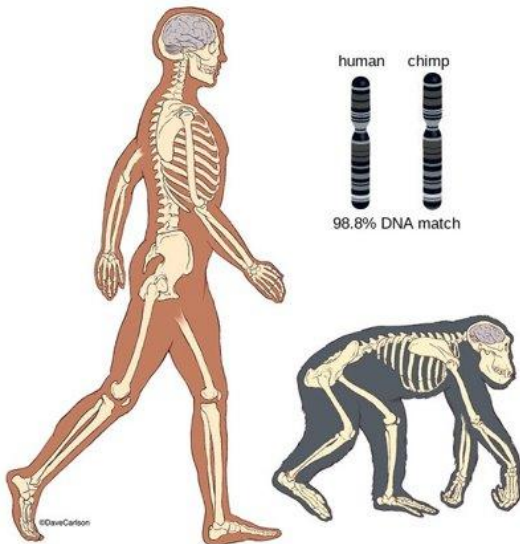


INTRODUCTION

Mammals

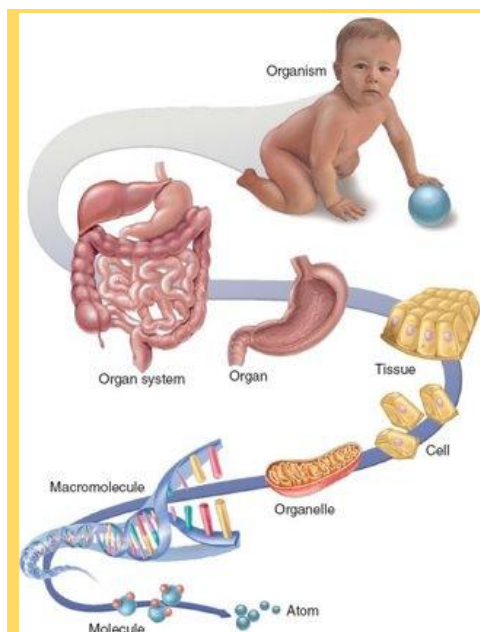
- Humans are mammals with DNA that is about 98.8 percent similar to chimpanzees, so we are mostly like animals
- This explains the great similarities in the body systems (skeletal, muscular, cardiovascular, respiratory, digestive, urinary, immune, reproductive, endocrine and nervous).
- There is a little but potent difference in language abilities which gives us vastly superior intellect. So humans can be viewed as having most of the abilities of animals plus extra powers for cognition.
 - You can see the animal-like behaviour in a bold confrontation where you respond quickly before your human intellect has time to properly consider appropriate responses.



Development

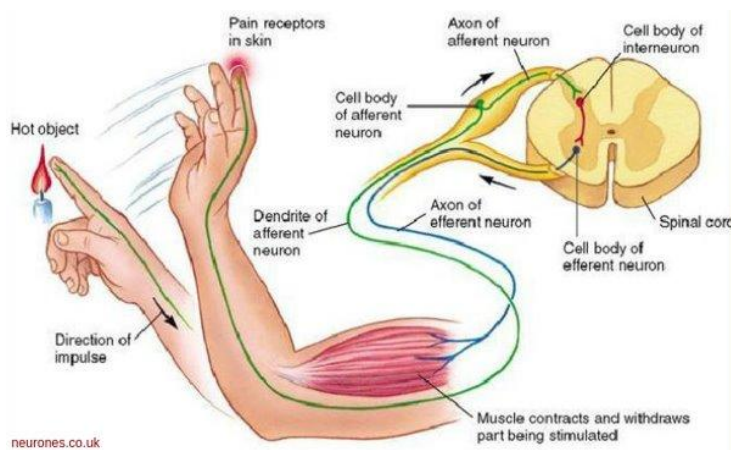
- The basic principles for the development of animals applies also to humans
- Atoms form molecules which form cells which form organs which forms an individual with instincts (pre-programmed responses to stimuli or situations) and a consciousness which is most developed in humans allowing them with the unique ability to perceive that they are simply atoms travelling together on a planet in a solar system in the universe.
- Human nature urges us to find an explanation for our abilities
- Plato (429-347 BC) believed that the brain was the source of our abilities because it had a round shape like the supreme shape of the celestial bodies of the universe.
- However, Aristotle (384-322 BC) was a better orator and successfully argued throughout his life that the heart is the source of our abilities and that the brain is simply a radiator to cool the blood.
 - He argued that the brains of men were bigger because they got more angry than women and needed more cooling of the blood

- Nowadays, our language contains a relic of the teachings of Aristotle. When describing the task to learn new information, we say you need to "memorize by heart".
- Nowadays everyone knows the brain is responsible for behaviour. However, the way the brain works is still a mystery. If we surveyed the class on the following general question, "Which of the following statements is true? (A) all humans have the same brain but make different choices or (B) all humans have different brains which explains their choices.", then there would be mixed responses.
- The external anatomy of the brain appears the same in all humans but the mechanisms of brain function depend on the microscopic connections which are different in everyone.
 - For example, identical twins have identical genes but different personalities because of different connections. So the facts show that all humans have different brains which explains their choices.
 - Despite this, common parlance is based on the premise that we all have the same brains: (a) The statement "I know what you're thinking" assumes we all have the same brain so our thoughts are the same as those in others. (b) The statement "You must read between the lines" assumes that we all interpret with the same brain so the hidden message is clear to everyone. (c) The statement "I don't understand why he does that" assumes that we all have access to the same analysis so why would anyone choose the worst option.
 - All individuals have unique brains. One may have a trait in common with others but the collection of traits forming one's personality is unique to each individual.
 - Identical twins also teach us that you can't predict someone's personality by their appearance (n.b. although the arts depict caricatures of honest or deviant people, personality is not reliably linked to appearance) including skin color.



Basic Behaviours

- We will use the withdrawal reflex to explain the fundamental mechanisms through which the nervous system produces all behaviours.
- A flame near a finger will stimulate nociceptors which send a signal to the spinal cord where it has an excitatory synaptic connection with an interneuron that has an excitatory connection with a motor neuron that will relay the signal to the biceps muscle whose contraction removes the finger from the harmful stimulus.
- This three neuron circuit for the withdrawal reflex is very simple but it contains all the components used in the most complex circuits, that is, it contains neurons communicating through chemical synaptic transmission.
- The nervous system developed this circuit as a reflex because withdrawal is always the right response to a painful stimulus.
- Furthermore, to promote survival, the nervous system generates the perception of pain which is purposely unpleasant so that we do not repeat the action causing injury.

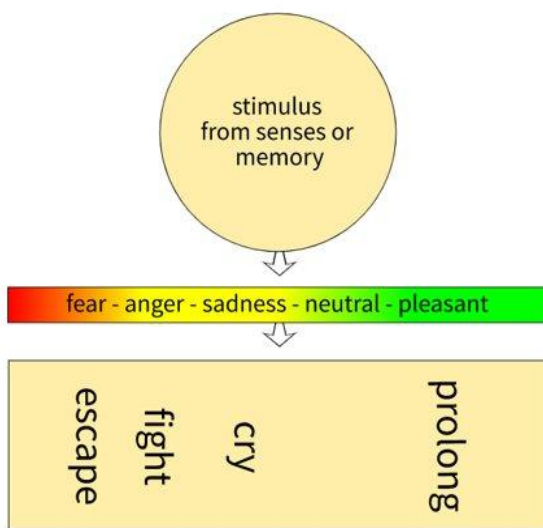


Complex Behaviours

- The nervous system has reflexes for cases where there is only one correct response to a stimulus but most cases are too complex to have a single correct response.
- Consequently, the nervous system uses a strategy where the stimulus triggers an emotion by the limbic system that urges us to select among a range of suitable responses.
- Thus for non-reflex actions, the flow of information through the nervous system is as follows
 1. The stimulus is either perceived from sensory receptors or from memory (e.g. taste sweetness of apple or remember its sweetness).
 2. Perception of the stimulus will trigger an emotion which is a guess by the nervous system as to how it pertains to survival (e.g. a pleasant emotion will occur for a sweet apple).
 3. The emotional response provided by the limbic system will urge you to take action (e.g. eat the sweet apple)
- So the limbic system is a preprogrammed circuit that tries to guess what type of response we should give in different situations.
- It provides a wide range of emotions such as fear, anger, and sadness in order to urge you to avoid stimuli that produce these negative emotions but also provides the

pleasant perception of happiness for stimuli which the nervous system believes you should prolong or repeat.

- Eating most fruits tastes great because the nervous system knows the chemical content (n.b. provided by chemoreceptors of taste and smell) is nutritious and it wants you to thrive.
- Conversely, stepping close to a cliff will trigger the uncomfortable feeling of fear because the nervous system knows it could be dangerous and you should escape this situation.
 - For such negative emotions, the limbic system will trigger the autonomic system to provide a burst of energy (e.g. release of fats into the blood and increased heart rate) to escape.

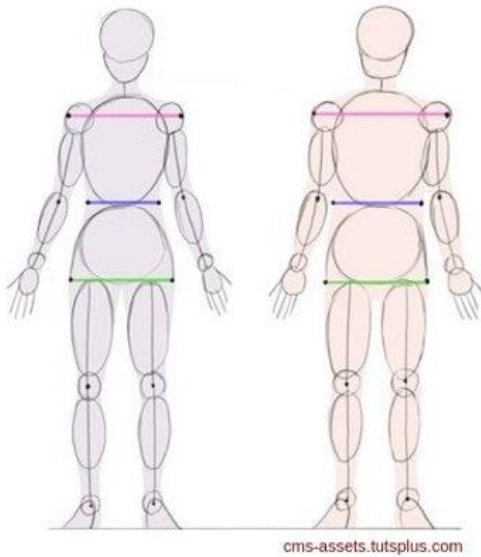


Humanoid

- To better understand that the nervous system is designed to promote survival of the species, let's consider what is the most important in creating male and female humanoids. Let's say we can assemble all the organs.
 - For the brain, we include sensory perception (touch, sight, sound, taste, smell, and balance) to perceive our environment and motor control to move within our environment.
- What other preprogrammed circuits must we include in the brain for survival of our humanoid species?
 1. Feeding. We must create feeding circuits.
 - The newborn child has feeding circuits that control the movements for feeding and also has chemoreceptors in the mouth to detect healthy food and provide pleasure (nutritious foods are given a pleasurable taste while poisons are perceived as having a very bad taste).
 - If the nervous system does not urge the child to eat then it will die and extinction of the species will occur.

