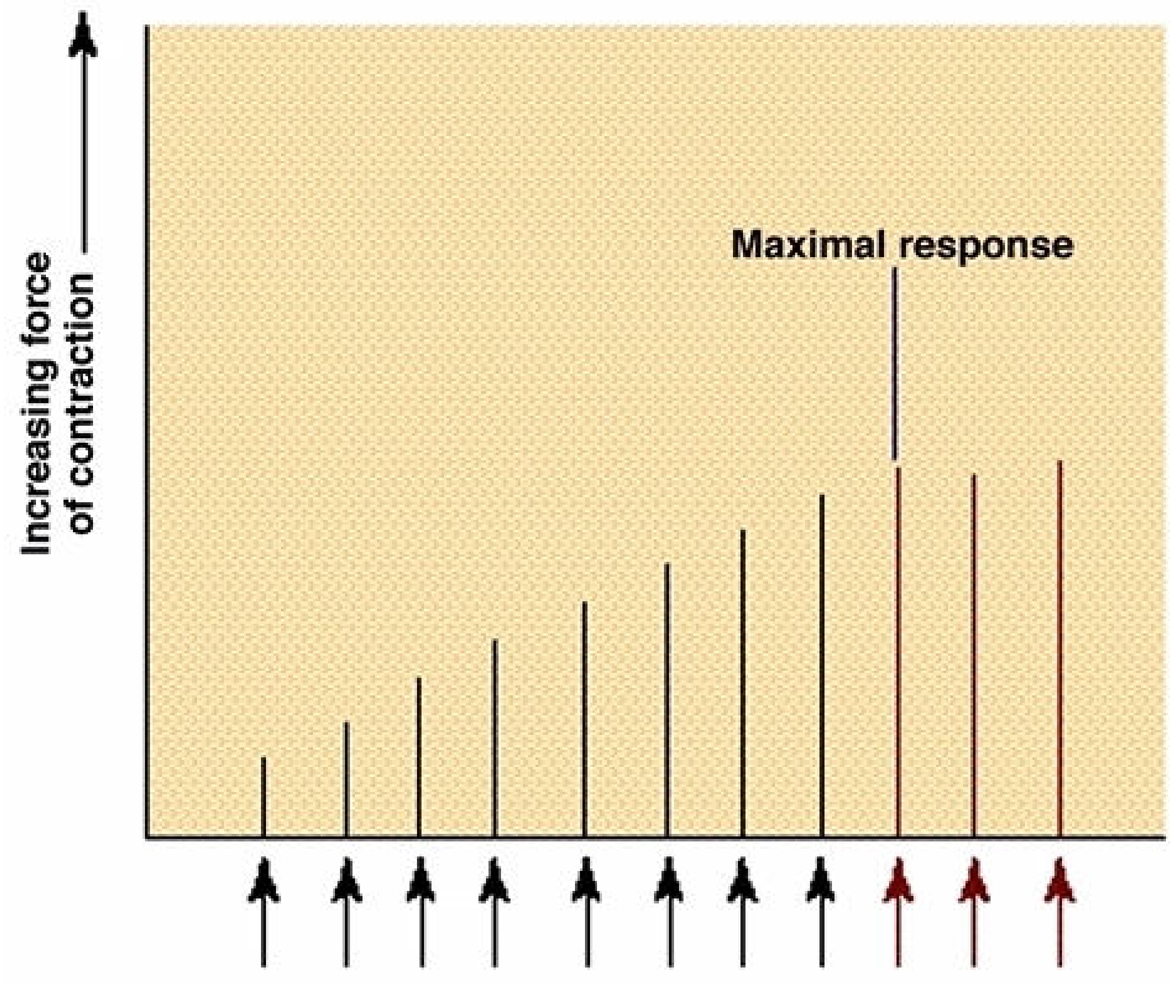
Illustration of a Simple Twitch



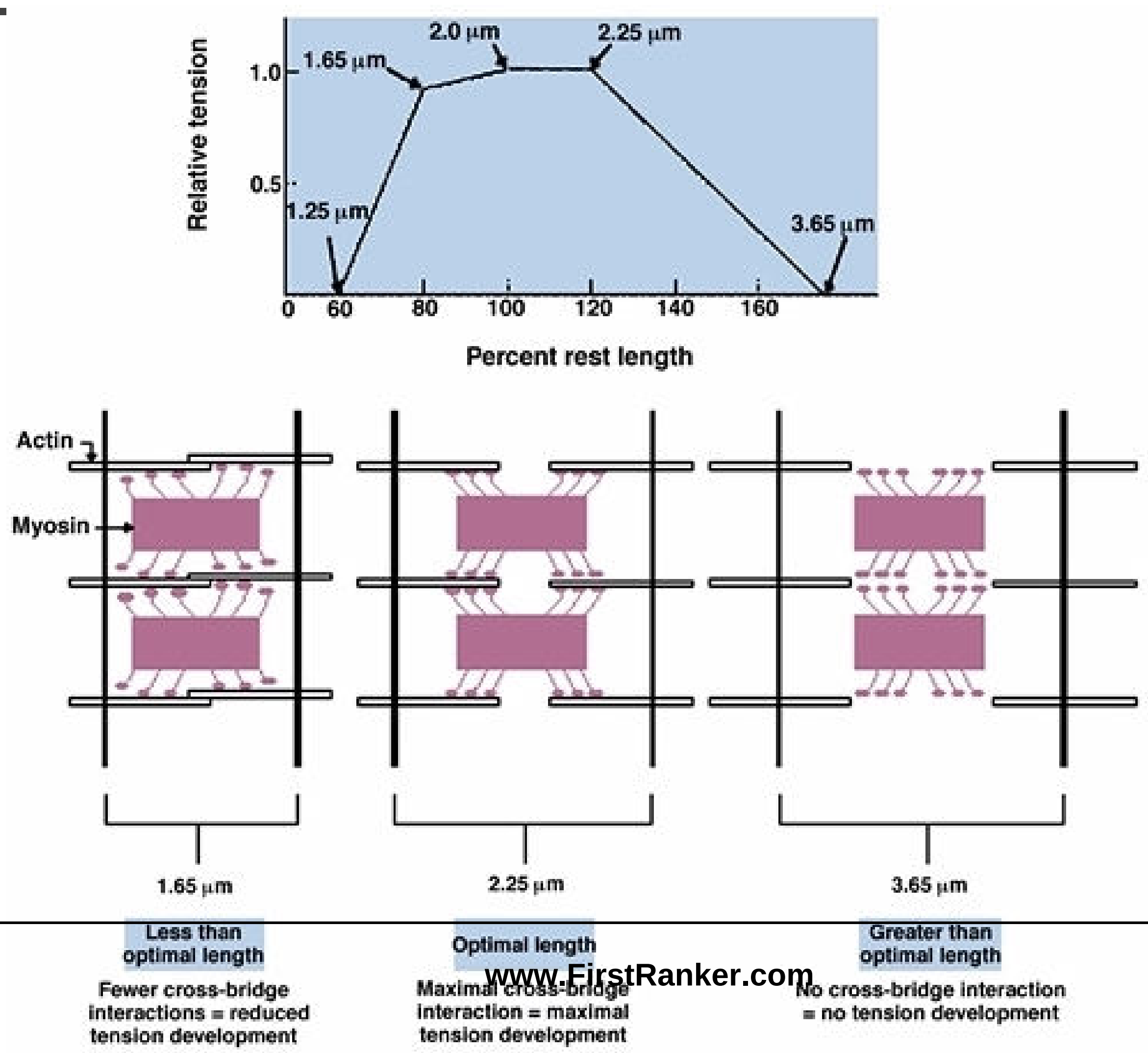
Force Regulation in Muscle

- Types and number of motor units recruited
  - More motor units = greater force
  - Fast motor units = greater force
- Initial muscle length
  - "Ideal" length for force generation
- Nature of the motor units neural stimulation
  - Frequency of stimulation
    - Simple twitch, summation, and tetanus

