BIOH111

- Cell Module
- Tissue Module
- Integumentary system
- Skeletal system
- Muscle system
- Nervous system
- Endocrine system
Textbook and required/recommended readings

- Muscle metabolism: Principles of anatomy and physiology. Tortora et al; 14th edition: Chapter 10; section 10.4 and 10.6
- Muscle tension, tone and fatigue: Principles of anatomy and physiology. Tortora et al; 14th edition: Chapter 10; section 10.5
BIOH111 – muscle system module

- Session 11 (Lectures 21 and 22) – Muscle physiology: Building of muscle organ – cells, tissue, organ and muscle contraction process and regulation

- Session 12 (Lectures 23 and 24) - Skeletal muscle metabolism

- Session 13 (Lectures 25 and 26) – Major muscle groups
BIOH111

Lectures 23 and 24

Skeletal muscle metabolism

Department of Bioscience
Objectives

Lecture 23:
- Muscle ATP supply
  - Investigate how muscle supplies itself with energy (ATP) to allow it to undertake all of its functions
  - Analyse how different types of supply relate to the activity body is doing

Lecture 24:
- Muscle tension
  - Describe the factors influencing force generation by muscle, including single twitch contraction, wave summation, fused and unfused tetanus and multiple motor unit contraction
  - Describe muscle tone and comment why is this important
Muscle contraction overview - revision

Basic steps:
1. Release of ACh in response to AP
2. Initiation of muscle AP results in release of Ca+2 from SR
3. Ca+2 interacts with troponin on thin filament. If thick filament is activated the sarcomere contraction is initiated – sliding theory
4. Ca+2 is sequestered back into SR and sarcomere relaxes – tropomyosin and titin
Contraction Cycle - revision

Key:  
= Ca^{2+}

1. Myosin heads hydrolyze ATP and become reoriented and energized.

2. Myosin heads bind to actin, forming crossbridges.

3. Myosin crossbridges rotate toward the center of the sarcomere (power stroke).

4. As myosin heads bind ATP, the crossbridges detach from actin.

Contraction cycle continues if ATP is available and Ca^{2+} level in the sarcoplasm is high.

https://www.youtube.com/watch?v=Ct8AbZn_A8A
MUSCLE METABOLISM
Production of ATP in Muscle Fibers

- Muscle uses ATP at a great rate when active.
- Sarcoplasmic ATP only lasts for few seconds.
- 3 sources of ATP production within muscle:
  1. creatine phosphate
  2. anaerobic cellular respiration
  3. aerobic cellular respiration
1. Creatine phosphate

- Excess ATP within resting muscle used to form creatine phosphate; Creatine phosphate is unique to muscle fibers
- Creatine phosphate 3-6 times more plentiful than ATP within muscle
- Its quick breakdown provides energy for creation of ATP
- This pathway is used to power maximal muscle contraction for about 15 seconds and is used for maximal short bursts of energy (e.g. 100-meter dash)
2. Anaerobic Cellular Respiration

- ATP produced from glucose breakdown into pyruvic acid during glycolysis
  - if no $O_2$ present: pyruvic converted to lactic acid which diffuses into the blood

- Glycolysis can continue anaerobically to provide ATP for 30 to 40 seconds of maximal activity (e.g. 200 meter race)

Also see BIOB111 Session 20
2. Aerobic Cellular Respiration

- In **presence of oxygen**, pyruvic acid enters the mitochondria to generate ATP, water and heat using process called cellular respiration
  - NOTE: fatty acids and amino acids can also be used by the mitochondria
- Provides 90% of ATP energy if activity lasts more than 10 minutes
Skeletal muscle is classified based on following characteristics:

1. **Structural characteristic**: Myoglobin, mitochondria and capillaries
   - **red muscle fibers**: more myoglobin, an oxygen-storing reddish pigment; more capillaries and mitochondria
   - **white muscle fibers**: less myoglobin and less capillaries give fibers their pale color