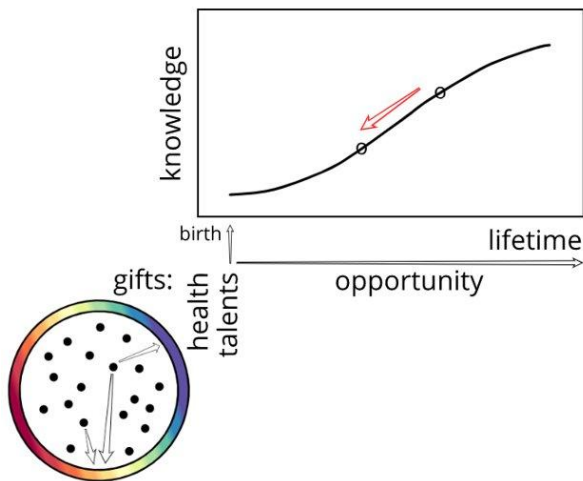
2. **Reproduction.** The nervous system must urge individuals to reproduce otherwise extinction would occur. As always, the strategy is to provide the greatest pleasure for the most important actions.
 - Of the many pre-programmed circuits for reproduction, facial recognition is a key circuit. Nowadays, we have phones with facial recognition coded using neural network software based on the principles that you will be learning in this course. For facial recognition on a phone, there must be a recording of the owner's facial features in memory for comparison to that of the user trying to unlock the phone. The phone unlocks only if there is a match.
 - Similarly, humans have a memory of suitable mates and when a match occurs there's a strong urge and pleasurable feeling. We conclude that the prospective mate is beautiful. But nothing is inherently beautiful because beauty is attributed by our brain and, since everyone is unique, everyone has a different opinion on beauty.
 - Gender identity is not defined by nature, that is, you know exactly whether you are genetically male or female, you know exactly how you feel, you know exactly what features you're attracted to but if someone asks you about your gender identity then you tell them what you are comfortable in answering since there's no objective definition of the gender identities (i.e. everyone uses their own definitions which only partially overlap) and they can't read your mind.
3. **Fear.** The nervous system must prevent individuals from falling off a cliff or from other harmful activities in order to thrive.
 - Consequently, the limbic system triggers fear when sensory stimuli from the environment suggest danger. This fear will encourage the person to escape by whatever means possible.
4. **Anger.**
 - The limbic system triggers anger when it perceives you need energy to fight back in order to protect yourself.
5. **Sadness.**
 - The emotion of sadness is triggered when the limbic system considers that you have lost something important so that the uncomfortable feeling urges you to cry and to use your cognitive abilities to prevent such occurrences in the future.
6. **Pain.**
 - Pain is a somatosensory stimulus whose perception is modulated by the limbic system producing the worst feelings in order to urge the individual to avoid repeating the action that caused the pain.
- As you can see, the nervous system triggers negative emotions to discourage individuals from harmful activities and triggers pleasure to encourage activities that help the individual to thrive.
- At birth, there is a limited number of pairing between stimulus and emotional response but we have the ability to pair more stimuli to the basic emotions.
 - For example, losing a hat is of no consequence to a toddler but an adult would likely feel sad because of the value attributed to the hat.
- It is important to remember that negative emotions are only guesses by the nervous system that a problem exists and it gives you a burst of energy to solve the problem.

If you solved the problem already or none really existed then it's up to you to let go of the emotion.



Gifts of nature

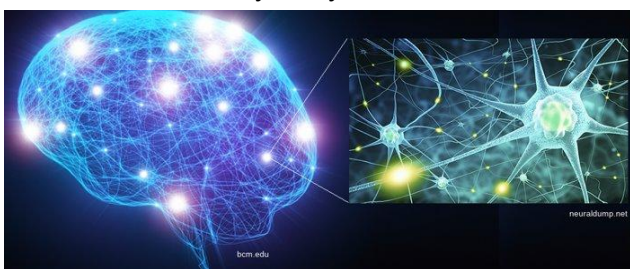
- At birth you have a highly functional nervous system with gifts uniquely chosen by nature, not by your parents or you.
- You get gifts of good health and talents.
 - A talent (e.g. proficiency in tennis, drawing, or singing) is an ability which comes easily to you compared to others.
 - The colored circle in the slide is meant to represent all the possible talents and each dot within the circle represents the proximity to talents a person has at birth with the length of arrows representing the effort required to master a talent.
 - You can see that a person (i.e. dot) at birth can be very close to mastering a talent but very far from mastering others.
 - Thus, it is easy and pleasing to master abilities for which we have a talent but it would require a lot of time and effort to master other talents.
 - There's no manual at birth so you must try many different activities to discover your talents.
- We are born without knowledge at birth so it's normal to learn by trial and error to gain knowledge throughout our lifetime.
- A key point (shown by the red arrow) is that if you look back in time, you are always considering decisions you made at a time when you had less knowledge. This is helpful to decide how you might do things differently in the future.
- Note that the knowledge obtained during a lifetime depends on opportunity (n.b. opportunities differ for a child born in a stable country compared to a child born in a war torn country).



Learning

Learning is essential in this course and it is a function of the nervous system. As a preview to help you, I provide here some key details about learning.

- The nervous system is made of neurons that link to form a neural network. It is the links that determine the flow of information for memory storage or retrieval.
- There's implicit memory like riding a bicycle and explicit memory like remembering a phone number. In learning to ride a bicycle, you try a pattern of muscle force then, based on the performance, you adjust the pattern of muscle force. Ultimately, you will find a pattern of muscle force for riding the bicycle. By repeating the procedure, you are activating the same neurons repeatedly.
 - Neurons that are activated repeatedly will lead to implicit memory of the movement.
- The same principle applies to explicit memory. You first attempt to memorize a phone number then you attempt to retrieve it. If retrieval fails then you retry to memorize the phone number.
 - By repeating the procedure, you are activating the same neurons again and facilitating storage of explicit memory of the phone number.
 - Interest in the subject helps memorization because you attend more to its details, relate it to previous knowledge and share it with others such that the same neurons are activated repeatedly.
 - Linking new information to older memorized information is key to memory storage and retrieval because neurons are linked to one another.
 - That's why mnemonics (making links between new and old information) help in memorizing. Neighboring links allow other relevant memories to emerge when you try to retrieve information.

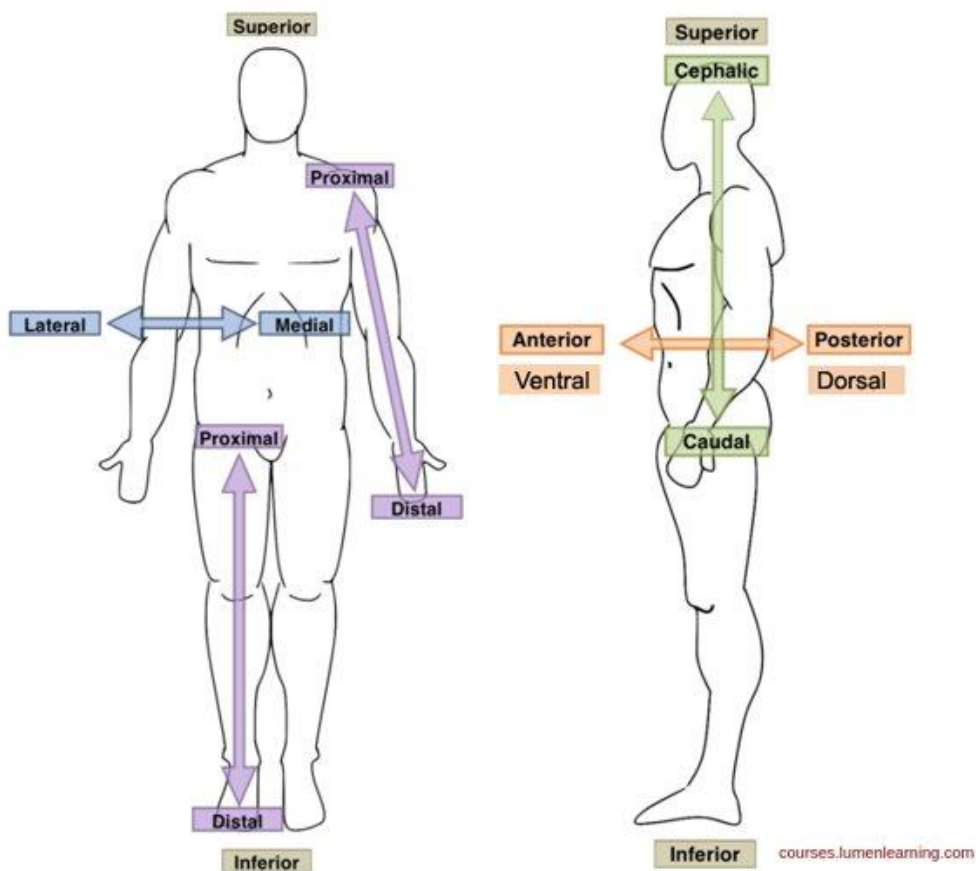


TERMINOLOGY

Terminology

Before starting to describe the anatomy and physiology of the body, we need to cover some general anatomical terms, planes of the body, divisions of the body, and body cavities. Here are some general anatomical terms:

- a. anatomical position is standing erect with legs uncrossed, arms at the side with palms and face forwards
- b. superior (cranial) is towards the head
- c. inferior (caudal) is towards the feet
- d. anterior (ventral) is towards the front
- e. posterior (dorsal) is towards the back
- f. midline is at the middle
- g. medial is towards the middle
- h. lateral is towards the side
- i. intermediate is between medial and lateral
- j. proximal is the part of a limb close to the trunk
- k. distal is the part of a limb far from the trunk,
- l. superficial is close to the body surface
- m. deep is far from the body surface or close to the core.



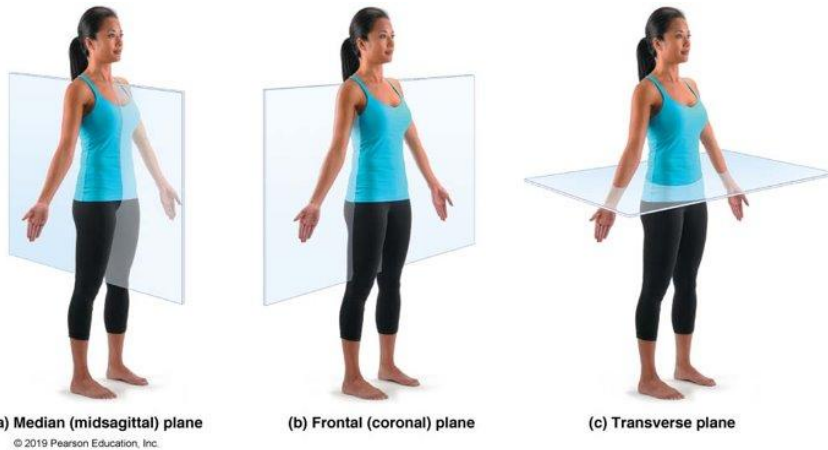
Planes and Sections

A section is made along a plane of the body which includes:

1. sagittal plane cuts the body in left and right halves
2. frontal (also called coronal) plane cuts the body into front and back halves
3. transverse (also called horizontal) plane cuts the body into top and bottom halves
4. The oblique plane is not parallel to any of the other 3 planes.

These body planes can be paired with modifiers:

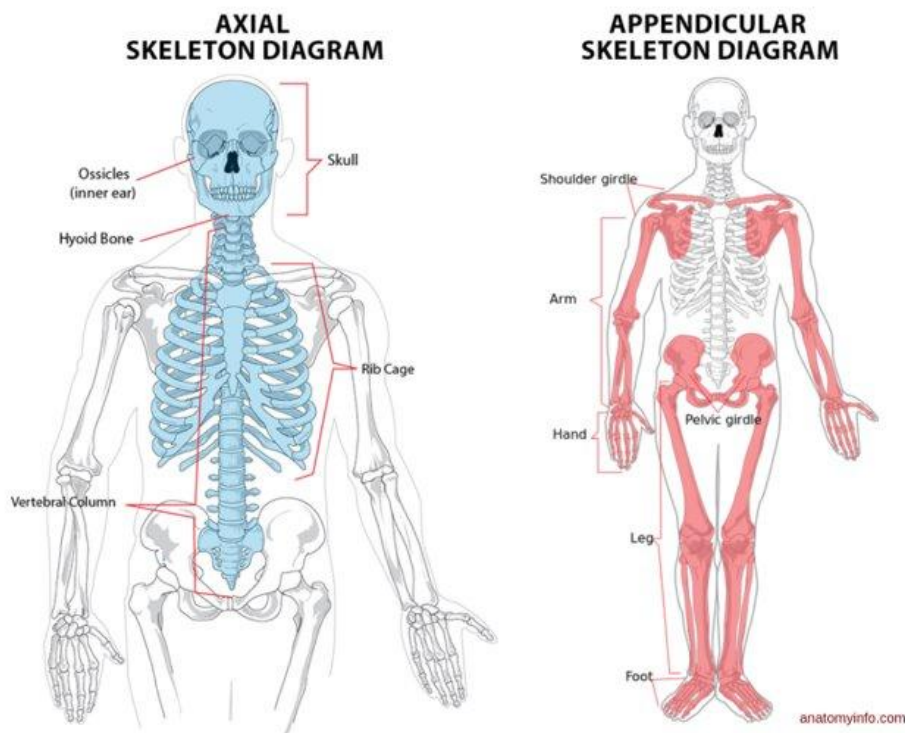
- a. mid (as in mid-sagittal section) refers to a section at the midline, and
- b. para (as in para-sagittal section) refers to a section adjacent to the midline.



