6 Human physiology

Introduction

- body functions are carried out by organ systems
- structure of small intestine allows it to move, digest, absorb
- blood system continuously transports substances to cells and collects waste products
- skin and immune system resist threat of invasion by pathogens
- lungs are actively ventilated to ensure gas exchange
- neurons transmit the message; synapses modulate it; hormones are for widely spread signals

6.1 Digestion and absorption

Peristalsis

- circular and longitudinal muscles in wall of gut is smooth rather than striated; short cells, not elongated fibers; exerts continuous force with short periods of more vigorous contractions
- peristalsis: waves of muscle contractions passing along intestine, occurs in one direction
- circular muscles behind food constricts gut to prevent it being pushed back
- contraction of longitudinal muscle moves food along gut
- contractions are controlled unconsciously by enteric nervous system
- during vomiting, abdominal muscles force food out rather than muscles in gut
- overall progression through intestine is slower, allowing digestion
- peristalsis churns food with enzymes to speed up digestion

Pancreatic juice

- pancreas contains two types of gland tissue: small cell groups secreting insulin and glucagon into blood and remainder secreting digestive enzymes into gut
- hormones from stomach and enteric nervous system mediate pancreas to production
- groups of gland cells cluster around ends of tubes (ducts) into which enzymes are secreted
- digestive enzymes are synthesized in pancreatic gland cells in ribosomes on rough endoplasmic reticulum, processed by Golgi apparatus and released by exocytosis
- pancreatic juice contains amylase (for starch), lipase (for triglycerides, phospholipids), proteases (for proteins, peptides)

Digestion in the small intestine

- enzymes carry out hydrolysis reactions: starch to maltose (amylase), triglycerides to fatty acids and glycerol or fatty acids and monoglycerides (lipase), phospholipids to fatty acids, glycerol and phosphate (phospholipase), proteins and polypeptides to shorter peptides (protease)
- wall of small intestine produces variety of other enzymes which digest more substances, most remain immobilized in plasma membrane of epithelium cells; continue to work when abraded
- DNA and RNA to nucleotides (nucleases), maltose to glucose (maltase), lactose to glucose and galactose (lactase), sucrose to glucose and fructose (sucrase), peptides to dipeptides (exopeptidases, remove single amino acids), dipeptides to amino acids (dipeptidases)
- cellulose is left undigested: humans cannot synthesize necessary enzymes

Villi and the surface area for digestion

- absorption: taking substances into cells and blood, takes place in small intestine
- rate of absorption depends on surface area: increased with villi
- villi: finger-like projections of mucosa to inside of intestine

Absorption by villi

- epithelium covering villi must form barrier to harmful substances
- villus cells absorb: glucose, fructose, galactose, monosaccharides, amino acids (any of 20), fatty acids, monoglycerides, glycerol, bases from nucleotides, mineral ions (calcium, potassium, sodium), vitamins (ascorbic acid (vitamin C))
- harmful substances passing through are removed from blood by liver
- some bacteria pass: quickly removed by phagocytic cells in liver

Methods of absorption

- nutrients must pass from lumen of small intestine to capillaries or lacteals in villi
- exposed part of plasma membrane is enlarged with microvilli
- two examples for mechanisms moving nutrients in and out of villus epithelium cells
- triglycerides: must be digested to fatty acids and monoglycerides beforehand, are absorbed by simple diffusion, fatty acids also by facilitated diffusion (transporters in membrane), once in cell fatty acids are combined with monoglycerides to produce triglycerides, these coalesce with cholesterol to form droplets which are coated in phospholipids and proteins, lipoprotein released by exocytosis through inner plasma membrane, either enter lacteal and carried away by lymph or enter blood capillaries in villi
- glucose: cannot pass through plasma membrane (polar), sodium-potassium pumps sodium ions by active transport to interstitial spaces in villus and potassium ions in opposite direction (low concentration of sodium in villus), sodium-glucose co-transporter proteins in microvilli transfer sodium ion and glucose from interstitial lumen to cytoplasm of epithelium cells (passive facilitated diffusion, but energy needed for concentration gradient), glucose channels allow it to move by facilitated diffusion to blood capillaries

6.2 The blood system

Arteries

- convey blood from heart to tissue of body; elastic and muscle tissue in walls facilitate and control blood flow
- main pumping chambers of heart are ventricles: thick strong muscles pumping blood into arteries reaching high pressure at peak of each pumping cycle
- recoil of elastic tissue helps propel blood down artery
- contraction of smooth muscle determines diameter and controls overall flow through them
- elastic and muscular tissues contribute to toughness of walls which have to withstand constantly changing and intermittently high blood pressure: progress is pulsatile
- active muscles of heart itself are supplied with blood by coronary arteries