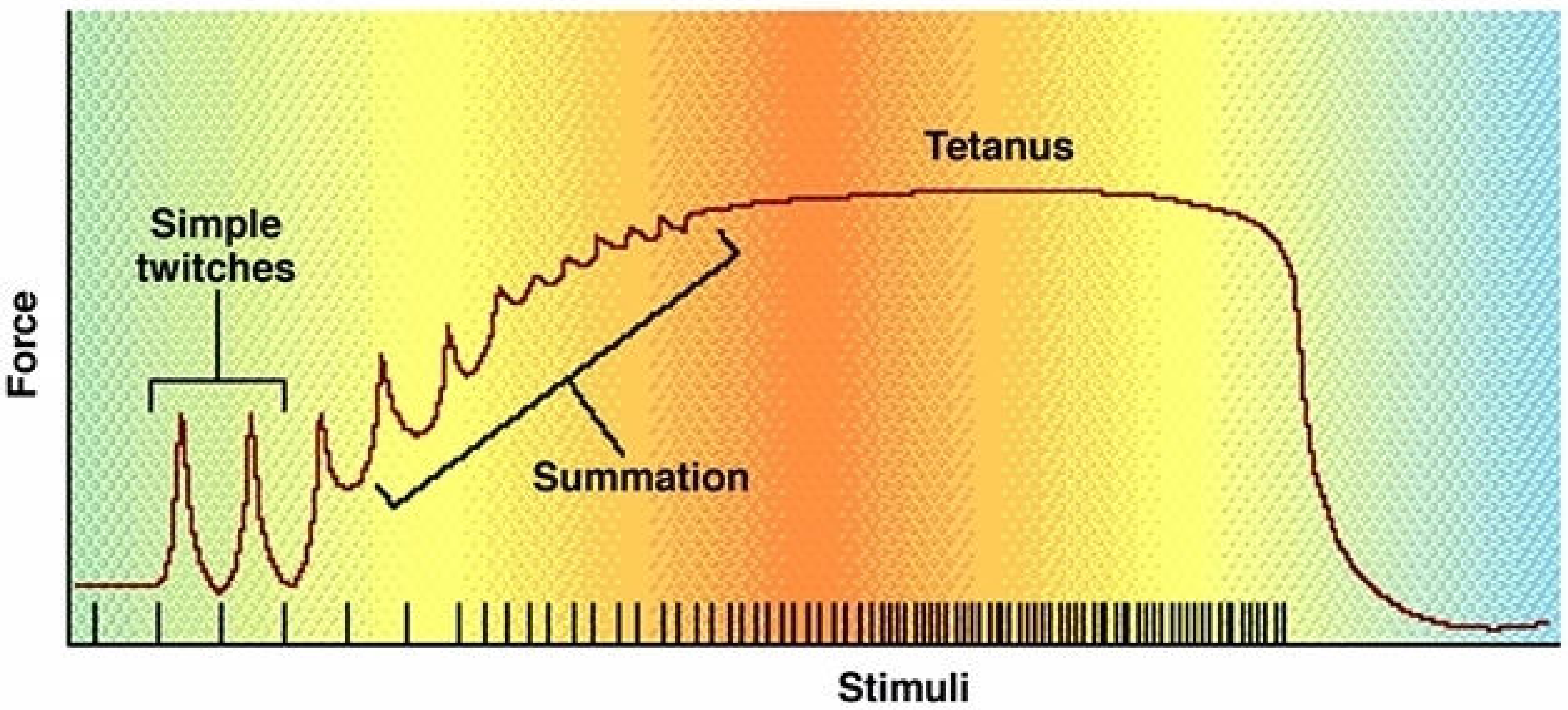
Relationship Between Stimulus Frequency and Force Generation