2. **Functional characteristic**: Contraction and relaxation speeds vary: depends on how fast myosin ATPase hydrolyzes ATP

3. **Functional characteristic**: Resistance to fatigue: depends on different metabolic reactions used to generate ATP
MUSCLE FIBER CLASSIFICATION

- Based on structure and function, skeletal muscle fibers are classified as:
  1. slow oxidative
  2. oxidative-glycolytic
  3. fast glycolytic fibers

Slow twitch vs fast twitch – how fast is it able to split ATP
1. Slow oxidative (slow-twitch)

- Red in color (lots of mitochondria, myoglobin & blood vessels)
- Designed for **aerobic exercise** and prolonged, sustained contractions for **maintaining posture and marathon running**
- Resistant to fatigue
2. Fast oxidative-glycolytic (FOG; fast-twitch A)

- Red in color (lots of mitochondria, myoglobin & blood vessels)

- Designed for anaerobic exercise (e.g. fast walking and running): myosin heads split ATP at very fast rate

- More resistant to fatigue than fast glycolytic fibers
3. Fast glycolytic (fast-twitch B)

- White in color (few mitochondria & blood vessels, low myoglobin)
- Large amount of glycogen; ATP generated by glycolysis
- Designed for intense anaerobic movements of short duration; myosin heads split ATP at very fast rate; e.g. weight-lifting and 100m sprints
- Fatigue easily
Fiber Types Within a Whole Muscle

- Most muscles contain a mixture of all three fiber types.
- Proportions vary with the usual action of the muscle; for example:
  - neck, back and leg muscles have a higher proportion of postural, slow oxidative fibers.
  - shoulder and arm muscles have a higher proportion of fast glycolytic fibers.
- All fibers of any one motor unit are the same and different fibers are activated as needed.
Muscle Fatigue

- Inability to contract after prolonged activity
- Factors that contribute to fatigue:
  - central fatigue is feeling of tiredness and a desire to stop (protective mechanism)
  - insufficient release of acetylcholine from motor neurons
  - depletion of creatine phosphate
  - decline of Ca+2 within the sarcoplasm
  - insufficient oxygen or glycogen
  - buildup of lactic acid and ADP
Anabolic Steroids

- Similar to testosterone
- Increases muscle size, strength, and endurance
- Side effects:
  - Liver cancer
  - Kidney damage
  - Heart disease
  - Mood swings
  - Facial hair & voice deepening in females
  - Atrophy of testicles & baldness in males
Objectives

Lecture 23:

- Muscle ATP supply
  - Investigate how muscle supplies itself with energy (ATP) to allow it to undertake all of its functions
  - Analyse how different types of supply relate to the activity body is doing

Lecture 24:

- Describe muscle tone and comment why is this important
- Muscle tension – GO TO ACTIVITY
  - Describe the factors influencing force generation by muscle, including single twitch contraction, wave summation, fused and unfused tetanus and multiple motor unit contraction
MUSCLE TONE

o Involuntary contraction of a small number of motor units (alternately active and inactive in a constantly shifting pattern)
  • keeps muscles firm even though relaxed
  • does not produce movement
o Essential for maintaining posture (head upright)
o Important in maintaining blood pressure
  • tone of smooth muscles in walls of blood vessels
Muscle tone

- constant, slightly contracted state of all muscles, which does not produce active movement
- resistance to stretch in resting muscle
- normal muscle tone is provided by titin (elastic/passive tension) and weak myosin-actin bonds (contractile/active tension) when myosin head is bound to ADP
TYPES OF MUSCLE ACTIONS

- **Isometric contraction**: constant muscle length; no movement occurs
  - tension is generated without muscle shortening
  - maintaining posture & supports objects in a fixed position

- **Isotonic contractions**: constant muscle tension; load is moved
  - **concentric contraction**: muscle shortens to produce force and movement
  - **eccentric contractions**: muscle lengthens while maintaining force and movement
CONTROL OF MUSCLE TENSION — GO TO ACTIVITY