Artery walls

- tunica externa (outer layer), tunica media (thick layer with muscle and elastin), tunica intima (smooth endothelium forming the lining)

Arterial blood pressure

- systolic pressure: peak pressure reached in artery, widens lumen (store of potential energy)
- stretched elastic fibers squeeze blood in lumen at end of heartbeat: prevents minimum pressure (diastolic pressure) becoming too low
- blood flow in arteries is relatively steady
- vasoconstriction: contraction of circular muscles in artery wall, increases blood pressure
- arterioles have high density of muscle cells responding to hormone and neural signals to control blood flow to tissue
- vasoconstriction reduces supply; vasodilation increases supply

Capillaries

- narrowest blood vessels; branch and rejoin to form network with huge total length
- transport blood through almost all tissues in body (exceptions: lens tissues and cornea in eye)
- all active cells are close to a capillary
- wall consists of very thin endothelium cells, coated with filter-like protein gel, pores between cells: wall is very permeable: allow part of plasma leak out and form tissue fluid
- tissue fluid contains oxygen, glucose, all other substances in blood plasma
- proteins cannot pass through capillary wall
- fluid flows between cells in tissue, allows cells to absorb useful substances and excrete waste
- then the tissue fluid re-enters capillary network
- permeabilities differ between tissues, enables particular proteins and other large particles to pass but not others; this may change over time and capillaries remodel to needs of tissue

Veins

- transport blood from capillary networks back to atria of heart at lower pressure

- have thinner walls than arteries and less muscle and elastin fibers
- can dilate and contain more blood than arteries
- blood flow is assisted with contraction of muscle squeezing on adjacent veins
- hepatic portal vein is unusual, carries blood from stomach and intestines to liver

Valves in veins
- pressure in veins is so low that there is danger of backflow: pocket valves (three cup-shaped flaps of tissue) maintain circulation and allow blood flow in one direction
- blood flowing back is caught in flaps, filling them with blood and blocking lumen
- blood flowing towards heart pushes flaps to sides of veins
- valves efficiently use intermittent and transient pressures from muscular and postural changes

The double circulation
- mammalian lungs are supplied with blood by separate circulation
- blood capillaries in lungs cannot withstand high pressures, blood pumped at lower pressure
- blood coming from lungs is at such low pressure that it must go to heart again
- humans have pulmonary circulation (for lungs) and systemic circulation (for organs)
- pulmonary circulation receives deoxygenated blood from systemic circulation
- systemic circulation receives oxygenated blood from pulmonary circulation
- important that blood from two systems is not mixed: heart is double pump

The sinoatrial node
- heart muscles contract without stimulation from motor neurons; contraction is called myogenic (generated by muscle itself)
- membrane of heart muscle cell depolarizes when cell contracts, activating adjacent cells
- region of fastest rate of spontaneous beating is in sinoatrial node (in wall of right atrium)
- sinoatrial node initiates each heartbeat as membranes are first to depolarize in each cardiac cycle; specialized cells in sinoatrial node have extensive membranes but few proteins which cause contractions in other cells

Initiating the heartbeat
- sinoatrial node sets pace for beating of heart: pacemaker
- if defective, it may be replaced by artificial pacemaker

Atrial and ventricular contraction
- heartbeat initiated by contracting and simultaneously sending of electrical signal that spreads throughout wall of atria: possible with interconnections between adjacent fibers
- fibers are branched so each fiber passes signal to several others
- after delay of 0.1 seconds, electrical signal is conveyed to ventricles: delay allows time for atria to pump blood into ventricle; then signal is propagated through ventricle to make it contract

Changing the heart rate
- sinoatrial node responds to signals from outside of heart including signals from branches of two nerves (one for in other for decrease) coming from medulla of brain called cardiovascular center
- cardiovascular center receives input form receptors monitoring blood pressure, pH (reflecting carbon dioxide concentration) and oxygen concentration
- all parameters being low suggests increase in heart rate and vice versa

Epinephrine
- sinoatrial node responds to epinephrine in blood to increase heart rate
- epinephrine (adrenalin) is hormone produced in adrenal glands, secretion controlled by brain
- secretion rises when vigorous physical activity may be necessary (“fight or flight”)