Length-Tension Relationship in Skeletal Muscle



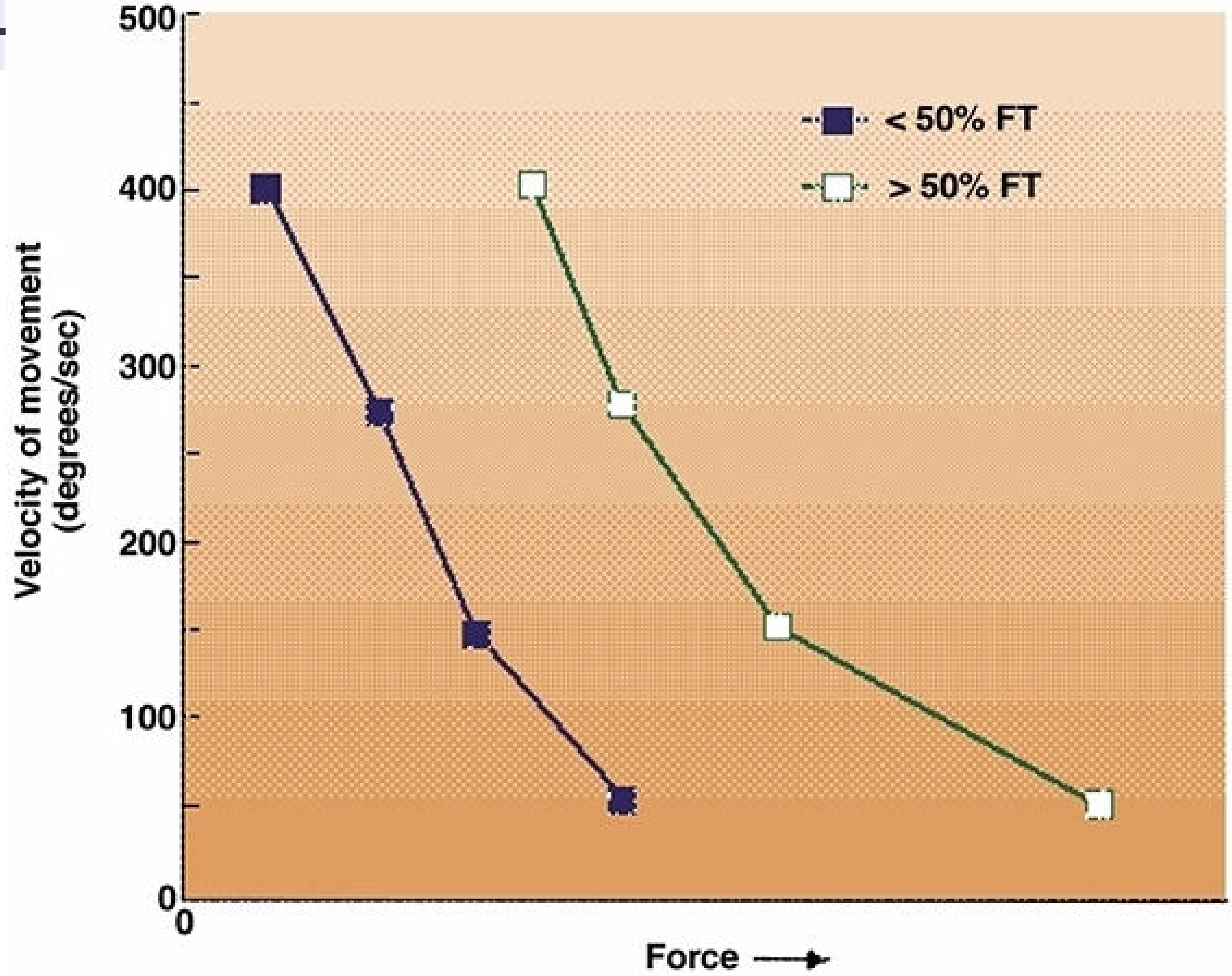
Simple Twitch, Summation, and Tetanus



Force-Velocity Relationship

- At any absolute force the speed of movement is greater in muscle with higher percent of fast-twitch fibers
- The maximum velocity of shortening is greatest at the lowest force
  - True for both slow and fast-twitch fibers

