11 Animal physiology

Introduction

- immunity based on recognition of self and destruction of foreign material
- all animals excrete nitrogenous waste products
- sexual reproduction involves development and fusion of haploid gametes

11.1 Antibody production and vaccination

Antigens in blood transfusion

- antigen: any foreign molecule that can trigger immune response; most common are proteins and very large polysaccharides (found on surface of cancer cells)
- surface of own cells contain proteins and polypeptides which are distinguished by immune system as “self”; others are “foreign” antigens
- antigens on surface of pollen are trigger for immune responses “allergies” and “hay fever”

The specific immune response

- immune systems uses “challenge and response”: antigens on surface of pathogens are “challenge”; response is in multiple stages
- pathogens ingested by macrophages, their antigens are displayed on surface of macrophages, lymphocytes (helper T cells) have antibody-like receptor protein in plasma membrane which bind, only few lymphocytes have receptor protein, these helper T cells bind and are activated by macrophage, these bind to B cells
- B cells have receptor protein to which antigen binds; helper T cell activates selected B cell by means of binding and release of signaling protein

The role of plasma cells

- plasma cells: mature B lymphocytes that produce and secrete large number of antibodies during immune response
- cell’s cytoplasm contains extensive network of rough endoplasmic reticulum which manufactures, modifies and transports antigens

Clonal selection and memory cell formation

- activated B cells divide many times by mitosis; clonal selection: large number of plasma cells that produce one specific antibody type
- antibodies only persist in body for few weeks and plasma cells producing them are gradually lost after infection is overcome
- most of clone B cells become active plasma cells, small number become memory cells which remain long after infection; remain inactive unless same pathogen appears again
- immunity involves either having antibodies or memory cells allowing rapid production

The role of antibodies

- antibodies aid in destruction of pathogens in number of ways
- opsonization: make pathogen more recognizable to phagocytes, more readily engulfed
- neutralization of viruses and bacteria: prevent viruses from docking to host cells
- neutralization to toxins: bind to toxins produced by pathogens, preventing them from affecting susceptible cells
- activation of complement: complement system is collection of proteins which lead to perforation of membranes of pathogens
- agglutination: cause sticking together of pathogens, so prevented of entering cells and easier for phagocytes to ingest

Immunity

- either due to presence of antibodies or memory cells
- immunity develops when immune system is challenged by specific antigen and produces antibodies and memory cells in response

- memory cells ensure that second time antigen is encountered, body is ready to respond rapidly by producing more antibodies at faster rate

Vaccines lead to immunity

- vaccine is introduced to body usually by injection
- vaccine may contain a live attenuated (weakened) version of pathogen or some derivative that contains antigens form pathogen: stimulates primary immune response

Zoonosis are a growing global health concern

- pathogens often highly specialized with narrow range of hosts
- some bacterial pathogens only cause disease in humans
- zoonosis: pathogen which can cross species barrier: emerging global health concern
- cause is growth of contact between animals and humans

The immune system produces histamines

- mast cells are immune cells found in connect tissue that secrete histamine in response to infection which causes dilation of small blood vessels in infected area which causes the vessels to become leaky: increases flow of fluid containing immune components

Effects of histamines

- histamine as contributor to number of symptoms of allergic reactions
- cells in variety of tissues have membrane-bound histamine receptors
- histamine plays role in bringing symptoms of allergy in nose, formation of allergic rashes and in dangerous swelling (anaphylaxis)
- to lessen effects, anti-histamines can be taken

The process for creating hybridoma cells

- monoclonal antibodies are highly specific; only recognize one antigen
- to produce clone of cells that will manufacture a monoclonal antibody, the antigen recognized by antibody is injected into a mammal; mammal's immune system makes plasma B cells that are capable of producing desired antibody
- B cells fused with cancer cells (myeloma cells): fusion of these two is hybridoma cell

Production of monoclonal antibodies

- full diversity of B cells are fused with myeloma cells: many different hybridomas are produced and individually tested to find the one that produces required antibody
- once identified, desired hybridoma cell is allowed to decide to secrete huge amounts of monoclonal antibodies
- hybridoma cell is multiplied in fermenter to produce large numbers of genetically identical copies, each secreting antibody produced by original lymphocyte
- monoclonal antibodies used for treatment and diagnosis of diseases

