Biology 48 - Human Physiology
Lecture Summary Sheet - Norris

Muscle Physiology

I. Three types of muscle tissue
   A. Skeletal (striated, voluntary)
   B. Visceral or Smooth (nonstriated, involuntary)
   C. Cardiac (striated, involuntary)

II. Basic Functions of Muscle
   A. Movement (primary)
   B. Maintain Posture
   C. Heat Generation

III. General Characteristics of Muscle
   A. Excitability
   B. Contractility
   C. Extensibility
   D. Elasticity

IV. Microscopic Structure / Anatomy (Skeletal Muscle)
   A. Sarcolemma (plasma membrane)
      1. Transverse tubules (T-tubules)
   B. Sarcoplasm (cytoplasm)
   C. Specialized organelles:

      1. Sarcoplasmic Reticulum (smooth endoplasmic reticulum)

      2. Myofibrils
         a. Sarcomere
            i. I band
            ii. A band

      3. Myofilaments (cytoskeleton)
         a. thick filaments (myosin)

         b. thin filaments (actin, tropomyosin and troponin)

V. Physiology of Skeletal Muscle Contraction
   A. Sliding Filament Theory
      1. Actin-Myosin Interaction

         a. actin-myosin binding
         b. power stroke / release of ADP + Pi
         c. ATP binding / unbinding of actin-myosin
         d. ATP hydrolysis / cocking of myosin head

   B. Activation of Muscular Contraction
      1. Anatomy of the Synapse – the "neuromuscular junction"
         a. neuron terminal
         b. synaptic cleft
         c. motor end plate

      2. motor units

3. Sequence (Excitation-Contraction Coupling):
    a. AP arrives at neuron terminal (at neuromuscular junction), Ca^{2+} rushes into terminal
    b. Vesicles release ACh into synaptic cleft, ACh diffusesacross synaptic cleft
    c. ACh binds to receptors on motor end plate (ACh destroyed by acetylcholinesterase)
    d. Chemically gated Na^{+} channels open in response to ACh binding – Na^{+} enters and produces a depolarizing graded potential (EPP)
    e. Graded potential triggers voltage gated channels producing an action potential
    f. AP propagates along membrane and down T-tubules opening Ca^{2+} channels in SR
    g. Sarcoplasmic reticulum releases calcium ions into sarcoplasm
    h. Calcium binds to troponin, troponin-tropomyosin moves exposing binding sites on actin
    i. Myosin heads bind to sites on actin and pull (power stroke)
    j. Relaxation occurs when Ca^{2+} is removed (actively pumped back into SR)

VI. Muscle Responses

A. Twitch Components
1. Latent Period
2. Contractile Interval
3. Relaxation Interval

B. Single Cell Contractile Properties
1. All-or-None
2. Temporal Summation (“piggyback”)
3. Length-Tension Relationship

C. Whole Muscle Contractile Properties
1. Spatial Summation ("recruitment")
2. Temporal (asynchronous contraction)
3. Elastic Components
4. Muscle Tone

VII. Endurance

A. Blood Supply

B. Fiber Type
1. slow twitch (type I) - aerobic
2. fast twitch (type II) - anaerobic

C. Fatigue

D. Oxygen Debt

VIII. Neural Control

A. Sensory Receptors
1. Golgi Tendon Organs

2. Muscle Spindles
   a. Extrafusal Fibers
   b. Intrafusal Fibers
   c. Sensory Endings

B. Skeletal Muscle Innervation
1. Lower Motor Neurons - "final common pathway"
   a. Alpha Motor Neurons - extrafusal fibers
   b. Gamma Motor Neurons - intrafusal

IX. Smooth Muscle
A. Structure / Anatomy

1. Filament Arrangement

2. Gap Junctions

B. Mechanism of Activation
1. Calcium Channels
2. Indirect Activation of Myosin

C. Types of Smooth Muscle
1. Single Unit
2. Multiple Unit

D. Special Features
1. Active Range (can contract over a long range of stretch)
2. Myogenic Contraction (intrinsically contracts in response to stretch)
3. Activated by Ca^{2+} influx (may be associated with AP or GP)

