TOPIC 12: SKELETAL MUSCLE MECHANICS

I. Events in muscle contraction

- A. Whole muscle is composed of muscle fibers bundled together by connective tissue and attached to bones by tendons
  - 1. Contraction of enough muscle fibers results in movement of bone or limb
- B. A single Action Potential produces a brief weak contraction called a twitch
  - 1. single AP does not normally occur
  - 2. muscle fibers are organized so they can cooperatively function to produce contractions stronger than a twitch
- C. Timing of contraction (Fig 12.12)
  - 1. Latent period
    - a) time between initiation of stimulation and start of contraction
    - b) action potential occurs during this time
    - c) 1-2 milliseconds (msec)
  - 2. Contraction time
    - a) time between onset of contraction and peak tension
    - b) continues until all Ca^{++} removed
    - c) 50 msec
  - 3. Relaxation time
    - a) time between peak tension and complete relaxation
    - b) 50 msec or more
  - 4. Total contractile response to single action potential is 100 msec or more, compared to the 2 msec AP that produced response

II. Factors influencing whole muscle tension

- A. Frequency of stimulation (voluntary control)
  - 1. Twitch Summation (Fig 12.17)
    - a) single AP: single twitch
      - (1) released Ca^{++} binds to troponin and contraction occurs, BUT Ca^{++} is immediately removed and contraction stops
    - b) two AP close together: summation of twitch
    - c) multiple AP close together: summation of twitches
      - (1) released Ca^{++} binds to troponin, and then is removed, but additional AP release more Ca^{++} so that contraction continues, i.e., some contractile activity from first AP continues as second AP has its effect
  - 2. Tetanus: many rapid stimuli <u>prevents</u> muscle relaxation
    - a) is a contraction of maximal strength
    - b) increased AP: so much Ca^{++} released that maximum number of cross bridge sites are uncovered = maximal tension
    - c) all fibers recruited, so asynchronous contracting not possible, fatigue eventually occurs
- B. Number of muscle fibers contracting within a muscle (Fig 12.19)
  - 1. motor unit recruitment (under voluntary control)
    - a) external eye muscles: ~ 12 muscle fibers/motor unit
    - b) leg muscles: ~ 2000 muscle fibers/motor unit

C. Length of fiber at onset of contraction (Fig 12.18)
   1. optimal resting length of muscle gives maximal tension
   2. non-optimal resting lengths five sub maximal tension
D. Diameter of muscle
   1. A bigger muscle cell (with more sacromeres and more crossbridges) can generate more force.

III. Muscle Metabolism and Fiber Types
A. ATP required for:
   1. Energizing of myosin head requires splitting of ATP
   2. Detachment of myosin cross bridge from actin requires binding (but not splitting) of ATP
   3. Active transport of Ca^{++} back into SR requires energy of ATP
B. ATP sources (Fig 12.11)
   1. Creatine phosphate is first energy storehouse tapped
      a) Energy reserves in resting muscle are stored in creatine phosphate (5 times as much in muscle as ATP)
      b) when energy needed for contraction:
         creatine phosphate + ADP ↔ creatine + ATP
         (requires activity of enzyme creatine phosphatase)
      c) in rested muscle, creatine phosphate is ready to go, and that's what you use as an ATP source during burst activity (1 min or less)
   2. Glycolysis + Krebs Cycle + Oxidative Phosphorylation
      a) Mitochondria in muscle require oxygen and fuel to produce ATP,
      b) Can make ~ 36 ATP/glucose this way
      c) But this is slow compared to creatine phosphate
      d) You can do this during aerobic (or endurance) exercise
      e) O_2 is supplied by blood, so during aerobic exercise your body maximizes O_2 delivery to muscles
   3. Anaerobic pathways (glycolysis alone)
      a) Can make ATP rapidly
      b) But only makes 2 ATP/glucose
      c) But rapidly depletes fuel supply (glycogen)
      d) But produces lactic acid
         (1) May contribute to muscle soreness & fatigue
         (2) Will lead to metabolic acidosis (= bad)
      e) But contributes to fatigue
      f) Bottom line: anaerobic exercise possible for only short time
C. Fatigue (Fig 12.25)
   1. Muscle fatigue
      a) asynchronous recruitment of motor units used to limit muscle fatigue (i.e., fibers "take turns" contracting)
      b) fatigue occurs when muscle can no longer respond to stimulation with same degree of contractile activity, probably because of lactic acid accumulation and depletion of energy reserves
   2. Neuromuscular fatigue: motor neurons can not make Ach fast enough
   3. Central fatigue: psychological, not well understood

- D. Oxygen consumption elevated during recovery from exercise
  - 1. Oxygen debt
    - a) contractile energy debt from nonoxidative ATP sources needs to be repaid during recovery
      - (1) creatine phosphate resynthesized
      - (2) lactic acid metabolized
      - (3) replenish glycogen stores
  - 2. Recovery from general metabolic disturbance
    - a) all chem rxns still speeded up
    - b) still high levels of epi
- E. Skeletal muscle fiber types
  - 1. Three types (must see Table 12.1 for characteristics of each)
    - a) slow oxidative (type I) fibers
    - b) fast oxidative (type IIa) fibers
    - c) fast glycolytic (type IIb) fibers
  - 2. Most muscles have all three types
  - 3. A motor unit is composed of all one type of fiber
  - 4. Within a muscle, fast oxidative and fast glycolytic can interconvert over time, depending on how muscle is trained
  - 5. Hypertrophy: increase in muscle fiber diameter
  - 6. Hyperplasia: increase in muscle fiber number; usually occurs by splitting muscle fibers, rarely happens

IV. Control of Motor Movement (review)

- A. Three levels of input control motor neuron output
  - 1. Spinal reflexes
  - 2. Primary motor cortex (in cerbral cortex)
  - 3. Other cortical and subcortical regions of the brain (basal nuclei, cerebellum, thalamus, and others) send signals to primary motor cortex and/or brain stem, each of which can then directly control motor neurons.