11.2 Movement

Bones and exoskeletons anchor muscles

- exoskeletons are external skeletons that surround and protect most of body surface of animals such as crustaceans and insects
- bones and exoskeletons facilitate movement by providing anchorage for muscles and acting as levers; levers change size and direction of forces; in a lever there are: pivot point (fulcrum), effort force, resultant force; relative positions of these three determine the class of lever
- spine acts as first-class lever when nodding backwards (fulcrum between effort and resultant)
- grasshopper leg acts as third-class lever
- muscles are attached to inside of exoskeletons, but to outside of bones

Skeletal muscles are antagonistic

- skeletal muscles occur in pairs that are antagonistic: when one contracts, the other relaxes
- antagonistic muscles produce opposite movements at a joint

Different joints allow different ranges of movement

- structure of a joint, including joint capsule and ligaments, determines the possible movements
- knee joint can act as hinge joint (only two movements: flexion, extension) or can act as pivot joint when flexed: knee has greater range of movement when it is flexed
- hip joint is a ball and socket joint: it can flex, extend, rotate, move sideways and back
- moving sideways and back are called abduction and adduction respectively

Structure of muscle fibers

- muscles used to move our body are attached to bones: skeletal muscles/ striated muscles
- two other types of muscles are smooth and cardiac
- striated muscle is composed of bundles of muscle cells known as muscle fibers
- single plasma membrane (sarcolemma) surrounds each muscle fibre: but many nuclei are present in muscle fibers and are much longer than typical cells
- embryonic muscle cells fuse together to form muscle fibers
- modified version of endoplasmic reticulum (sarcoplasmic reticulum) extends throughout muscle fibre: wraps around every myofibril conveying signal to contract to all parts of muscle at once
- sarcoplasmic reticulum stores calcium
- between myofibrils are large number of mitochondria which provide ATP for contractions

Myofibrils

- myofibrils: within each muscle many parallel, elongated structures: have alternating light and dark bands; in centre of each light band is a disc shaped structure (Z-line)

Structure of myofibrils

- number of repeating units alternating between light and dark bands are visible; in centre of light band is Z-line: part of a myofibril between one Z-line and the next is called a sarcomere
- pattern of light and dark bands is due to precise and regular arrangement of two types of protein filaments: thin actin and thick myosin filaments
- actin filaments are attached to Z-line at one end; myosin filaments are interdigitated with actin filaments on both ends and occupy the centre of sarcomere
- myosin filament is surrounded by six actin filaments, forms cross-bridges during contraction

Mechanism of skeletal muscle contraction

- during muscle contraction, myosin filament pull actin filaments towards centre of sarcomere
- process shortens each sarcomere and therefore overall length of muscle fibre
- contraction of skeletal muscle occurs by sliding of actin and myosin filaments: myosin filaments cause this sliding: have heads binding to special sites on actin filaments, create cross-bridges through which they excerpt force using ATP
- heads are regularly spaced along actin filaments so many cross-bridges can form at once

The control of skeletal muscle contraction

- tropomyosin in relaxed muscle blocks binding sites on actin
- when motor neuron sends signal to muscle fibre to contract, sarcoplasmic reticulum releases calcium ions, these bind to protein troponin which moves tropomyosin: exposes actin's binding sites: myosin heads bind and pull actin filaments to centre of sarcomere

The role of ATP in the sliding of filaments

- for significant contraction, myosin heads must carry out action repeatedly: happens in sequence of stages
- ATP causes breaking of the cross-bridges by attaching to myosin heads
- hydrolysis of ATP to ADP and P provides energy for myosin heads to move from centre
- new cross-bridges form by binding of myosin heads to actin binding sites, each head binds one position further from centre of sarcomere
- energy is stored in myosin head from hydrolyzing ATP
- sequence of stages continues until motor neuron stops sending signals; calcium ions are pumped back to sarcoplasmic reticulum, regulatory protein covers binding sites on actin, muscle fibre relaxes