6.3 Defense against infectious disease

Skin as barrier to infection
- many different microbes in environment that can cause disease (pathogens)
- primary defense is skin: outermost layer is tough and provides physical barrier

- sebaceous glands (associated with hair follicles) secrete chemical sebum which maintains skin moisture and lowers skin pH (inhibits growth of bacteria and fungi)
- mucous membranes are thinner and softer type of skin (nasal passages, penis, vagina)
- mucus (sticky solution of glycoproteins) secreted, acts as physical barrier: pathogens and harmful particles are trapped in it and either swallowed or expelled
- mucus has antiseptic properties due to presence of anti-bacterial enzyme lysozyme

Cuts and clots

- when skin is cut, blood vessels are severed and start to bleed; stops due to clotting
- emerging blood changes from liquid to semi-solid gel: seals wound, prevents further loss of blood and blood pressure; cut is breach barrier to infection provided by skin
- clots prevent entry of pathogens until new tissue has grown to heal cut

Platelets and blood clotting

- blood clotting involves cascade of reactions, each producing catalyst for next reaction
- important that clotting is under strict control; if it occurred in blood vessels it would block it
- clotting only occurs if platelets (cellular fragments circulating blood) release clotting factor
- after cut, platelets aggregate at site forming temporary plug, then release clotting factors

Fibrin production

- cascade of reactions after platelets release clotting factors leads to production of enzyme thrombin; this converts soluble protein fibrinogen to insoluble fibrin
- fibrin forms mesh trapping more platelets and blood cells
- resulting clot is initially gel but when exposed to air it dries to hard scab

Phagocytes

- after physical barriers, white blood cells (many different types) provide next line of defense
- some squeeze through pores in capillary walls and move to sites of infection: engulf pathogens by endocytosis and digest them

Antibody production

- proteins and other molecules on surface of pathogens are recognized as foreign by body: stimulates specific immune response: production of antibodies
- lymphocytes (type of white blood cell) produce antibodies; each lymphocyte only one type
- normally have small numbers of lymphocytes for each of antibody
- antigens on pathogen stimulate cell division of small group of specific lymphocytes
- plasma cells (large clone of lymphocytes) are produced within few days
- antibodies are large proteins with two functional regions: hyper-variable region (binds to specific antigen) and region that helps body to fight pathogen (making it recognizable, preventing viruses from docking to host cells)
- antibodies only persist for few weeks but some lymphocytes are not active plasma cells but became memory cells (very long-lived): remain inactive unless same pathogen infects again
- immunity is either having antibodies or memory cells that allow for rapid production of antibody

Antibiotics

- chemical that inhibits growth of microorganisms, mostly antibacterial
- block processes occurring in prokaryotes but not in eukaryotes: do not harm human cells
- processes targeted are bacterial DNA replication, transcription, translation, ribosome function, cell wall formation
- many antibacterial antibiotics found in saprotrophic fungi as these compete with saprotrophic bacteria for dead organic matter: fungi inhibit growth of bacterial competitors

Viruses and antibiotics

- viruses: non-living and only reproduce in living cells: use chemical processes of living host
- processes virus uses cannot be targeted by drugs as the host cell would also suffer
- commonly used antibiotics are ineffective against viruses
- few viral enzymes can be targeted by drugs to control virus without harming host cell: antivirals

Resistance to antibiotics
- bacteria develop resistance to antibiotics by natural selection
- bacteria with resistance are usually discovered shortly after introduction of new antibiotic; not a huge concern unless strain develops multiple resistance
- methicillin-resistant Staphylococcus aureus or multi-drug-resistant tuberculosis
- measures to avoid antibiotic resistance: prescription only for serious infections, completing courses of antibiotics, high standards of hygiene in hospitals, no antibiotics in animal feeds, pharmaceutical developing new types of antibiotic

6.4 Gas exchange

Ventilation
- gas exchange: all organisms absorb one gas form environment and release different one
- leaves absorb carbon dioxide for photosynthesis; humans absorb oxygen for cell respiration
- terrestrial organisms exchange gases with the air; in humans this happens in small air sacs called alveoli inside lungs
- gas exchange happens by diffusion between air in alveoli and blood flowing through adjacent capillaries: gas diffuses due to concentration gradient: air in alveolus has more oxygen and blood capillary has more carbon dioxide
- ventilation: fresh air pumped into alveoli, stale air removed to maintain concentration gradient