- 1 AP → 1 muscle AP; both the same size

- Force of muscle fiber contraction varies due to:
  1. **Frequency of stimulation** — how often nerve impulses elicit muscle contraction - activity
  2. **Amount of stretch** before contraction
  3. **Nutrient and oxygen availability** (oxygen debt)
  4. **Number of muscle fibers** contracting in unison
Motor Unit - revision

- **Motor unit** = 1 somatic motor neuron + all the skeletal muscle cells (fibers) it stimulates (10 cells to 2,000 cells)
  - muscle fibers normally scattered throughout belly of muscle
  - one nerve cell supplies on average 150 muscle cells that all contract in unison.

- Total strength of a contraction depends on how many motor units are activated & how large the motor units are.
Twitch Contraction

A twitch contraction is a brief contraction of all the muscle fibers in a motor unit in response to a single action potential. Myogram has 4 parts:

1. **Contraction period**: 10 to 100 msec
   - Filaments slide past each other

2. **Relaxation period**: 10 to 100 msec
   - Active transport of Ca\(^{2+}\) into SR

3. **Latent period**: 2 ms
   - Ca\(^{2+}\) is being released from SR
   - Slack is being removed from elastic components

4. **Refractory period**: 5 msec for skeletal & 300 msec for cardiac muscle
   - Muscle cannot respond and has lost its excitability
1. FREQUENCY OF STIMULATION

- **Wave summation**: increased strength of a contraction resulting from the application of a second stimulus before the muscle has completely relaxed after a previous stimulus.

- **Incomplete (unfused) tetanus**: sustained muscle contraction that permits partial relaxation between stimuli.

- **Complete (fused) tetanus**: sustained contraction that lacks even partial relaxation between stimuli.

  - **Physiological explanation for tetanus**: $\text{Ca}^{+2}$ remains in the sarcoplasm and force of 2nd contraction is easily added to the first because the elastic elements remain partially contracted and do not delay the beginning of the next contraction.
Frequency of stimulation

- Second stimulation applied after the refractory period.
- If muscle fiber is stimulated at 20-30 times/second: only partial relaxation between stimuli.
- If muscle fiber is stimulated at 80-100 times/second: sustained contraction with no relaxation between stimuli.
2. AMOUNT OF STRETCH BEFORE CONTRACTION

- Length-Tension relationship
- Optimal overlap at the 100%

Graph of Force of contraction (Tension) vs Length of sarcomere

- More resistance
- Most cross bridges/least resistance
- Fewest cross bridges
3. OXYGEN DEBT

Oxygen debt: where demand for oxygen is greater than the supply

- added oxygen taken in by the body after exercise over the resting oxygen consumption: extra oxygen = “pay back”

- Extra oxygen used for:
1. Conversion of lactic acid back into glucose (liver)
2. Re-synthesis of used creatine phosphate
3. Replacing oxygen removed from myoglobin
4. NUMBER OF MUSCLE MOTOR UNITS CONTRACTING IN UNISON

**Recruitment**: process of increasing the number of active motor units (multiple motor unit summation); prevents fatigue and helps provide smooth muscular contraction rather than a series of jerky movements.
Motor unit recruitment

- Motor units in a whole muscle fire asynchronously
  - some fibers are active others are relaxed
  - delays muscle fatigue so contraction can be sustained
- Produces smooth muscular contraction
  - not series of jerky movements
- Precise movements require smaller contractions
  - motor units must be smaller (less fibers/nerve)
- Large motor units are active when large tension is needed
Revision

Read one of the following: section 10.10, section 10.12 or Homeostatic Imbalances (Tortora, p 323) and define following terms: 
regeneration of muscle, aging, myasthenia gravis, muscular dystrophy, abnormal muscle contraction and exercise-induced muscle damage. Then in groups of 2-3 think about:

- What are the risk factors for these processes, conditions and disorders?
- Describe structural and comment on molecular level changes that occur in these muscle disorders and conditions.
- Link the described causes and affected muscle physiology to comment on possible treatments of these disorders within your particular interest.
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