11.3 The kidney and osmoregulation

Different responses to changes in osmolarity in the environment

- osmolarity: solute concentration of a solution
- many animals are osmoregulators (maintain constant internal solute concentration, usually at third of seawater): all terrestrial animals, freshwater animals and some marine organisms
- osmoconformers have same internal solute concentration as concentration of environment

The Malpighian tubule system

- arthropods have circulating fluid (hemolymph) that combines characteristics of tissue and blood
- osmoregulation is a form of homeostasis
- breakdown of amino acids causes nitrogenous waste which is toxic and needs to be excreted: in insects excreted as uric acid and in mammals as urea
- Malpighian tubules: tubes in insects branching off from intestinal tract; cells lining tubules actively transport ions and uric acid from hemolymph into lumen of tubules, draws water by osmosis into lumen, tubules empty contents into gut, water and salts are reabsorbed, uric acid is excreted with feces

Comparing the composition of blood in the renal artery and the renal vein

- kidneys function in osmoregulation and excretion: remove substances from blood that are not needed or harmful
- composition of renal artery (entering kidney) is different to renal vein (leaving kidney)
- substances in higher amounts in renal artery: toxins and other substances ingested but not fully metabolized and excretory waste (nitrogenous waste, mainly urea) and removed things that are not excretory products (excess water and salt)
- water and salt aren't excretory products because they are produced by body cells
- water and salt content may vary in renal artery, but more constant in renal vein: osmoregulation
- kidneys filter around fifth of volume of plasma from blood flowing through; filtrate contains all substances from plasma membrane apart from large protein molecules; needed substances are then actively reabsorbed: process for unwanted substances passing out of body through urine
- substances passing to urine are present in renal artery but not renal vein
- small difference due to metabolic activity of kidney itself: blood is deoxygenated, higher partial pressure of carbon dioxide, less glucose
- plasma proteins are not filtered and should be present in same concentration in both

The ultrastructure of the glomerulus

- blood in capillaries is at high pressure in many tissues, pressure forces some of plasma through capillary wall to form tissue fluid
- in glomerulus of the kidney, pressure in capillaries is particularly high and capillary wall is particularly permeable so volume of fluid forced out is high: glomerular filtrate
- most solutes filtered out freely, almost all proteins are retained: ultrafiltration (separation in size)
- permeability to larger molecules depends on shape and charge
- basement membrane separates capillaries; gaps in wall of capillary are called fenestrations
- podocytes function as barrier through which waste products are filtered
- three parts to ultrafiltration system: fenestrations, basement membrane, podocytes
- fenestrations: 100nm in diameter, allow fluid to escape but not blood cells
- basement membrane: covers and supports wall of capillaries, made of negatively charged glycoproteins: prevents plasma proteins being filtered due to size and negative charge
- podocytes: form inner wall of Bowman's capsule, have extensions wrapping around capillaries of glomerulus and short side branches called foot processes; narrow gaps between foot processes prevent small molecules being filtered out of blood in glomerulus
- if particles pass through they are part of the glomerular filtrate

The role of the proximal convoluted tubule

- glomerular filtrate flows into the proximal convoluted tubule
- almost all of the filtrate must be reabsorbed into the blood: happens in the first part of the nephron: the proximal convoluted tubule: by its end all glucose and amino acids and 80% of water, sodium and other mineral ions have been absorbed

- sodium ions: moved by active transport from filtrate, pass to peritubular capillaries; pump proteins located in outer membrane of tubule cells
- chloride ions: attracted to space outside of tubule because charge gradient of sodium ions
- glucose: co-transported out of filtrate by co-transporter proteins in outer membrane of tubule cells, sodium ions move down concentration gradient from outside tubule into tubule cells which provides energy for glucose to move at the same time to fluid outside of tubule; same process is used to reabsorb amino acids
- water: pumping solutes away creates solute concentration gradient: reabsorbed by osmosis