Type I pneumocytes
- lung contains large numbers of alveoli with very large total surface area for diffusion
- wall of each alveolus consists of single layer of cells: epithelium
- most cells in epithelium are Type I pneumocytes which are flattened cells
- air in alveolus and blood in alveolar capillaries are less than 0.5 μm apart: distance the gas has to diffuse is very small: adaptation to increase rate of gas exchange

Type II pneumocytes
- rounded cells that occupy about 5% of alveolar surface area
- secrete fluid which coats inner surface of alveoli: allows oxygen in alveolus to dissolve and diffuse to blood and provides area from which carbon dioxide can evaporate into air
- fluid contains a pulmonary surfactant: form monolayer on surface of moisture lining alveoli: reduces surface tension and prevents water from causing sides of alveoli to adhere exhaling
- this helps to prevent collapse of lungs
- premature babies are often born with insufficient pulmonary surfactant

Airways for ventilation
- air enters ventilation system through mouth or nose; passes down trachea
- trachea has rings of cartilage in its wall: keeps it open even when air pressure inside is low or pressure in surrounding tissues is high
- trachea divides into two bronchi (also strengthened with cartilage)
- one bronchus leads to each lung; bronchi divided repeatedly (tree-like) to narrower airways called bronchioles (have smooth muscle fibers in walls allowing width to vary)
- at the end of narrowest bronchioles are groups of alveoli for gas exchange

Pressure changes during ventilation
- if gas is free to move, it will always flow from regions of higher to regions of lower pressure
- inspiration: muscle contractions cause pressure inside thorax to drop below atmospheric pressure, air is drawn into the lungs until lung pressure is same to atmospheric
- expiration: muscle contractions cause pressure in thorax to rise above atmospheric, so air is forced out

Antagonistic muscles
- muscles can be contracting or relaxing
- muscles perform work when contracting and become shorter
- muscles lengthen while relaxing (happens passively); requires the contracting of another muscle
- muscles can only cause movement in one direction

- when one muscle contracts and causes movement, second muscle relaxes and is elongated
- antagonistic pair of muscles: when muscles work together: inspiration and expiration

6.5 Neurons and synapses

Neurons

- two systems for internal communication: endocrine system and nervous system
- endocrine system: glands that release hormones
- nervous system: consist of nerve cells (neurons) that transmit electrical signals (nerve impulses)
- neurons have a cell body with cytoplasm, nucleus, narrow outgrowths (nerve fibers) along which nerve impulses travel, dendrites (short branched nerve fibers, in brain), axons (very elongated nerve fibers, from toes to spinal chords)

Myelinated nerve fibers

- basic structure of nerve fiber: cylindrical in shape, with plasma membrane enclosing narrow region of cytoplasm: conducts nerve impulses at around 1m per second
- some nerve cells are coated by myelin: consists of many layers of phospholipid bilayer
- Schwann cells deposit myelin by growing around nerve fiber many times
- node of Ranvier: gap between adjacent Schwann cells
- saltatory conduction: in myelinated nerve fibers, nerve impulse can jump form one node of Ranvier to the next one; quicker than continuous transmission (up to 100m per second)

Resting potentials

- resting potential: neuron not transmitting a signal has a potential difference across membrane
- sodium-potassium pumps pump sodium ions (Na^+) out and potassium ions (K^+) in; number of ions pumped is unequal (3 Na^+ out, 2 K^+ in), creating concentration gradients for both
- membrane is a lot more permeable to K^+ ions than Na^+ ions, so K^+ leak back across membrane faster; Na^+ concentration gradient is steeper than K^+ gradient: charge imbalance
- proteins in nerve fibers are negatively charged, increase imbalance
- neuron has a resting membrane potential of about -70mV

Action potentials

- rapid change in membrane potential consisting of two phases: depolarization (change from negative to positive) and repolarization (change back from positive to negative)
- depolarization is due to opening of sodium channels in membrane, allowing Na^+ ions to diffuse into neuron: reverses charge imbalance across membrane: inside is positive relative to outside (membrane potential increases to +30mV)
- repolarization happens rapidly after depolarization: closing of sodium channels and opening of potassium channels: potassium ions diffuse out of cell until potential close to -70mV is reached
- diffusion of potassium repolarizes neuron but does not restore resting potential: concentration gradients of sodium and potassium not re-established: this takes a few milliseconds and the neuron can then transmit another nerve impulse

Propagation of action potentials

- nerve impulse: action potential that starts at one end of neuron and is propagated along axon
- propagation of action potential happens because ion movement in one part of neuron triggers depolarization in neighboring part of neuron
- nerve impulses always travel in one direction along neurons: impulse can only be initiated at one terminal of neuron
- refractive period after depolarization preventing propagation of impulse backwards