X. Cardiac Muscle - to be covered in detail at a later time
A. Structure / Anatomy

B. Functional Syncytium

XI. Additional Key Terms

aerobic	anaerobic	ATP	atrophy	creatine phosphate	extrafusal	hypertrophy
in vitro	in vivo	intrafusal	isometric	isotonic	recruitment	tetanus

Study Questions – Muscle Physiology:

1. Compare and contrast Skeletal, Visceral and Cardiac muscle. Discuss each in terms of location, histology, control and general structure.
2. Describe the basic functions of muscle.
3. Identify and describe the four general characteristics of muscle.
4. Name and describe the different components (aka organelles) of a skeletal muscle cell. Describe the function of each, and their structural and functional relationship to each other.
5. Describe the structure of the myofibril. Identify the different bands and explain them with reference to the arrangement of the thin and thick filaments.
6. Describe the structural and functional relationship between the bands in the myofibril and the T-tubule.
7. Describe the molecular structure of the thin and thick filaments. Explain the significance of the different molecular components.
8. Myosin exhibits three different properties necessary to its role in contraction, what are they?
9. What is the functional significance of the troponin-tropomyosin complex?
10. Describe the evidence supporting the sliding filament theory (as opposed to filament shortening).
11. Describe the sequence of events of the sliding filament phase of contraction (see fig 1). When is calcium needed? At which two points is ATP required?
12. Describe the structure of a generic chemical synapse. Compare and contrast the neuromuscular junction with this generic synapse.
13. What is a motor unit?
14. Explain in detail ALL of the events leading up to contraction beginning at the time the nerve impulse (action potential) arrives at the neuron terminal of the neuromuscular junction.
15. What is a muscle twitch?
16. Define and describe what is occurring during the latent, contraction and relaxation intervals of a muscle twitch.
17. What does “all-or-none” mean?
18. Define “temporal summation”. Describe temporal summation as it applies to a single muscle cell.
19. Describe and explain how the initial length of the muscle cell (or sarcomere) influences the contractile strength of the muscle cell.
20. Define “spatial summation”. Describe spatial summation as it applies to a muscle.
21. Describe the pattern of motor unit recruitment as muscle contraction strength increases. How does this influence the fine control of a muscle as contraction strength increases?
22. Explain how a muscle can contract continuously without any of the cells within the muscle contracting continuously.
23. Compare and contrast slow and fast twitch muscle fibers.
24. Define “oxygen debt”.
25. Describe the location, general structure and function of Golgi tendon organs and muscle spindles. What do these receptors respond to?
26. How do smooth muscle cells structural differ from skeletal muscle cells?
27. How do smooth muscle cells functionally differ from skeletal muscle cells?
28. Distinguish between single unit and multi-unit smooth muscle.
29. Compare and contrast the structure of skeletal, visceral and cardiac muscle cells.
30. Compare and contrast the functional characteristics of skeletal, visceral and cardiac muscle cells.

THE LOVE STORY OF ACTIN AND MYOSIN

By C. Norton

The Cast of Characters: The Lovers: Actin and Myosin (seeking chemical bondage)
The Jealous Stepmother: Troponin
The "Innocent" Accomplice: Tropomyosin
The Diversion: Calcium
The Spark of Love: Any Neural Impulse
The "Fools": All the Crossbridges

ONCE UPON a time there were two protein filaments called Actin and Myosin. Actin was rather slight of build whereas Myosin was quite hefty and of considerable size. Despite these differences, however, these two proteins were very much in love and whenever together displayed a strong chemical and physical attachment. Unfortunately, Actin and Myosin were kept apart by the action of Actin's ugly stepmother, Troponin. Troponin, with the help of her accomplice, Tropomyosin, literally stayed on Actin's back and made her work so hard she didn't have the energy necessary to "slip" away to see Myosin. Actin beseeched the Fairy of Love to help put an end to her misery and inactivity and much to her surprise her wishes were answered one day with a Spark of Love. The Spark of Love showered Actin and Myosin with Calcium. The stepmother, Troponin, was quite taken by this new fellow and immediately bound Calcium to her chemical complex changing her conformation and that of Tropomyosin. Upon seeing this change, Actin's activation sites were "turned on" and she broke away from Troponin's hold. Now that Actin was free to "turn-on", Myosin became charged too. Within an instant, the Crossbridges were extended and the filaments were in chemical bondage (called Acto-Myosin). As long as the Spark of Love remained, the Calcium bound to Troponin and ATP was sufficient, Acto-Myosin lived happily ever after and the love story of Actin and Myosin is complete.