The role of the loop of Henle

- overall effect is to create gradient of solute concentration in the medulla
- energy to create gradient is expended by wall cells in ascending limb: sodium ions are pumped out of filtrate to fluid between cells in medulla (interstitial fluid)
- ascending limb is impermeable to water: water is retained even though interstitial fluid is hypertonic (higher solute concentration) relative to filtrate
- normal body fluids have concentration 300 mOsm; sodium pumps can create gradient of up to 200 mOsm, interstitial concentration of 500 mOsm is achievable
- cell walls of descending limb are permeable to water, but impermeable to sodium ions; as filtrate flows down descending limb it is drawn out due to solute concentration of interstitial fluid: filtrate entering ascending has 500 mOsm: sodium ion pumps get this to 700 mOsm this again affects descending limb to 900 mOsm; this cycle can go up to 1'200 mOsm (humans)
- system for raising solute concentration is example of countercurrent multiplier system; countercurrent because fluid flows in opposite directions
- countercurrent system is also present in vasa recta preventing blood flowing through vessel from diluting solute concentration of medulla, still allowing to carry away water and sodium

Some animals have relatively long loops of Henle

- the longer the loop of Henle, the more water volume will be reclaimed: animals adapted to dry habitats will often have long loops
- in order to accommodate the long loops, the medulla has to be thicker

Function of ADH

- filtrate entering distal convoluted tubule from loop of Henle is hypotonic: more solutes passed out of filtrate in the medulla
- if solute concentration is too low, little water is reabsorbed in distal convoluted tubule and collecting duct (usually low permeability to water); large volume of urine is produced with low solute concentration: solute concentration of blood is increased
- if solute concentration is too high, hypothalamus detects it: causes pituitary gland to secrete antidiuretic hormone (ADH): hormone causes walls of distal convoluted tubule and collecting duct to become much more permeable to water: most water is reabsorbed; kidney produces small volume of concentrated urine: solute concentration of blood is reduced

Animals vary in terms of the type of nitrogenous waste they produce

- breaking down amino and nucleic acids creates nitrogenous waste in form of ammonia
- ammonia is highly basic and can alter pH balance, toxic because it is a highly reactive chemical
- marine/freshwater habitat animals can release ammonia directly: easily diluted in environment
- terrestrials expend energy to convert it into less toxic urea or uric acid
- marine mammals release urea due to evolutionary history
- converting ammonia to urea requires energy and conversion to uric acid even more
- advantage of uric acid that it isn't water-soluble: does not require water to be released: birds don't have to carry water for excretion
- uric acid is linked to adaptations for reproduction: within eggs uric acid (insoluble) crystallizes rather than building up toxic concentrations

11.4 Sexual reproduction

Similarities between oogenesis and spermatogenesis

- oogenesis: production of egg cells in ovaries, starts in ovaries of a female fetus: germ cells in fetal ovary divide by mitosis and distribute themselves through cortex of ovary

- when fetus is four or five months, cells grow and divide by meiosis (primary follicle), by seventh moth they are still in first meiotic division, single layer of cells (follicle cells) forms around them
- no further development takes place until after puberty
- no more primary follicles are produced, but at start of each menstrual cycle, some are stimulated to develop by FSH: mature follicle containing a secondary follicle
- spermatogenesis: production of sperm, happens in testes which are composed of mass of narrow tubes (seminiferous tubules) with small groups of cells (interstitial cells, Leydig cells) filling the gaps (interstices) between the tubules
- seminiferous tubules are also made of cells; outer layer is called germinal epithelium where process of sperm production begins
- most mature stages are found closest to the fluid-filled center of seminiferous tubule
- cells that have developed are spermatozoa (sperm)
- in wall of tubules are large nurse cells (Sertoli cells)

Differences in the outcome of spermatogenesis and oogenesis

- each mature sperm consists of a haploid nucleus, system for movement, system of enzymes and other proteins that enable it to enter the egg
- each complete meiotic division results in four spermatids; process of sperm differentiation eliminates most of the cytoplasm (egg must increase its cytoplasm)
- all requirements for beginning growth and development of embryo must be present in egg
- first division of meiosis produces one large and one very small cell (first polar body, degenerates); large cell goes to second division of meiosis, completing it after fertilization
- in second division again one large and one small cell are produced; small cell, second polar body, degenerates and dies
- result of division is egg that is much larger than the sperm cell
- process of egg formation happens once per menstrual cycle, usually one egg per cycle
- from puberty onwards, testes produce sperm continuously