Local currents

- propagation of action potential is due to movements of sodium ions
- sodium entering through sodium channels reduces concentration of sodium ions outside of axon and increases inside
- depolarized part has different sodium concentration than neighboring part: sodium ions diffuse between these regions
- inside axon sodium ions diffuse from depolarized part to region which is still polarized; outside the axon, concentration gradient goes in opposite direction: movements are local currents

- local currents reduce concentration gradient in part of neuron that has not yet depolarized: resting potential is changed from -70mV to -50mV
- sodium channels in axon membrane are voltage-gated: -50mV as threshold potential
- opening of sodium channels causes depolarization
- local currents cause wave of depolarization and also repolarization

Synapses
- junctions between cells in the nervous system; in sense organs they are between sensory receptor cells and neurons, in brain and spinal cord they are immense numbers of them between neurons, in muscles and glands they are between neurons and muscle fibers or secretory cells
- effectors: muscles and glands: they carry out a response to a stimulus
- neurotransmitters are used to send signals across synapses
- in all synapses: there is pre-synaptic and post-synaptic cells, separated by a fluid-filled gap (synaptic cleft) so electrical impulses cannot pass

Synaptic transmission
- synaptic transmissions occur very rapidly
- nerve impulse is propagated along neuron up to pre-synaptic membrane, pre-synaptic membrane depolarizes which causes diffusion of calcium ions (Ca^{2+}) into neuron
- calcium entering causes vesicles containing neurotransmitter to move to pre-synaptic membrane and fuse with it, releasing neurotransmitter into synaptic cleft by exocytosis
- neurotransmitter diffuses across synaptic cleft and binds to receptors on post-synaptic membrane causing adjacent sodium ion channels to open, sodium ions diffuse down concentration gradient into post-synaptic neuron causing post-synaptic membrane to reach threshold potential: action potential is triggered in post-synaptic membrane
- neurotransmitter is rapidly broken down and removed form synaptic cleft

Acetylcholine
- is used as neurotransmitter in many synapses
- produced in pre-synaptic neuron; combining choline (diet) and acetyl group (aerobic respiration)
- is loaded into vesicles and released into synaptic cleft during synaptic transmission
- acetylcholine remains bound to receptor of post-synaptic membrane for short time during which one action potential is initiated
- enzyme acetylcholinesterase is present in synaptic cleft and rapidly breaks acetylcholine down into choline and acetate (choline is reabsorbed by pre-synaptic neuron)

Threshold potentials
- nerve impulses follow all-or-nothing principle: action potential is only initiated if threshold potential is reached; only at this potential do sodium channels open, causing depolarization
- positive feedback effect of sodium channels: if threshold potential is reached, there will always be a full depolarization
- at synapse, amount of neurotransmitter secreted of pre-synaptic membrane may not be enough to cause threshold potential to be reached in post-synaptic membrane; post-synaptic membrane does not depolarize and sodium ions are pumped back out
- typical post-synaptic neuron in brain or spinal chord has synapses with many pre-synaptic neurons; may be necessary for several of these to release neurotransmitter at same time to reach threshold potential and cause nerve impulse to be initiated

6.6 Hormones, homeostasis and reproduction

Control of blood glucose concentration
- cells in pancreas respond to changes in blood glucose levels; if it deviates, homeostatic mechanisms mediated by pancreatic hormones insulin an glucagon are initiated
- pancreas: two glands in one organ: most is exocrine gland tissue (digestive enzymes to small intestine), small regions of endocrine tissue (islets of Langerhans; hormones to bloodstream)
- two cell types in islets of Langerhans secrete different hormones
- α cells: synthesize and secrete glucagon if blood glucose levels fall below set point; hormone stimulates breakdown of glycogen into glucose in liver cells

- β cells: synthesize and secrete insulin if blood glucose rises too much; hormone stimulates uptake of glucose by various tissues (esp. skeletal muscle and liver), in liver it stimulates conversion of glucose to glycogen
- insulin is broken down by cells acting upon it, so secretion must be ongoing

Thyroxin

- secreted by thyroid gland in neck; molecule contains four atoms of iodine
- prolonged deficiency of iodine prevents synthesis of thyroxin
- almost all cells in the body are targets; regulates body's metabolic rate so all cells need to respond, most active are liver, muscle and brain
- higher metabolic rate supports more protein synthesis, growth and generation of body heat
- importance of thyroxin is shown by effects of thyroxin deficiency (hypothyroidism): lack of energy, forgetfulness, weight gain despite loss of appetite (less glucose and fat are being broken down for energy), feeling cold, constipation, impaired brain development in children