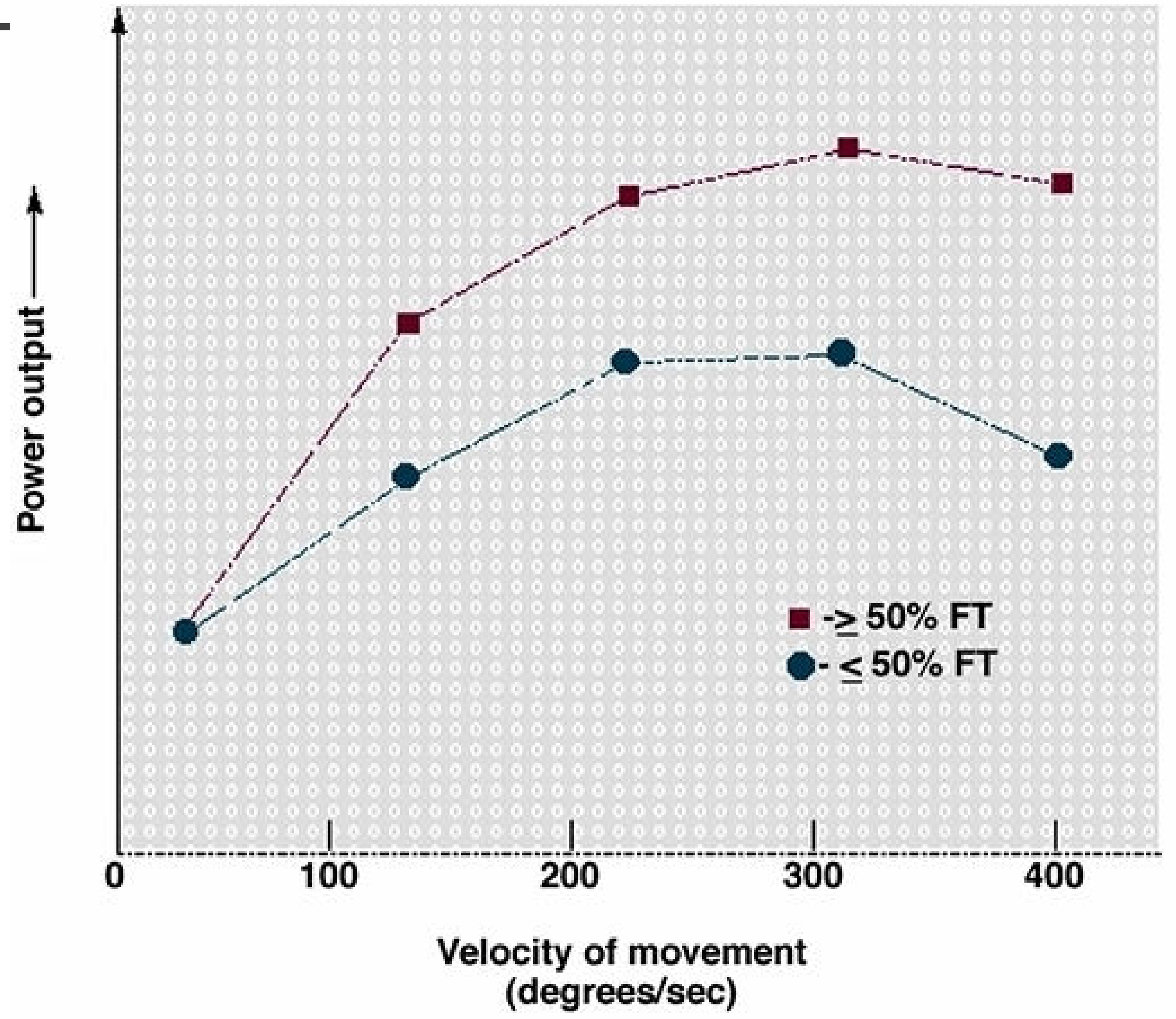
Force-Velocity Relationship



Force-Power Relationship

- At any given velocity of movement the power generated is greater in a muscle with a higher percent of fast-twitch fibers
- The peak power increases with velocity up to movement speed of 200-300 degrees•second^{-1}
  - Force decreases with increasing movement speed beyond this velocity