Preventing polyspermy

- membranes of sperm have receptors that can detect chemicals released by egg (navigation)
- events happening once sperm arrive at egg, are designed to result in the union of a single sperm with egg and to prevent multiple sperm entering (polyspermy)
- the acrosome reaction: zona pellucida is coat of glycoproteins that surround the egg, acrosome is a large membrane bound sac of enzymes in head of sperm, sperm binds to zone pellucida and contents of acrosome are released, enzymes for it digest the zona pellucida
- penetration of the egg membrane: acrosome reaction exposes an are of membrane on tip of sperm that has proteins to bind to egg membrane, first sperm to get to zona pellucida binds and their membranes fuse together, sperm nucleus enters the egg cell (fertilization)
- the cortical reaction: sperm causes activation of egg, cortical granules (vesicles near eggs cell membrane) release their contents form egg by exocytosis once egg is activated, cortical vesicle enzymes digest binding proteins so no further sperm can bind and hardens zona pellucida

Internal and external fertilization

- aquatic animals often release gametes directly into water, fertilization outside of female's body
- external fertilization has risks as predation, pollution and susceptibility to environmental variation such as temperature and pH fluctuations
- terrestrial animals depend on internal fertilization (gametes would be at risk of drying out)
- internal fertilization ensures that sperm and ova are placed in close proximity and developing embryo can be protected inside female

Implantation of the blastocyst

- fertilized ovum divides by mitosis to form two diploid nuclei and cytoplasm divides equally
- two cells replicate DNA, carry out mitosis and divide again
- further cell divisions occur, but some divisions are unequal and there is migration of cells, giving the embryo the shape of a hollow ball (blastocyst)
- 7 days old blastocyst is made of 125 cells and has reached uterus, having been moved down by the oviduct by the cilia of cells in the oviduct wall
- zona pellucida which has protected the embryo breaks down

- blastocyst has used up its resources and needs an external supply: sinks into the endometrium or uterus lining (process is implantation)
- outer layer of blastocyst develops finger-like projections to penetrate uterus lining; exchanges materials with mother's blood
- after 8 weeks it is considered to be a fetus rather than embryo

Role of hCG in early pregnancy

- pregnancy depends on maintenance of the endometrium, which depends on continued production of progesterone and estrogen: hormones prevent degeneration of uterus lining
- early in pregnancy, embryo produces human chorionic gonadotropin (hCG): stimulates corpus luteum to continue secreting progesterone and estrogen: stimulate development of uterus wall

Materials exchange by the placenta

- three groups of mammals: placental, monotremes (lay eggs), marsupials (offspring in a pouch)
- placenta is needed because body surface are to volume ratio becomes smaller as fetus grows
- placenta is made of fetal tissue, which is in close contact with maternal tissues in uterus wall
- fetus develops membranes forming amniotic sac with amniotic fluid for support and protection
- basic functional unit of placenta is a finger-like piece of fetal tissue (placental villus), maternal blood flows in the inter-villous spaces around the villi (not confined to vessels)
- fetal blood circulates in blood capillaries also to surface of each villus
- cells separating maternal and fetal blood form the placental barrier; selectively permeable

Release of hormones by the placenta

- in ninth week, placenta starts to secrete estrogen and progesterone to sustain pregnancy; corpus luteum is no longer needed for this function
- danger of miscarriage if this switch-over fails

The role of hormones in parturition

- durning pregnancy, progesterone inhibits oxytocin secretion by pituitary glands and contractions of the muscular outer wall of the uterus (myometrium)
- at end of pregnancy, fetal hormones signal to placenta to stop secreting progesterone; oxytocin is secreted and stimulate contractions of muscle fibers in myometrium
- contractions are detected by stretch receptors, which signal pituitary gland to secrete more oxytocin: makes contractions more frequent and more vigorous; this causes more oxytocin to be secreted (positive feedback system)
- gradual increase in myometrial contractions, allows baby to be born with minimum intensity of contraction
- relaxation of muscle fibers in the cervix causes it to dilate; uterine contraction bursts amniotic sac and amniotic fluid passes out; further uterine contractions push baby out through cervix and vagina; umbilical cord is broken and baby takes its first breath