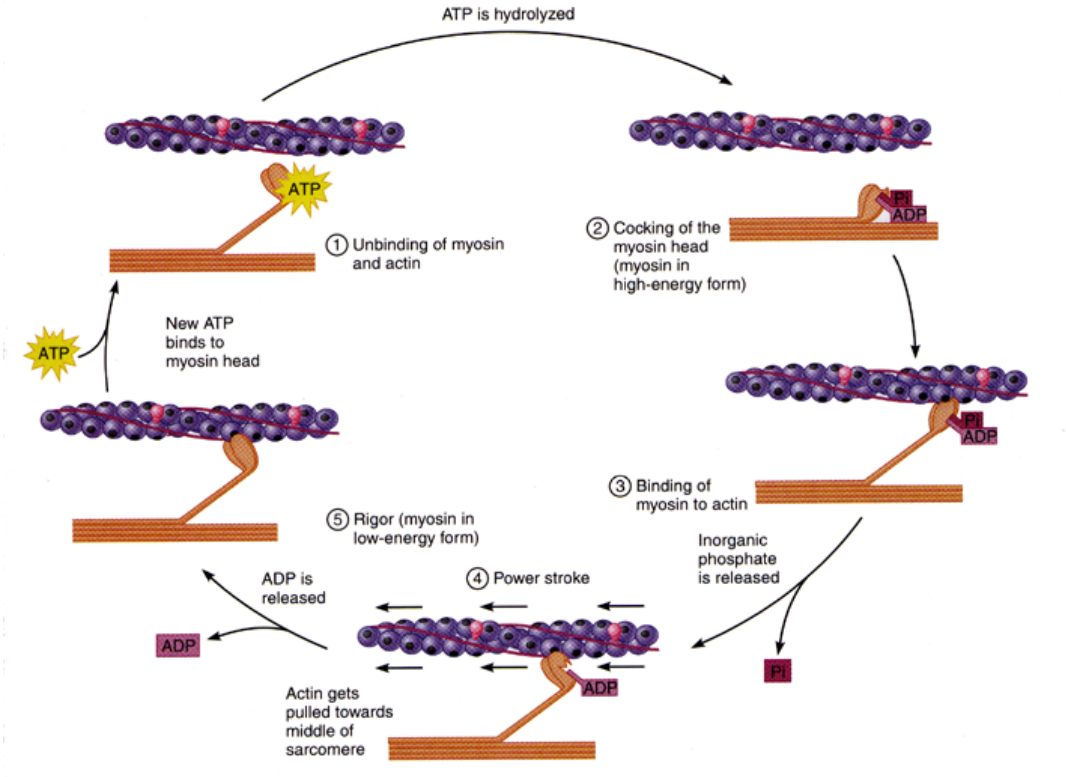

Figure 1 - Sliding Filament Theory

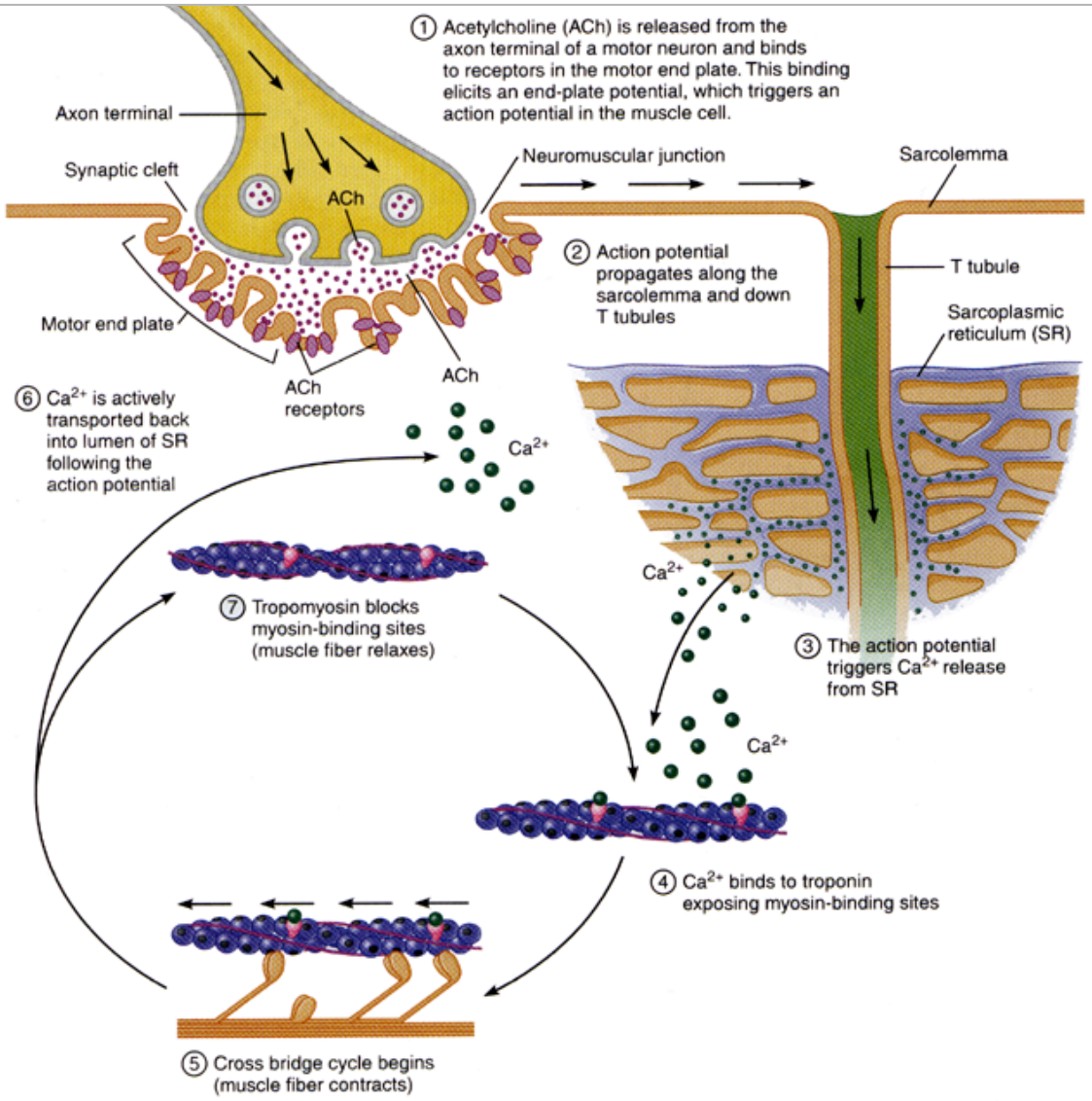

Figure 2 - Excitation-Contraction Coupling

A. Neuronal Events
1. AP arrives at neuron terminal (at neuromuscular junction), Ca^{++} rushes into terminal
2. vesicles release ACh into synaptic cleft

B. Synaptic Events
1. ACh binds to receptors on motor end plate (ACh destroyed by acetylcholinesterase)
2. sodium channels open in response to ACh binding - sodium enters and depolarizes cell

C. Muscular Events
1. Action Potential propagates along sarcolemma and down T-tubules.
2. Action potential in T tubules triggers the sarcoplasmic reticulum to release calcium ions from the terminal cisternae into the sarcoplasm.
3. Calcium binds to troponin causing a conformational change (shape change) in the troponin molecule resulting in the movement of the troponin-tropomyosin complex into the groove between the actine chains anbd cosequent exposure of myosin binding sites on actin.
4. Myosin heads alternately bind to and release the exposed sites on actin pulling the actin filament towards the center of the sarcomere (power stroke). This cycle continues as long as calcium ions are present (and ATP is available) (see figure 2).
5. Calcium (Ca^{++}) is continuously removed from the sarcoplasm by active re-uptake into the sarcoplasmic reticulum (actively pumped back into SR). In the absence of a stimulus (AP) causing the release of calcium, calcium will be rapidly removed from the sarcoplasm.
6. In the absence of calcium troponin resumes its original conformation (shape) resulting in the troponin-tropomyosin complex covering the myosin binding sites on actin.