Body Divisions

The body has 2 divisions:

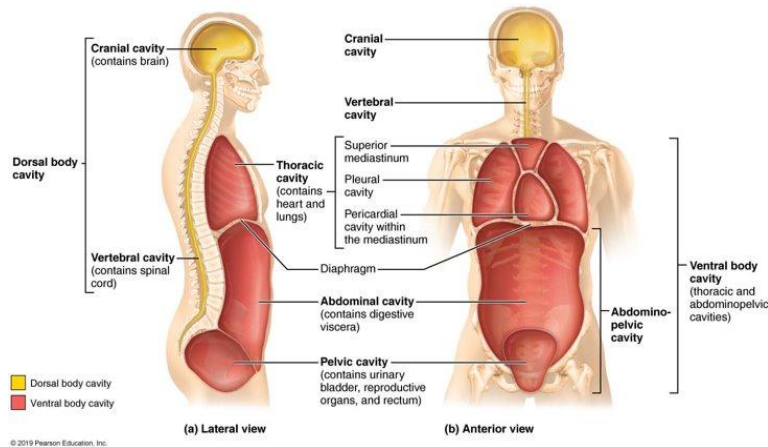
1. axial division which includes the head, neck and trunk
2. appendicular division which includes the limbs.



Body Cavities

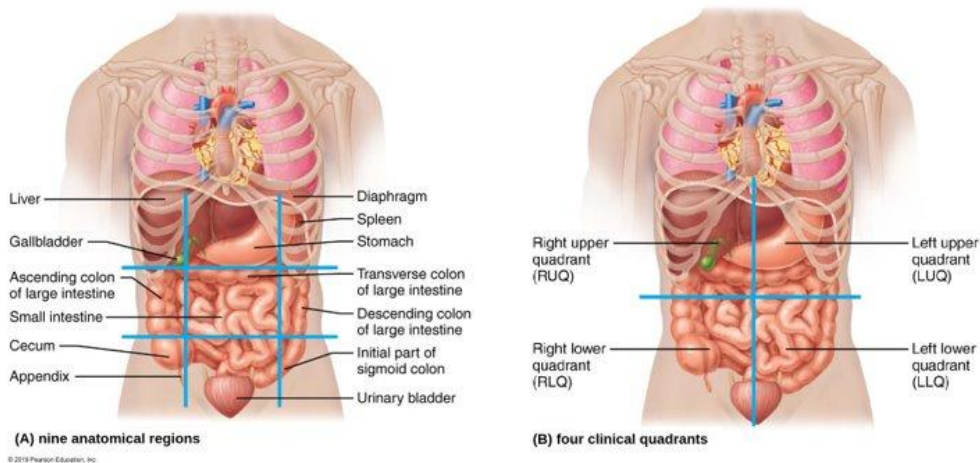
Internal organs are within cavities:

1. dorsal cavity includes the cranial and vertebral cavities
2. ventral cavity includes 2 cavities separated by the diaphragm:
 - a. the thoracic cavity composed of 2 lateral pleural cavities and a medial mediastinum (contains pericardial cavity and other structures)
 - b. the abdominopelvic cavity whose abdominal part includes the stomach, intestines, spleen, and liver while the pelvic part includes the bladder, some reproductive organs and the rectum.



Terminology / Cavities / Abdominopelvic

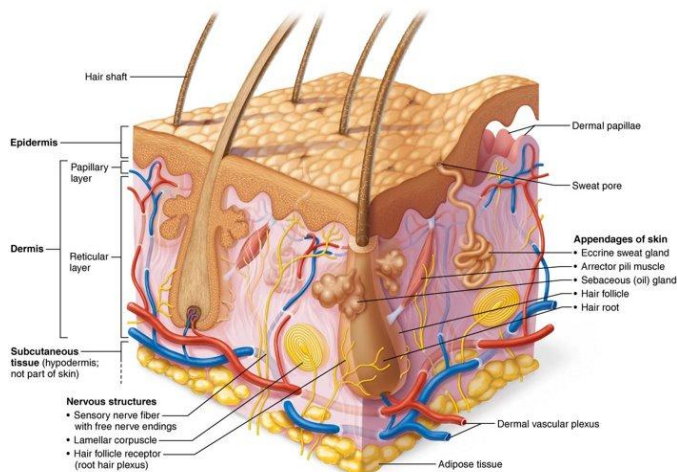
Anatomists divide the abdominopelvic cavity into nine regions but clinicians divide it into only 4 quadrants (centered on the navel or belly button) because non-invasive manipulations of a patient do not offer the same resolution as invasive manipulations (anatomists cut open the cavity of cadavers to view structures).



INTEGUMENTARY SYSTEM

Integumentary System

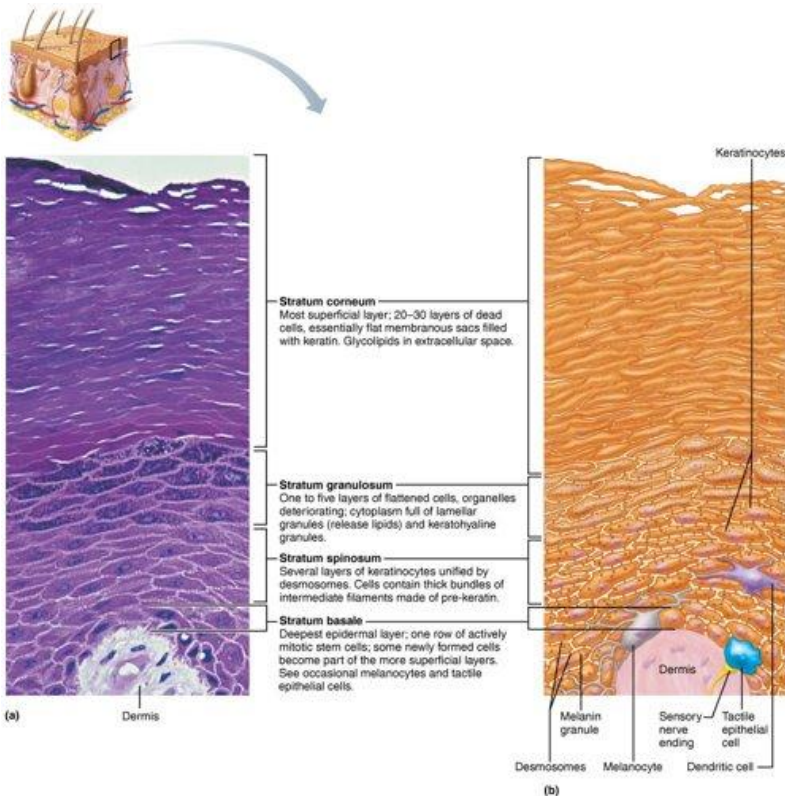
- The integumentary system includes the skin (cutaneous tissue), subcutaneous tissue, and several accessory structures: sweat and sebaceous glands, hair, and nails.
- Also found in the skin are somatosensory receptors for touch and pain but these will be covered later when we cover neurophysiology. We will begin by covering the major functions of the integumentary system and end with the effects of burns.
- Major Functions.
 1. protection from toxic substances:
 - a. chemical: acidic skin secretions with anti-bacterial agents retard bacterial replication, for example, dermacidin is an anti-microbial peptide secreted by sweat glands to provide innate host defense by the immune system
 - b. sunlight: melanin produced by melanocytes in the basal layer of the epidermis protects against UV-induced damage,
 - c. physical: barrier to water, bacterial invasion, and trauma, and
 - d. biological: dendritic cells of the epidermis trigger immune responses when exposed to pathogens and macrophages of the dermis phagocytose pathogens but they can also trigger immune responses.
 - However, the skin is not impermeable to gasses, fat-soluble vitamins and steroids, plant oleoresins, organic solvents, salts of heavy metals, and penetration enhancers for ointment administration.
 2. body temperature regulation by increasing skin blood flow and sweating to release body heat or by decreasing skin blood flow to retain body heat
 3. provide sensory information like touch and pain through sensory receptors
 4. provide key metabolic reactions such as the conversion of skin cholesterol by ultraviolet light into vitamin D3
 5. serves as a blood reservoir (skin holds 5% of blood volume) which can be released to organs requiring more blood flow,
 6. excretion of urea, uric acid and ammonia in sweat. Structure of Skin. The skin is composed of an external epidermis lying over an internal dermis. A blister is a fluid-filled separation of epidermis from dermis.



Epidermis

The epidermis contains several types of cells forming layers in the epidermis.

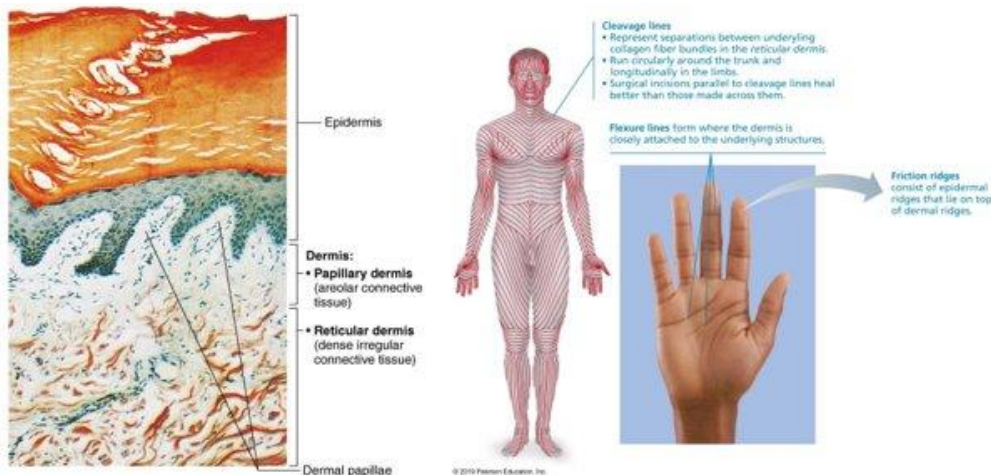
1. Cells include:
 - a. keratinocytes live 25-45 days to produce keratin and are stimulated by the hormone epidermal growth factor to begin mitotic division in the deepest layers of the epidermis (site of hormone production is obscure),
 - b. melanocytes are in the deepest layers releasing melanosomes (organelles containing melanin) to keratinocytes (ingested plant carotene is also inserted in keratinocytes to give an orange hue and capillary hemoglobin give a pinkish color when oxygenated but blue when deoxygenated)
 - c. dendritic (Langerhans) cells are macrophages that have migrated from the bone marrow
 - d. tactile (Merkel) cells have disc-like sensory nerve endings
2. Layers include:
 - a. stratum corneum is the most superficial and is 20-30 cells thick where each are flat and anucleated
 - b. stratum lucidum (only in thick skin of palms of hands and soles of feet) is formed of 2-3 rows of clear, flat, dead keratinocytes
 - c. stratum granulosum is several cells thick where cells accumulate the protein keratin
 - d. stratum spinosum is several cells thick
 - e. stratum basale is the deepest layer adjacent to the dermis formed of a single row of stem cells continually renewing keratinocytes for the overlying epidermis.