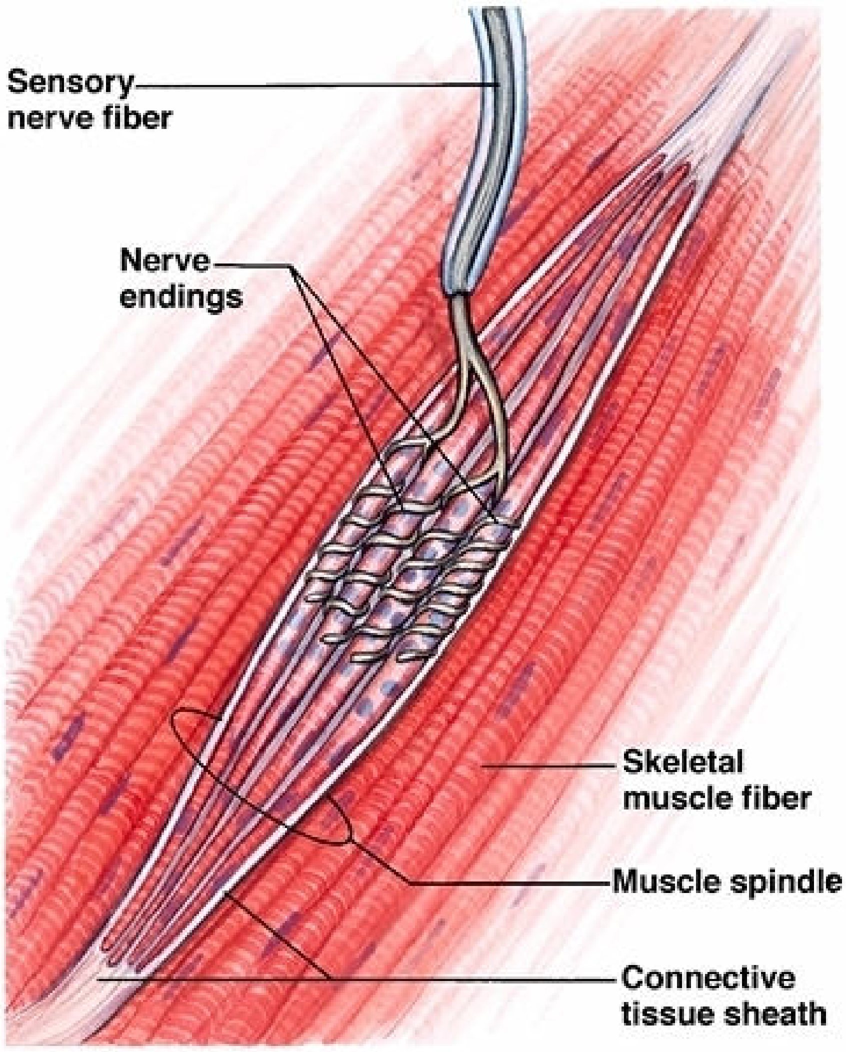
Force-Power Relationship



Receptors in Muscle

- Muscle spindle
  - Detect dynamic and static changes in muscle length
  - Stretch reflex
    - Stretch on muscle causes reflex contraction
- Golgi tendon organ (GTO)
  - Monitor tension developed in muscle
  - Prevents damage during excessive force generation
    - Stimulation results in reflex relaxation of muscle

Muscle Spindle



Golgi Tendon Organ