Leptin

- protein hormone secreted by adipose cells (fat storage cells); controlled by food intake and amount of adipose tissue in body
- target of hormone is group of cells in hypothalamus of brain that contribute to appetite control
- if adipose tissue increases, blood level concentrations increase, causing long-term appetite inhibition and reduced food intake
- importance of hormone shown in experiment with mice that cannot produce leptin

Melatonin

- circadian rhythms: 24-hour cycle and behavior rhythms adapted to this cycle
- cycle continues when person is placed into continuous light or darkness: internal system
- circadian rhythms depend on two cell groups in hypothalamus (suprachiasmatic nuclei, SCN)
- SCN set the daily rhythm, even without external clues
- in the brain, SCN control secretion of hormone melatonin in pineal gland
- melatonin increases in evening and drops to low level at dawn (rapidly removed by liver)
- most obvious effect is sleep-wake cycle; falling levels encourage waking
- contributes to night-time drop in core body temperature
- melatonin receptors in kidney suggest decreased urine production at night
- SCN and pineal gland maintain rhythm of slightly over 24h: timing of rhythm is normally adjusted by few minutes each day
- ganglion cell in retina of eye detects light (wavelength 460-480nm) and passed impulses to cells in SCN, indicating to SCN the timing of dusk and dawn

Sex determination in males

- human reproduction involves fusion of a sperm and egg
- development of embryo is initially same in all embryos and embryonic gonads develop which can either become ovaries or testes
- development pathway of embryonic gonads depends on presence or absence of gene
- if SRY is present, embryonic gonads develop into testes; gene is located on Y chromosome
- SRY codes for a DNA-binding protein (testis determining factors, TDF) which stimulates the expression of other genes that cause testis development
- embryos with two X chromosomes do not have SRY gene, TDF is not produced and embryonic gonads develop as ovaries

Testosterone

- testes develop form embryonic gonads in about 8th week of pregnancy
- testes develop testosterone-secreting cells in early stage and produce it by 15th week
- testosterone causes male genitalia to develop
- at puberty, testosterone secretion increases: stimulates sperm production (primary sexual characteristic) and secondary sexual characteristics such as penis enlargement, growth of pubic hair and deepening of voice due to growth of larynx

Sex determination in females

- in absence of SRY, embryonic gonads develop as ovaries
- no testosterone is secreted, but estrogen and progesterone are always present in pregnancy; at first they are secreted by mother's ovaries, later by placenta
- during puberty, secretion of estrogen and progesterone increases: development of female secondary sexual characteristics including enlargement of breasts and growth of pubic hair

Menstrual cycle

- occurs from puberty until menopause, apart from pregnancies
- each time the cycle occurs, it gives the chance of a pregnancy
- first half: follicular phase: group of follicles is developing in the ovary, in each follicle an egg is stimulated to grow, lining of uterus (endometrium) is repaired and thickens
- the most developed egg breaks open, releasing its egg into oviduct; other follicles degenerate
- second half: luteal phase: wall of follicle which released egg becomes corpus luteum, endometrium prepares for implantation of embryo
- if fertilization does not occur, corpus luteum in ovary breaks down; thickening of endometrium in uterus breaks down and is shed during menstruation
- four hormones control menstrual cycle by negative and positive feedback
- FSH and LH are protein hormones, produced by pituitary gland, bind to receptors in membranes of follicle cells; estrogen and progesterone are ovarian hormones, produced by wall of follicle and corpus luteum
- FSH rises to peak at end of menstrual cycle, stimulates development of follicles, each containing an oocyte and follicular fluid, and stimulates secretion of estrogen by follicle wall
- estrogen rises to peak at end of follicular phase, stimulates repair and thickening of endometrium, increase in FSH receptors, making follicles more receptive to FSH (positive feedback); in high levels, estrogen inhibits FSH (negative feedback) and stimulates LH secretion
- LH rises to sharp peak at end of follicular phase, stimulates completion of meiosis in oocyte, partial digestion of follicle wall (allows it to burst open), promotes development of wall of follicle after ovulation into corpus luteum, secreting estrogen (positive feedback) and progesterone
- progesterone levels rise at start of luteal phase, promotes thickening and maintenance of endometrium, inhibits FSH and LH secretion by pituitary gland (negative feedback)