Dermis

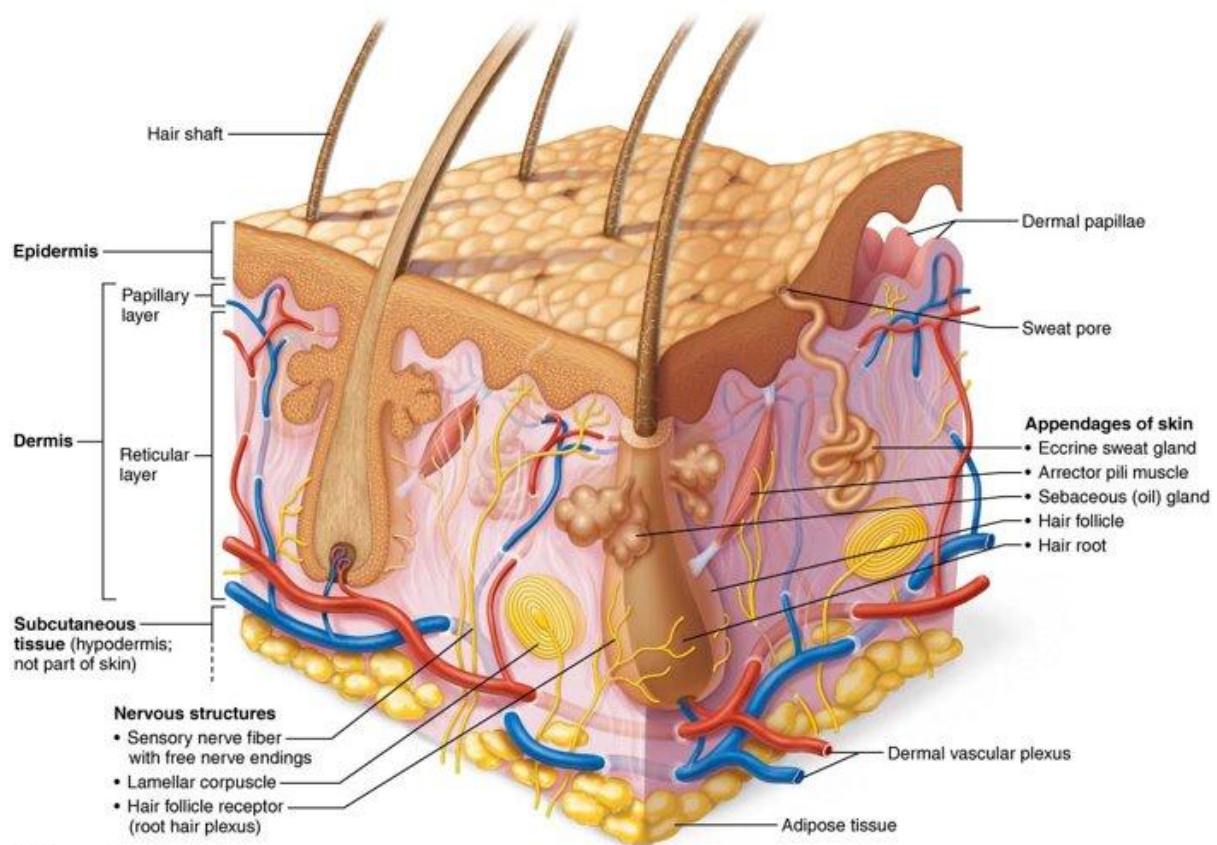
The dermis contains additional types of cells in a matrix and forming layers. Flexure lines are places (e.g. fingers and toes) where the dermis has folds to accommodate joint movement.

1. Cells include:
 - a. Fibroblasts which secrete collagen proteins that are used to maintain a structural framework
 - b. Macrophages which are specialized cells involved in the detection, phagocytosis and destruction of bacteria and other harmful organisms
 - c. Mast cells respond to infections by releasing histamine which causes vasodilatation to allow entry of immune cells from the blood, and
 - d. (d) white blood cells for triggering an immune response.
2. Matrix is composed of collagen (strong), elastin (elastic), and reticular (delicate and branched) fibers (n.b. tearing of the dermis occurs when its connective tissue is stretched beyond the limits of its elasticity leaving stretch marks called stria which appear most often on the abdomen during pregnancy)
3. Layers include:
 - a. papillary layer is superficial and thin containing areolar connective tissue which forms indentations in the epidermis called dermal papillae containing blood vessels and sensory nerves (dermal papillae in palms and soles form an epidermal ridge which forms friction ridges known as the finger and toe prints)
 - b. reticular layer is deep and thick containing dense irregular connective tissue which runs in every direction but mostly along cleavage (tension) lines such that incisions along these lines yield less scarring



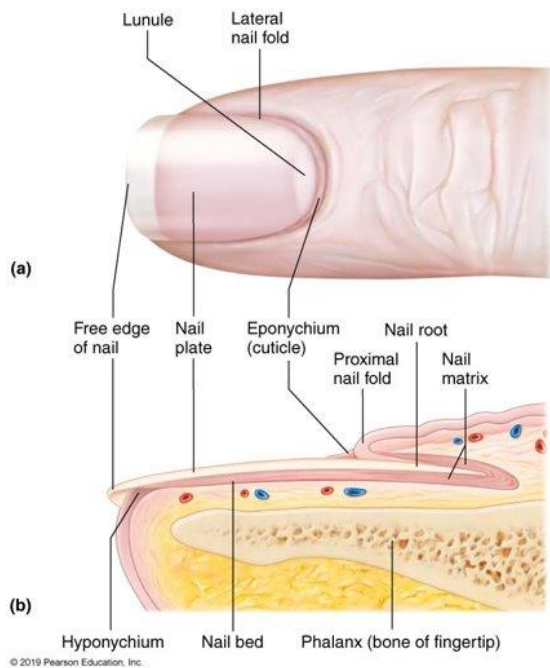
Subcutaneous Tissue

- This is also called hypodermis or superficial fascia and contains blood vessels, adipose tissue, and areolar connective tissue which is anchored to underlying structures.



Nail

- The accessory structures of the integument include nails, hair with arrector pili muscle, and several types of glands. The nail includes the free edge, body and root of the nail
- . The lateral edges are under the lateral nail folds and the proximal edge is under the proximal nail fold and the cuticle. The nail lies on the nail bed and derives from the nail matrix part of the nail bed.
- The white crescent-shape appearance is called the lunula which is due to the thicker nail bed which blocks the pink color from the capillaries.
- The hyponychium is the skin past the nail bed and under the free edge of the nail near your fingertip to serve as a barrier from germs and debris.
- Some clinical manifestations of nail disease are
 - a. yellowish nail suggests a fungal infection (confirmed by growth of a sample in a lab) or a serious respiratory disease or else thyroid gland disorder
 - b. thickened yellowish nail suggests a fungal infection
 - c. spoon shaped nail suggests an iron deficiency
 - d. Beau's lines (horizontal lines due to uneven growth) suggest malnutrition.



Hair

Another accessory structure of the integumentary system is hair.

There are 2 types of hair:

1. fine vellus body hair covering most of the body
2. terminal hair which is thick, long, pigmented hair found on the scalp, face, armpits, and pubic area.

Hair is formed of 3 layers:

1. a centrally located medulla containing large keratinocytes separated by air spaces (n.b. medulla missing in fine or vellus hair)
2. a cortex surrounding the medulla containing several layers of flattened and pigmented keratinocytes
3. a cuticle covering the cortex formed by a single layer of overlapping keratinocytes which prevent the inner layers from unraveling into split ends.

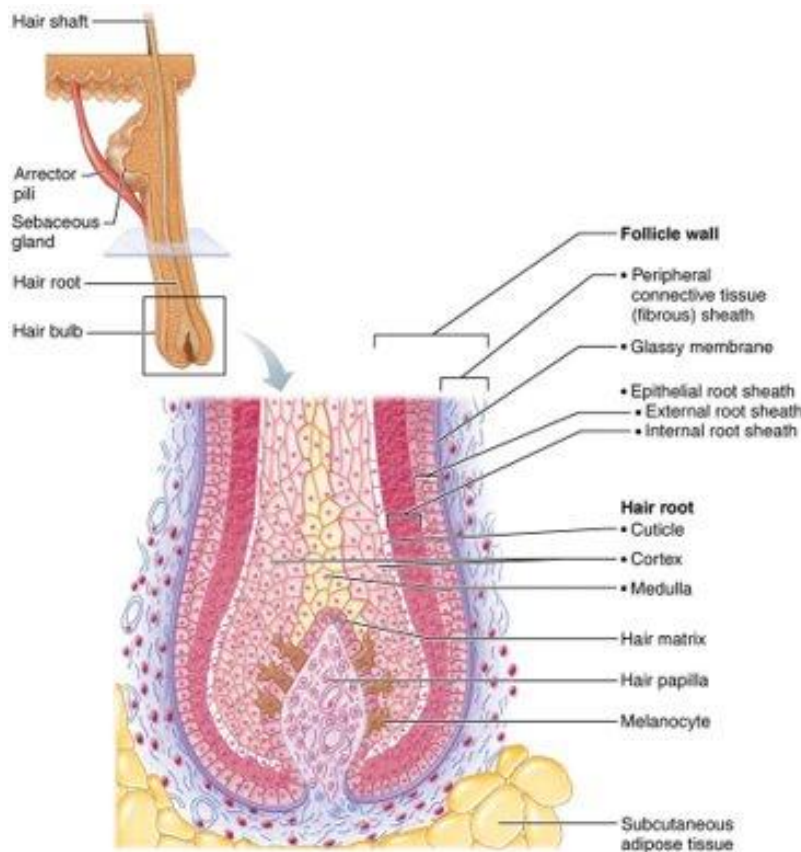
The hair has 3 parts:

1. a shaft which projects from the skin (a circular shaft yields straight hair while an oval shaft yields wavy or curly hair)
2. a root surrounded by the hair follicle
3. a bulb which is the source of hair growth (bulb is wider than follicle because a papilla surrounded by hair matrix cells and melanocytes is inserted into the hair center).

The hair follicle is formed of the following layers covering the hair cuticle:

- an internal and external epithelial root sheath, a glassy membrane and a connective tissue root sheath. The pigment cells in hair follicles gradually die with advancing age such that new hair growth turns gray or white. The growth cycle of a hair includes an active growth cycle (longer duration for longer hair) where the hair grows 2-2.5 mm per week followed by a regressive growth cycle (hair falls out).
- A follicle has a limited number of growth cycles before baldness (alopecia) appears.

- Male pattern baldness is partly due to androgens shortening the hair growth cycles. Conversely, hirsutism is male pattern growth on the face, chest and back in women.
- The follicle includes the following structures:
 1. arrector pili muscle to raise hair (causes skin dimpling)
 2. sebaceous gland (holocrine gland) that secretes sebum into the hair follicle which is bactericidal, waterproof and acts as a lubricant
 3. sweat glands (sudoriferous glands) of type apocrine with a pore in the hair follicle (only in axilla and anogenital areas possibly for sexual bait) where sweat includes fat and proteins which only gives rise to odor when converted by bacteria. Otherwise sweat glands are everywhere on the skin, except nipples and external genitalia, in the form of eccrine glands with a pore on the surface of skin (most common on forehead, palms and soles) to release sweat composed of 99% water plus salt, vitamin C, antibodies, dermcidin (antibacterial), and traces of the metabolic wastes urea, uric acid and ammonia.



