Cardiovascular Structure and Function

KINE 5320
Advanced Physiology of Exercise
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Components

- A pump
  - The heart
- A high-pressure distribution circuit
  - Arteries and arterioles
- Exchange vessels
  - Capillaries
- A low-pressure collection and return circuit
  - Veins and venules

The Heart

- Impetus for blood flow
- Two pumps
  - Right – pulmonary (low pressure)
    - Receive deoxygenated blood
    - Pump blood to lungs for oxygenation
  - Left – systemic (high pressure)
    - Receive oxygenated blood
    - Pump blood into aorta into systemic circulation
  - Pumps are in series – match blood volume to avoid volume shifts between pulmonary and systemic circulation

Cardiovascular System

- The cardiovascular system integrates the body as a unit.
  - Provides active muscles with continuous stream of nutrients and oxygen
  - Removes metabolic byproducts
The Parts

- Interventricular septum – separates the right and left sides
- Atrioventricular valves – one way flow between atria and ventricles
  - Tricuspid (right)
  - Bicuspid or mitral (left)
- Chordae Tendineae are attached to the leaflets on the ventricular side and to papillary muscles in ventricular walls
  - Limit movement of the valves so they do not swing into the atrium causing backflow

Valves

- Semilunar valves – in arterial wall outside heart preventing backflow into heart between contractions
  - Pulmonary (right)
  - Aortic (left)
- No valves at entrance of Venae Cavae into right atrium and pulmonary veins into left atrium
- Valves close passively by difference in pressure across valve

The Chambers

- Atria – thin-walled, saclike, receive and store blood
  - Contraction accounts for only 10-40% of ventricular filling
- Ventricles -
  - Right is smaller and pumps to lungs
  - Left is larger and pumps to systemic circulation

Myocardium

- Form of striated muscle
- Individual cells (fibers) interconnect in latticework fashion
- Depolarization of one cell spreads AP to all cells
- Heart functions as a unit
- Mitochondria occupy 40% of cytoplasm volume of myocardial cells vs 2-6% in skeletal muscle cells reflecting need for continuous aerobic metabolism

Myocardium

- Cardiac muscle cells shorter and joined by intercalated disks with gap junctions so minimal electrical resistance between cells
- Cardiac muscle in atria and ventricles contracts synchronously
- All or none principle applies to an entire area of heart muscle but only to a motor unit in skeletal muscle
Cardiac Cycle

- Systole - contraction phase
- Diastole - relaxation phase

Cardiac vs Skeletal Muscle

- Cardiac - involuntary
- Skeletal - voluntary
- Cardiac muscle cells -

Cardiac Cells

- 2 types
  - Contractile - bulk of myocardial cells - pumping action
  - Electrical - specialized conducting cells
    - important for rapid conduction
    - intrinsic rhythmicity or autorhythmicity

Resting Myocyte

- Negative charge on inside, more potassium (K) - polarized
- Positive on the outside, more sodium (Na)
- Resting membrane potential is -90mV

Depolarization Before Contraction

- The inside of the cell must become more positive by approximately 20-30 mV in order to depolarize
- Phase 0 - Depolarization - increased permeability of the cellular membrane to Na+
  - Membrane potential toward 0 (more positive)
  - If adequate - brief all or none reversal of membrane potential called an action potential
  - Calcium activates contractile proteins

Repolarization

- Phase 1 - 3 - return of the membrane potential to resting values - Na/K pump restores ions to their previous resting locations
- Calcium is pumped back into SR
- During phase 1-3 cell is refractory to initiation of new action potentials – prevents tetanic contractions
Diastole

- Phase 4 - no electrical activity - cell is at resting membrane potential

Pacemaker/Electrical Cells

- Pacemaker cells exhibit intrinsic rhythmicity – 1%
- Generate regular spontaneous action potentials
- Tissue with highest rate determines HR (overdrive suppression)
- Most important concentration of autorhythmic cells in SA node
- Note: if SA node is blocked or rate is extremely slow, another part of the conduction system can take over as pacemaker - fastest pacemaker sets the rate

Pacemaker Action Potentials

- No true resting potential – generate regular spontaneous APs
- Three phases
  - Phase 0 – depolarization - slow inward Ca\(^{++}\) currents
  - Phase 3 – repolarization – increase in K\(^{+}\) conductance and decrease in Ca\(^{++}\) conductance
  - Phase 4 – spontaneous depolarization

Specialized Conduction Sites

- SA Node - located in posterior wall of right atrium
- Atrial Tracts
- AV Node - base of the right atrium - delay before stimulation of AV node (1/10 of a second, allowing blood from atria to enter ventricles)
- Bundle of His
- Right and Left Bundle Branches
  - Left BB – divides into two main branches called fascicles
    - Anterior Fascicle (superior)
    - Posterior Fascicle (inferior)
- Purkinje Fibers
Surface ECG Tracing

- Atrial depolarization - P wave
- Pause at AV node – PR segment (15% of Q)
- Atrial repolarization not seen on surface ECG as it is small and lost within the QRS complex
- Ventricular depolarization - QRS complex
- ST segment – pause after QRS complex
- Ventricular repolarization - T wave