(c) Diagram of a longitudinal view of the expanded hair bulb of the follicle, which encloses the matrix

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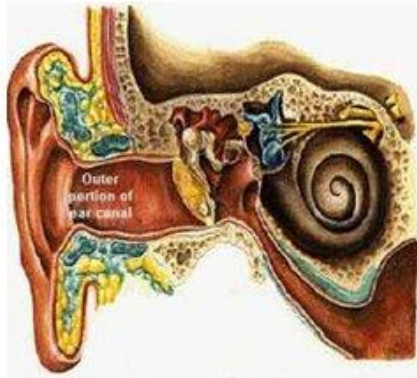
Modified Sweat Glands

During development, some cells from the same lineage as those forming sweat glands are modified to form:

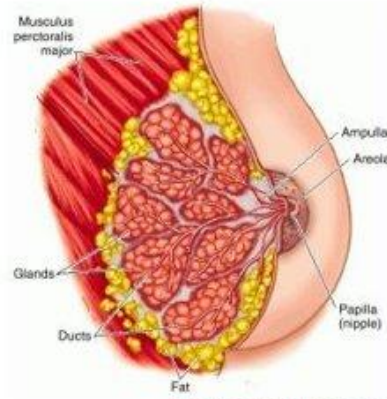
1. ceruminous glands which secrete cerumen (wax) in the external ear canal which acts as a repellent for insects

2. mammary glands in women for milk production.

Ceruminous glands



Mammary glands



Burns

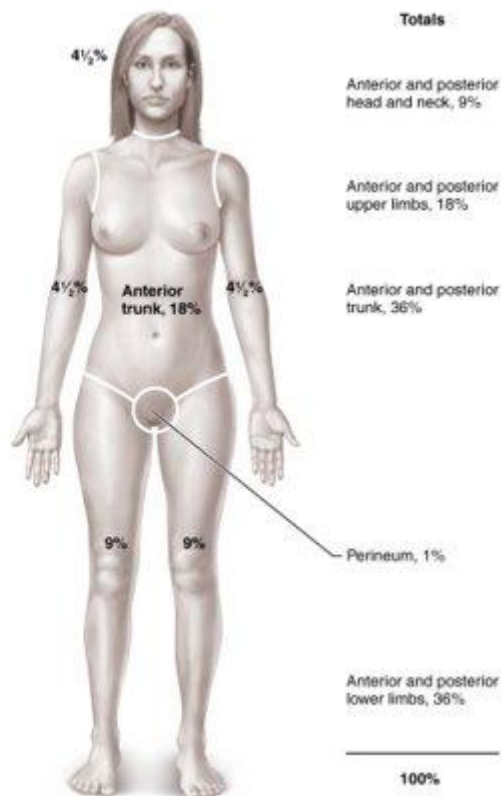
Burns are quantified by the degree or depth of damage:

- (1st degree) damages the epidermis
- (2nd degree) damages the epidermis and superficial dermis
- (3rd degree) damages the epidermis and dermis.

A rule of nines (multiple of 9 such as $2 \times 9 = 18$, $1 \times 9 = 9$ and $0.5 \times 9 = 4.5$) is used to quickly estimate the burn surface area. For the front surface, the trunk is 18%, each lower limb is 9% and the head and each upper limb are 4.5%. This sums to 49.5% for the front and also the back side for a total of 99%. The remaining 1% is the perineum.



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SKELETAL SYSTEM

Skeletal System

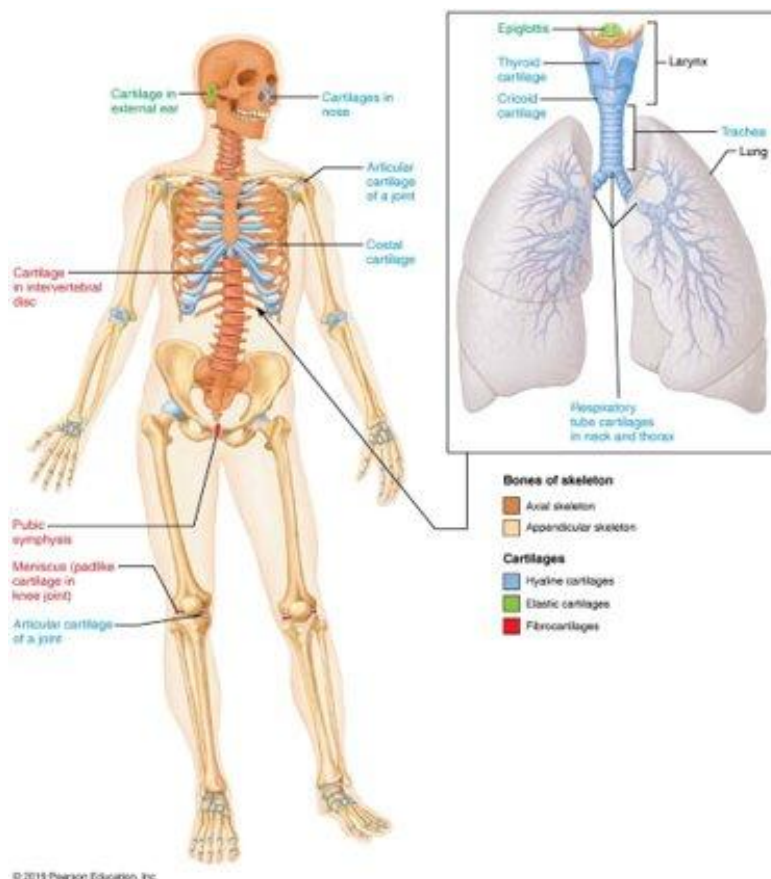
- The skeletal system provides a solid structure to protect and support the body. It includes bone and cartilage tissues.

The functions of bone tissue include:

1. support whose strength adapts such that increased force applied to bone stimulates remodeling to increase bone strength (denser matrix of calcium and fibers) while decreased force, as in immobilization or paralysis, stimulates remodeling to decrease bone strength
2. protection of fragile organs like the brain or the heart
3. anchorage for muscles to produce movement
4. mineral storage where a drop in blood calcium triggers parathyroid hormone release which stimulates osteoclasts to degrade bone and release calcium into the blood to restore normal levels
5. blood cell formation in red bone marrow
6. fat storage in yellow bone marrow
7. hormone production (osteocalcin) which is not only involved in bone remodeling but appears to play a critical function in multiple physiological processes such as glucose metabolism.

The functions of cartilage include:

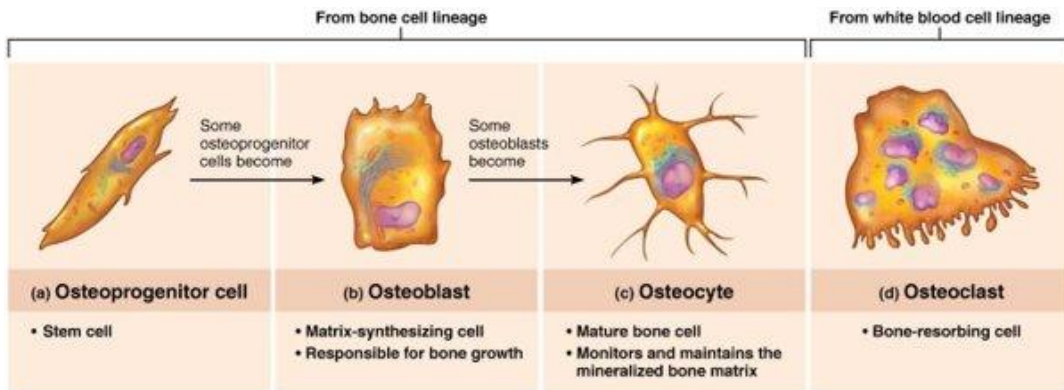
1. providing flexible support which bends rather than breaks
2. providing a smooth and compressible surface for articulations
3. provides a matrix for the development of bone.



Bone Cells

The cells of bone tissue include:

- a. osteogenic cell (stem cell) which forms osteoblasts
- b. osteoblast for bone growth
- c. osteocyte to repair and maintain health of mature bone
- d. osteoclast to resorb bone (remodeling of mature bone together with osteocyte)

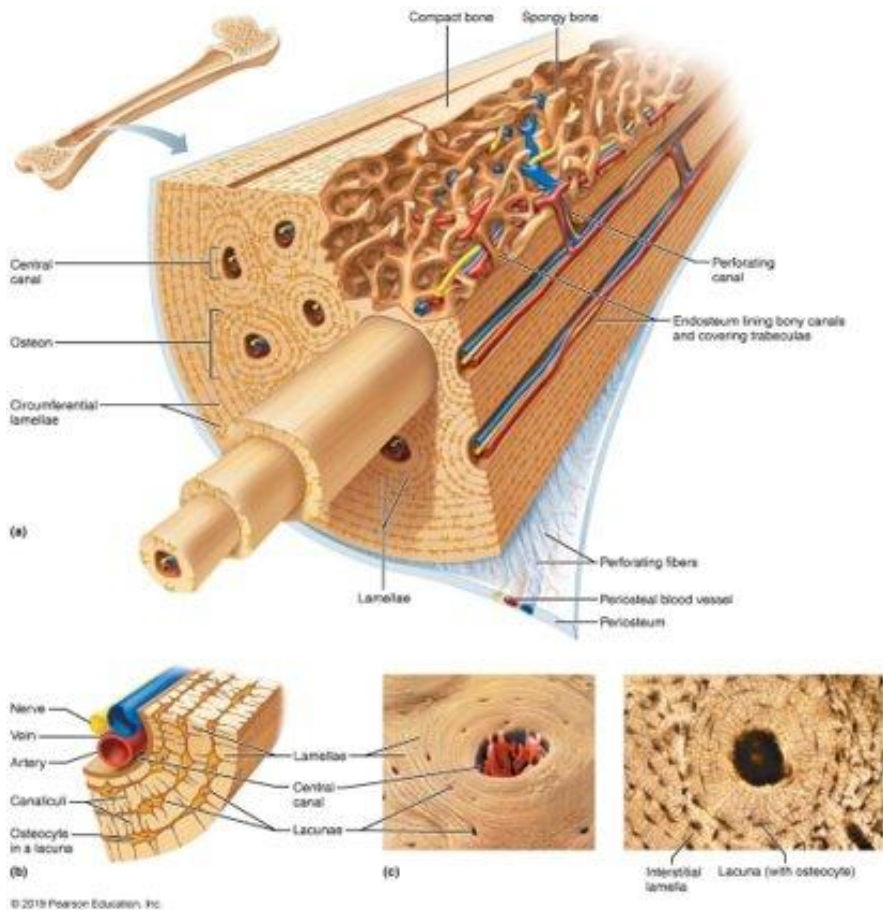


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Bone Design

The architecture of all bones includes an outer compact bone and an inner spongy bone:

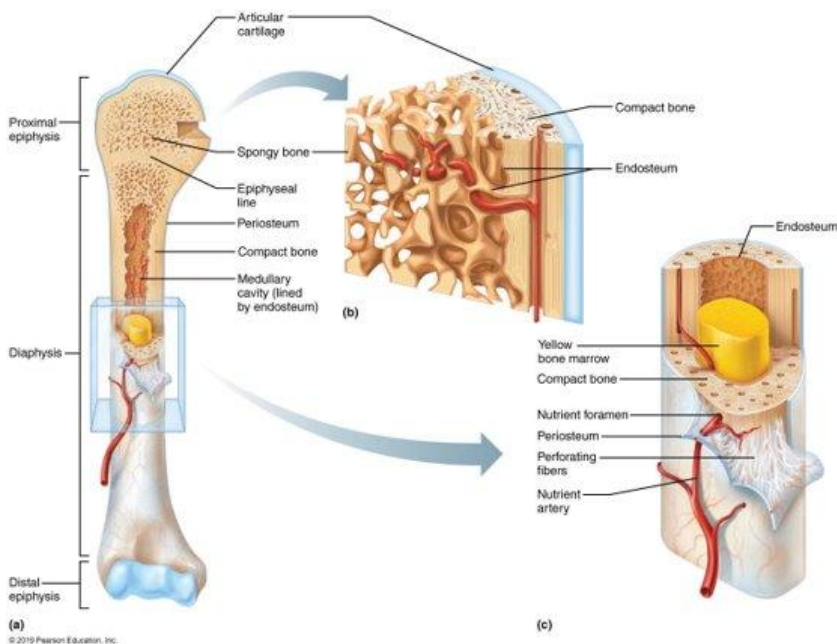
1. Compact bone forms a dense outer layer of all bones. Its design consists of
 - a structural unit called the osteon (haversian) system formed of elongated cylinders (osteons) oriented parallel to the long axis of bone containing several hollow tubes of bone matrix arranged like the rings of a tree (each ring is called a lamella).
 - Osteocytes (mature bone cells) are between the lamellae in small cavities called lacunae. These lacunae are interconnected by very small canals called canaliculi which allow the passage of extracellular fluid.
 - The center of the osteon has a larger canal for the blood supply to flow along the long axis of the bone.
 - Blood flow perpendicular to this haversian canal is provided by perforating (volkmann's) canals. Several osteons are packed together but their cylindrical shape leaves spaces that are filled with interstitial lamellae.
 - Finally, the entire structure is covered by circumferential lamellae which form sheets of bone.
2. Spongy (trabecular) bone forms the inner core of bones.
 - has a sponge-like appearance (trabeculae) with spaces containing red marrow for forming red blood cells and yellow marrow for storing fat.
 - The bony trabeculae are only a few cell layers thick, irregularly shaped and contain osteocytes in lacunae interconnected by canaliculi.
 - Nutrients from blood vessels diffuse into the marrow spaces of the trabeculae and pass through canaliculi to reach the osteocytes.
 - The trabeculae are continually remodeled along lines of stress to give sufficient bone strength.



Bone Linings

The connective tissue linings of bone are:

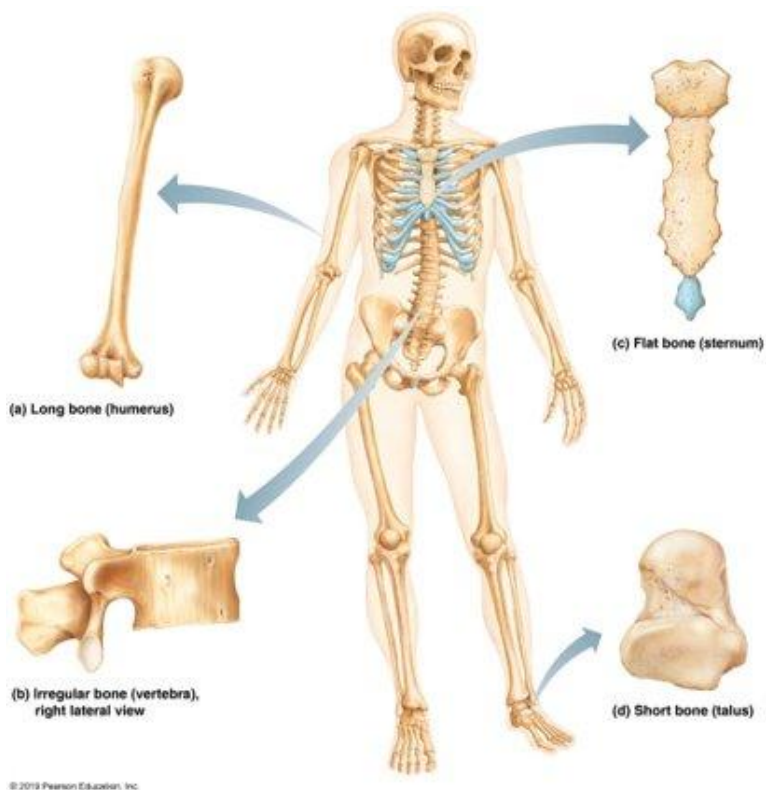
1. periosteum which covers bone with an outer fibrous layer and inner osteogenic (bone forming) layer
2. endosteum which lines canals of compact bone and trabeculae of spongy bone.



Bone Shape

Bones are classified by their shape (not size)

- long bones are much longer than wide with a shaft (diaphysis) formed mostly of compact bone with a yellow marrow cavity (fat storage) and 2 ends (epiphyses) formed of compact and spongy bone covered with hyaline cartilage (n.b. between the diaphysis and each epiphysis of an adult bone is an epiphyseal line which is a remnant of the cartilaginous epiphyseal growth plate)
- irregular bones are primarily spongy bone containing marrow with a thin covering of compact bone (e.g. vertebrae and hip bones)
- flat bones are thin, flat, and sometimes curved bones (e.g. skull bones, ribs, and breastbone) formed of a compact bone exterior and a spongy bone interior with marrow between trabeculae
- Short bones are roughly cube-shaped (e.g. wrist and ankle bones) formed primarily of spongy bone with marrow covered by a thin outer layer of compact bone.



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Bone Formation

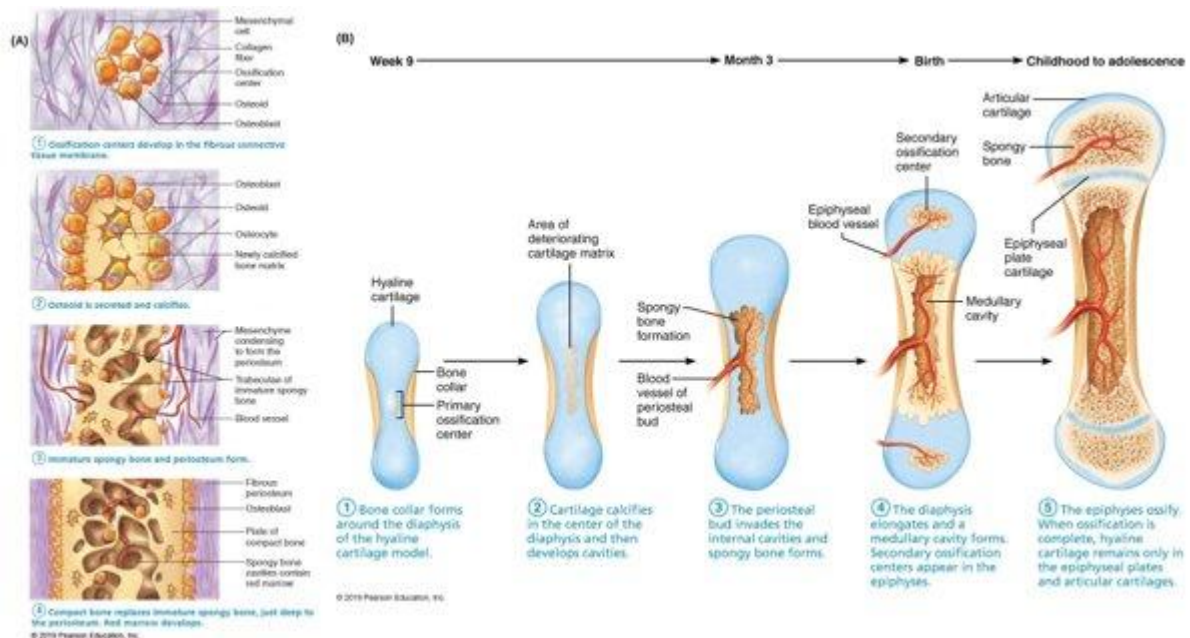
Osteogenesis or ossification includes formation of the bony skeleton in embryos, growth of bones to maturity, and remodeling or repair of bones in adults. There are 2 types of osteogenesis:

- Intramembranous ossification. At about 8 weeks of embryonic development the flat bones of the skull and clavicles develop from a fibrous connective tissue membrane containing mesenchymal cells which differentiate into bone forming cells.
- Endochondral ossification. For all bones below the skull except the clavicles, bone formation starts in the second month via the replacement of a hyaline cartilage. For long bones, there is a primary ossification center for the shaft and secondary ossification centers for the 2 ends. When secondary ossification is complete, hyaline cartilage remains on the epiphyseal surfaces as the articular cartilages and at the

junctions of the diaphysis and epiphysis to form the epiphyseal plates which allow the long bones to continue growing. Most irregular bones are formed using several distinct ossification centers which are not identified as primary or secondary.

Some facial bones, such as the nose and lower jaw, continue to grow throughout life. During infancy and adolescence or early adulthood, long bones lengthen by interstitial growth which occurs entirely by growth from the epiphyseal plates.

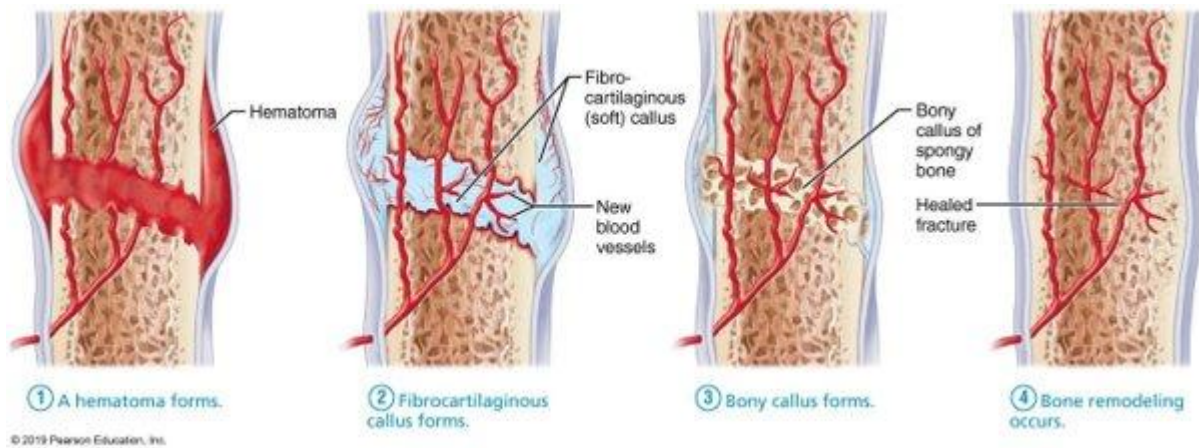
- Longitudinal growth ends when bone tissue of the epiphysis and diaphysis fuses (epiphyseal plate closure) to form the epiphyseal line which occurs about age 18 in females or age 21 in males because the chondroblasts reproduce more slowly and get replaced by bone.
- All bones grow in width by appositional growth where osteoblasts on the periosteal side secrete bone matrix while osteoclasts on the endosteal side remove bone matrix.



Bone Repair

Fracture repair includes the following steps:

1. Bleeding stimulates the formation of a hematoma, death of oxygen-deprived bone cells, and inflammation which causes pain.
2. The hematoma is transformed into a soft fibrocartilaginous callus that is invaded by blood vessels bringing macrophages to clean up the area then osteoclasts resorb damaged bone while fibroblasts, chondroblasts, and osteoblasts get busy laying down tissue components to span the break.
3. Conversion of the fibrocartilaginous callus into a trabecular bone callus (usually requires 2 months).
4. Bone remodeling to regain original shape by removal of any extra bony material and converting trabecular bone callus into original compact bone (n.b. process can take a few years).



Bone Disease

Osteoporosis is when bone resorption outpaces bone formation so the bone becomes porous. This occurs mostly in the neck of the femur and bones of the spine.

- Such loss of bone occurs with insufficient exercise (reduced stress promotes bone remodeling)
- a diet poor in calcium and protein, abnormal vitamin D receptors, and smoking (reduces estrogen levels which normally inhibit bone resorption).
- Age reduces estrogen and testosterone so there is less restraint on osteoclast bone resorption and less promotion of osteoblast bone deposition.



(a) Normal bone



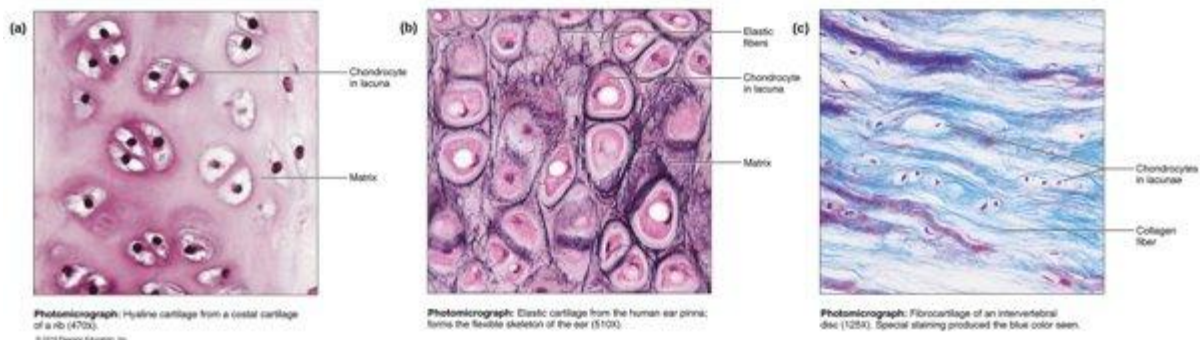
(b) Osteoporotic bone

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Cartilage

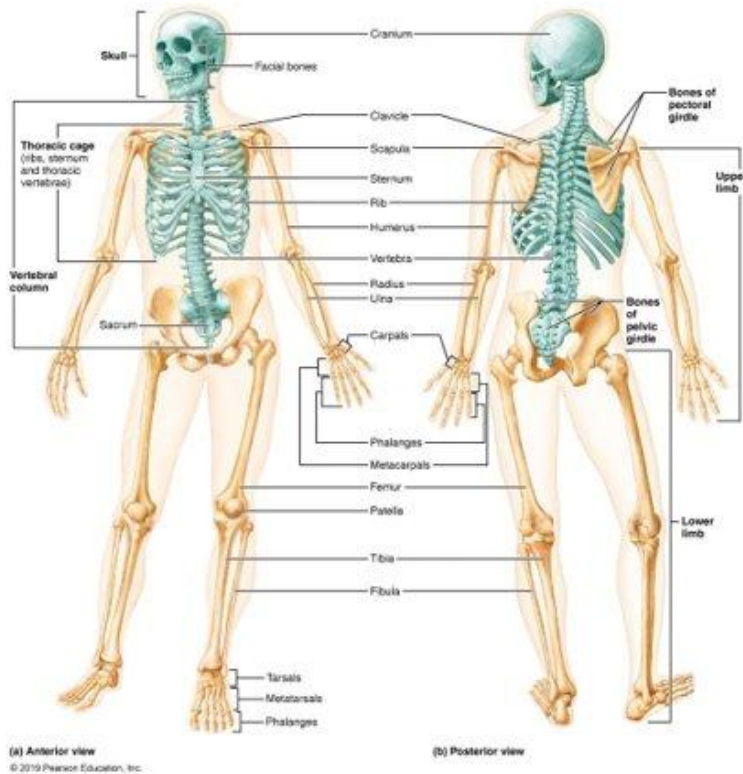
It is strong and flexible with properties between connective tissue and bone. The composition of cartilage includes ground substance (all components of the extracellular matrix except for fibrous materials) with lots of glycosaminoglycans, chondroitin sulfate, and hyaluronic acid held together with chondronectin (adhesive protein). The matrix also includes collagen fibers (n.b. can have some elastic fibers as for the ear). Cartilage is 80% water but is devoid of blood vessels (results in poor repair) and nerves (no nociceptors). Cartilage is covered by perichondrium which is a dense layer of fibrous connective tissue that can form scar tissue following damage to cartilage.

- There are 2 types of cartilage cells:
 1. chondroblasts which are immature cartilage cells that actively form cartilage
 2. chondrocytes which are mature cartilage cells found in lacunae that maintain cartilage.
- There are 3 types of cartilage:
 1. Hyaline cartilage. It is the most abundant, has a glassy blue-white appearance, has chondrocytes forming only 1-10% of the volume, and is firm but pliable because of the collagen. It is found in embryonic skeleton, articular ends of long bones (also epiphyseal plates in growing children), costal cartilages of ribs, cartilages of nose, trachea, and larynx. Its role is to provide support and cushioning during compressive stress.
 2. Elastic cartilage. It is like hyaline cartilage but with more elastic fibers. It is found in the external ear and epiglottis. Its role is to allow bending and the return to its original shape.
 3. Fibrocartilage. It appears as rows of chondrocytes alternating with rows of thick collagen fibers producing a structure intermediate between hyaline cartilage and dense regular connective tissue. It is found in the intervertebral discs, pubic symphysis, and discs of knee joints where hyaline cartilage meets a ligament or a tendon. Its role is to provide tensile strength (resist pulling) with the ability to absorb stress (resist compression).



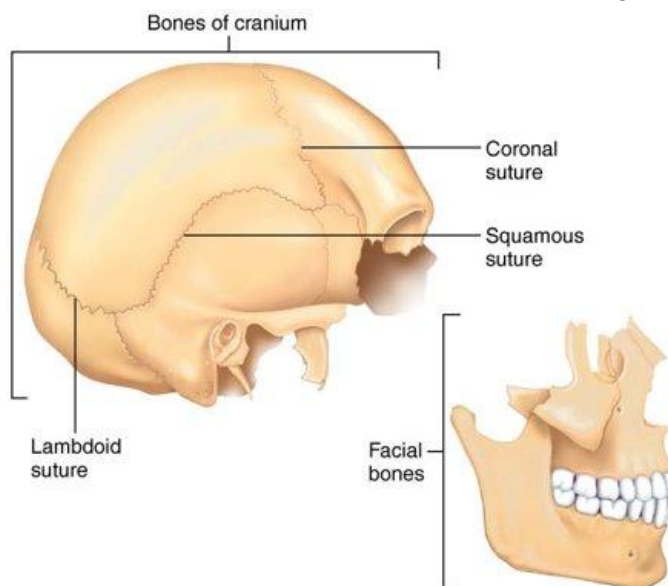
Skeleton

There are 206 bones in the human skeleton comprising about 20% of body weight divided into axial skeleton (skull, vertebral column, and rib cage) with 80 bones and appendicular skeleton (upper limbs and pectoral girdles plus lower limbs and pelvic girdles) with 126 bones.



Skull

The skull includes the cranial and facial bones united by sutures as well as the bone of the tongue. It houses special sensory organs (sight, sound, balance, smell, and taste), paranasal sinuses, the CNS, and has 85 openings for nerves and blood vessels.



(a) Cranial and facial divisions of the skull

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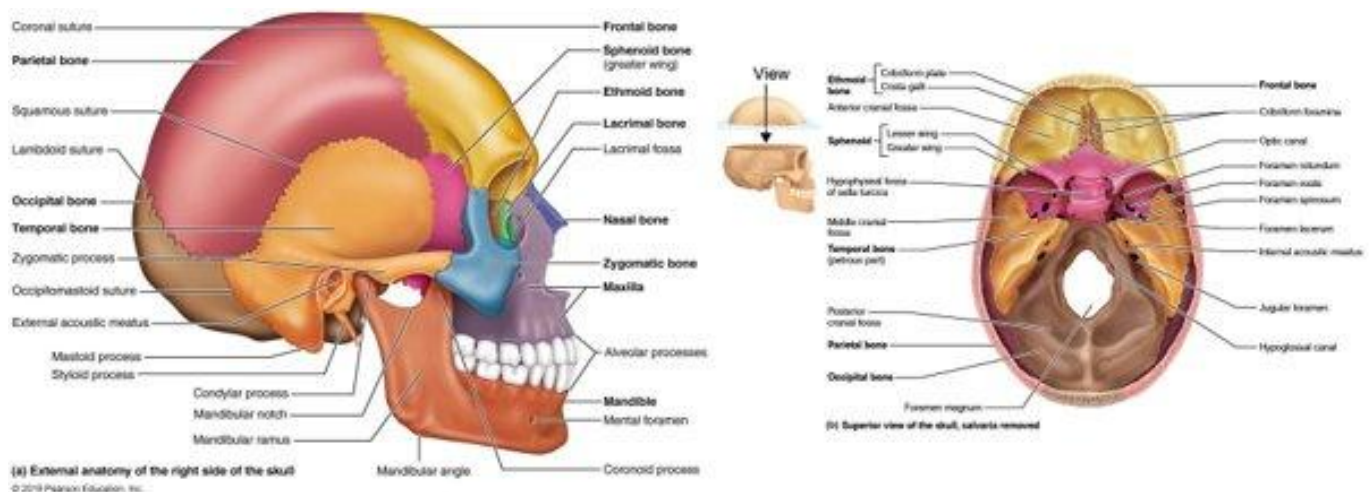
Cranial Bones

The cranial bones form the vault of the skull (space inside skull) containing 3 bony ridges dividing the cranial base internally into 3 distinct areas: anterior fossa (highest), middle fossa, and posterior fossa (lowest). The 8 cranial bones are the paired parietal and temporal bones plus the unpaired frontal, occipital, sphenoid, and ethmoid bones:

- parietal bones are paired bones forming the bulk of the cranial vault on the superior and lateral aspects of the skull
- temporal bones are paired bones located just below the 2 parietal bones forming inferior and lateral aspects of the skull and cranial floor
- frontal bone is a dome-shaped bone forming the anterior cranial fossa and the roof of the orbits with its supraorbital margin, supraorbital foramen (passage for blood vessels and nerve fibers), and glabella (margin above nose containing inside the left and right frontal sinuses) and it articulates with the paired parietal bones posteriorly
- occipital bone is a single bone at the base of the skull forming the posterior cranial fossa and the posterior aspect of skull which attaches anteriorly to the 2 parietal bones, 2 temporal bones and sphenoid, and has the foramen magnum (a large hole at the base of occipital bone for passage of CNS), occipital condyles on each side of foramen magnum (sites of articulation with first cervical vertebra), and external occipital protuberance which is a projection at back of skull (more prominent in males) for the attachment of muscles
- sphenoid articulates with all other cranial bones, forms the base of middle cranial fossa and contributes to the base of anterior cranial fossa
- The ethmoid lies deep between the orbits and the nasal cavities.