Surface ECG Tracing

- The entire event of ventricular depolarization and repolarization is represented by the QT interval
- U wave – follows T wave sometimes
  - Represents repolarization of Purkinje fibers
  - Best seen in V2 and V3 with rates <90 bpm

Note: the electrical event of depolarization precedes the mechanical event of contraction
Systemic or Peripheral Circulation

- In parallel
- Liver exception (series and parallel)
- Prevents blood flow changes in one organ from significantly affecting flow in other organs

Systemic Circulation

- Systemic Circulation
  - Arteries transport blood under pressure
  - Arterioles, metarterioles and precapillary sphincters – act as valves to control flow
  - Capillaries – exchange medium between blood and tissues
  - Venules – collect blood from capillaries
  - Veins – return blood to heart

Peripheral Circulation “in parallel”

- Arteries (includes aorta)
  - High pressure
  - Carry oxygenated blood
  - Thick muscular walls
  - Large radii (low resistance to flow)
  - Act as a “pressure reservoir” – maintain flow during diastole
  - Only 1/3 of stroke volume leaves arteries during systole
  - During diastole stretched walls recoil passively to maintain arterial pressure and flow
Aortic Pressure Fluctuations during the Cardiac Cycle

Arterioles
- Smaller arterial branches
- Circular layers of smooth muscle
- Primary determinant of blood flow distribution
- Dramatically alter diameter to rapidly regulate blood flow
- Major site of vascular resistance in arterial tree
- Resistance dampens pulse felt upstream in arteries
- Variety of physiological factors that alter diameter

Capillaries
- Exchange of nutrients and metabolic end products
- .01 mm in diameter
- No cell >0.01 cm from a capillary (small diffusion distances)
- Greatest capillary density in heart – no cell > .008 mm from capillary
- 25,000 miles of capillaries in adult
- 1 mm in length
- Flow is intermittent

Capillaries
- One-layer thick (usually)
- Flat cells that interlock with pores between
- Small diameter offers considerable resistance to flow but less than arterioles
  - Due to large cross sectional area for flow (800 X 1 in. aorta)
  - 1.5 sec for cell to pass through av. sized capillary

Metarterioles
- Connect arterioles and venules directly
- Precapillary sphincter – ring of smooth muscle controlling flow from arterioles and metarterioles to capillaries
  - Controls capillary diameter
  - Continually opens and closes due to local metabolic factors
  - More active the tissue the more precapillary sphincters that are open
    - Rest – 1/10 of sphincters open
Capillary Flow at Rest

Capillaries
- Tissue cells do not exchange substances directly with the blood
- Nutrients diffuse across capillary wall into interstitial fluid then enter tissues
- Metabolic end products – vice versa

Capillary Flow during Exercise

Venules
- Small veins that exit capillaries
- Carry deoxygenated blood (mixed venous blood)
- Small exchange of materials
- Little smooth muscle
- Lower pressure than arterial and capillary systems

Veins
- Larger than venules
- Largest – Inferior Vena Cava
- Inferior and Superior Vena Cava join at heart level
- Pressure ~0 mm Hg at right atrium
- Thinner, less muscular walls than arteries, more distensible
- Capacitance vessels – large storage capacity with largest blood volume (65% total blood volume at rest)
- Mobilize blood volume via muscle pump

Valves in Veins
- Valves that prevent backflow of blood in low pressure system
- Valves help counteract the effects of upright posture
Muscle Pump

One-way valves

Blood Pressure

- Systolic pressure – maximum pressure during peak ventricular ejection
- Diastolic pressure – minimum pressure immediately prior to ventricular ejection
  - 120/80
  - Borderline ≥140/90
  - Hypertension ≥160/100
- NIH Classification System for Adults (p 311)

- Pulse pressure – pressure felt in the artery
  - SBP – DBP
- Mean Arterial Pressure (MAP) – average arterial pressure during cardiac cycle
  - Rest: MAP = DBP + 1/3 PP
  - Exercise: DBP + 1/2 PP
  - MAP = Q X TPR

Mean Arterial Pressure

- Total Peripheral Resistance – sum of all forces which oppose flow
- SBP – indicative of SV
- DBP – indicative of TPR
Resting Pressures

- Resting BP – 120/80
- Resting PP – 40 mm Hg
- Resting MAP – 90-100 mm Hg
- Pulse Pressure – 40 mm Hg

Exercise Pressures

- Systolic Pressure – increase
  - ≤ 200 mm Hg
- Diastolic Pressure – stay same or decrease
- Pulse Pressure – increase
  - 40-100 mm Hg
- MAP – increase slightly
  - 90-130 mm Hg
- Total Peripheral Resistance - decreases

Myocardial Oxygen Consumption

- RPP (Rate Pressure Product)
- Double Product or Index of Relative Cardiac Work
- HR x SBP/100
- Relates closely to directly measured oxygen consumption and coronary blood flow in healthy subjects
- Rest: 60
- Exercise: 400

Next Week

- Central Command
- Regulation of Q
  - HR
  - SV
  - Chapters 16 and 17