There are 4 sutures connecting the cranial bones (n.b. sutures may contain sutural bones which are tiny irregular bones formed by ossification centers that appeared during fetal development):

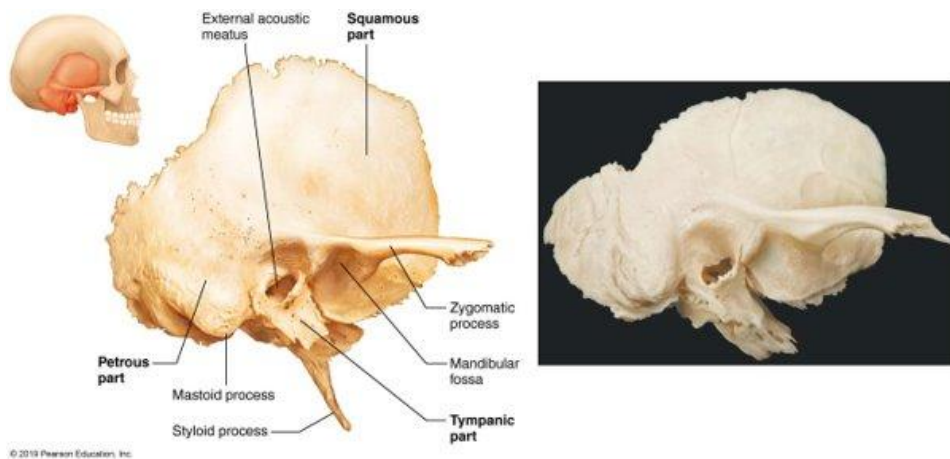
- coronal suture between frontal bone and 2 parietal bones
- squamous suture between parietal bone and temporal bone
- lambdoid suture between occipital bone and 2 parietal bones
- sagittal suture between 2 parietal bones.



Cranial/Temporal

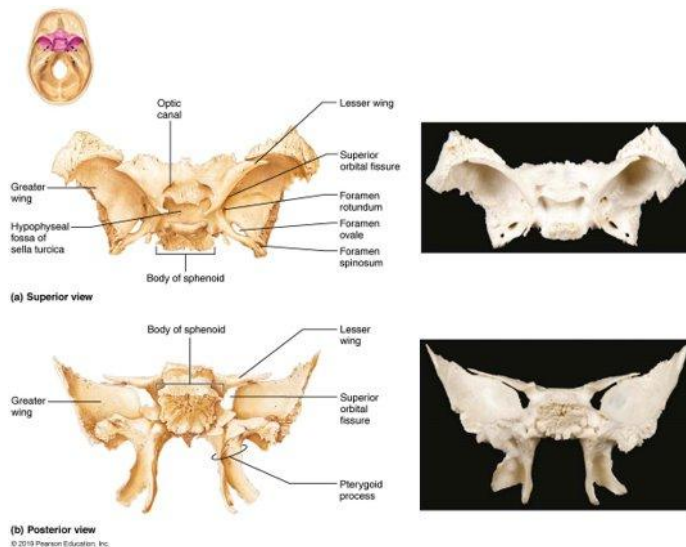
The temporal bone has 3 different parts:

1. squamous part is the flattened bone from the zygomatic process to the cheekbone (zygomatic bone of face) with a mandibular fossa for articulating with condyle of the mandible
2. tympanic part surrounds the external acoustic meatus
3. petrous part is on the internal aspect of the temporal bone where it contributes to the cranial base, houses middle and inner ear cavities, and forms mastoid process (attachment site for some neck muscles), styloid process (attachment site for muscles of the tongue and some neck muscles), and several foramina (jugular foramen, carotid canal, and internal acoustic meatus)



Cranial/Sphenoid

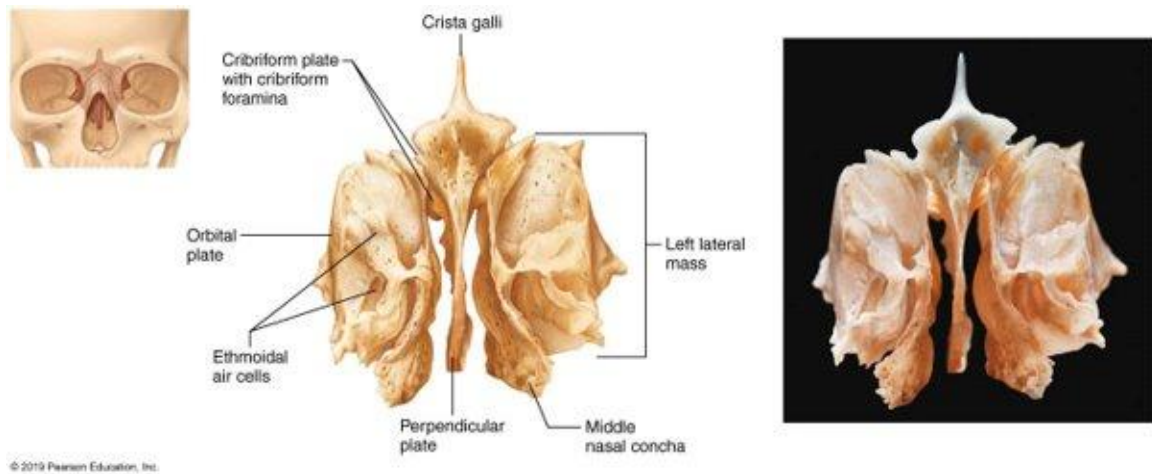
The central body of the sphenoid bone contains sphenoid sinuses, optic foramina (canals for optic nerves), superior orbital fissure between greater and lesser wings (passage for cranial nerves producing eye movement), and has 3 projections: greater wing, lesser wing (forms orbits and the middle and anterior cranial fossae), and pterygoid process (for muscles of mastication).



Cranial/Ethmoid

The ethmoid includes:

- the cribriform plate which forms the roof of the nasal cavity and the floor of the anterior cranial fossa with tiny holes (olfactory foramina) for passage of olfactory nerves
- a perpendicular plate projecting inferiorly to contribute to the nasal septum
- a crista galli which projects superiorly to attach to the dura mater of brain
- lateral masses containing ethmoid sinuses
- medially located superior and middle nasal conchae
- laterally located orbital plates contributing to the medial walls of orbits.

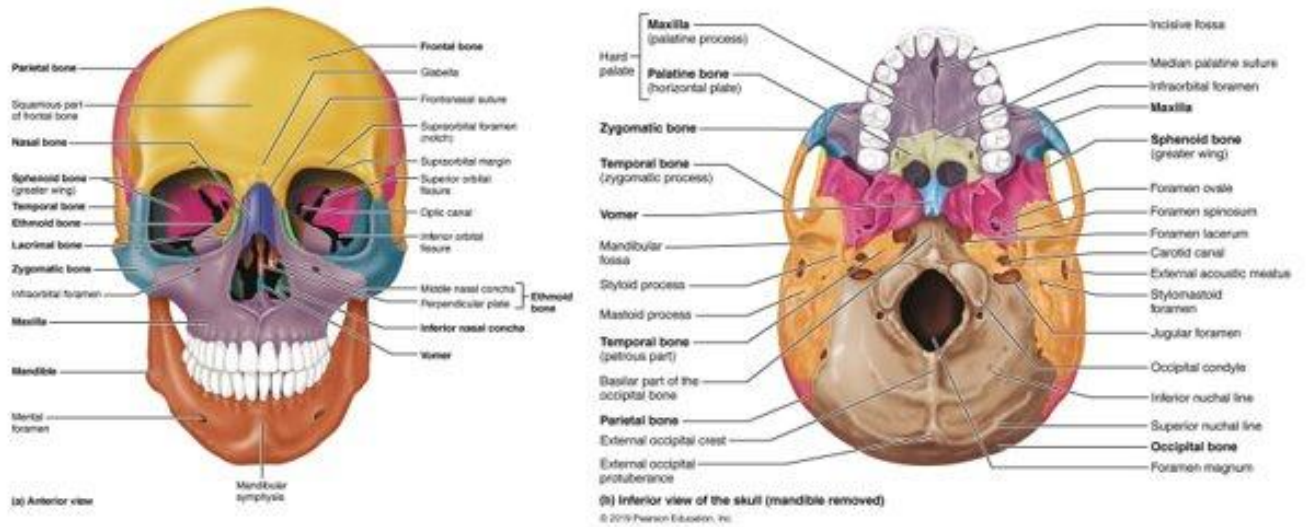


Facial Bones

The facial bones form the framework of the face, anchor the facial muscles for expression, secure the teeth, contain the cavities for the sensory organs of sight, smell and taste, and provide openings for passage of food and air. Paranasal sinuses in the frontal, maxillary, sphenoid, and ethmoid bones are mucosa-lined, air-filled spaces that connect to the nasal cavity to warm and humidify incoming air but also to lighten the skull and enhance resonance of the voice. The face comprises 14 bones of which mandible and vomer are unpaired whereas maxillae, zygomatic, nasal, lacrimal, palatine and inferior conchae are paired:

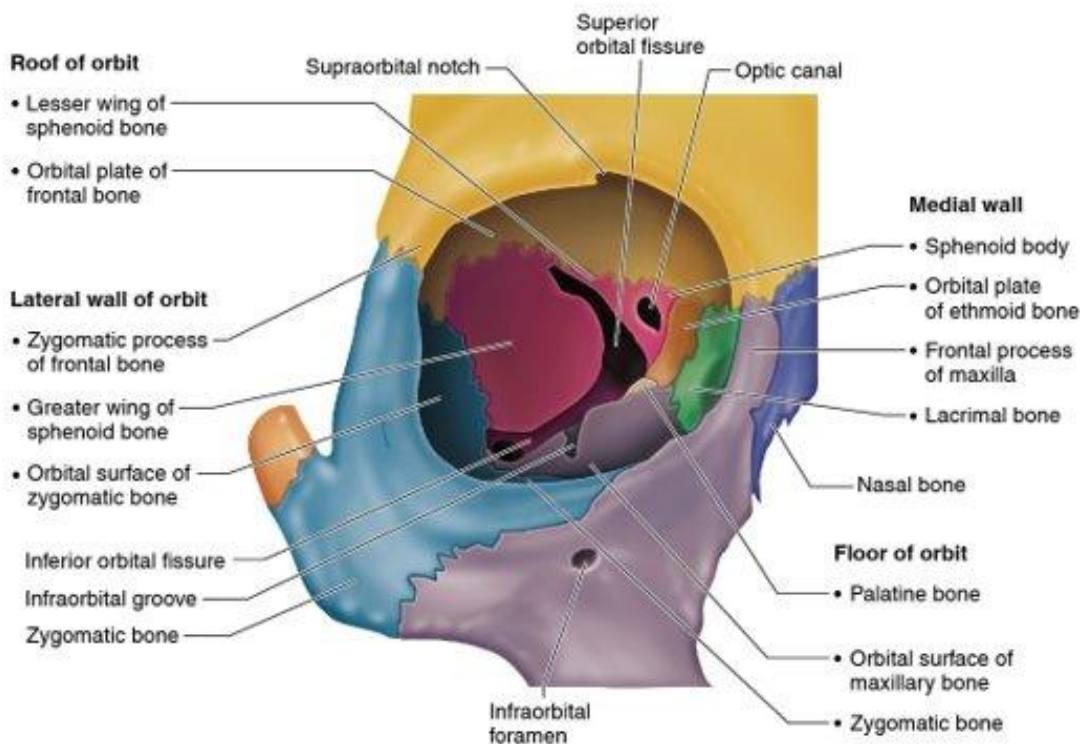
- mandible is the lower jaw bone (strongest and largest bone of the face)
- maxillary bones are fused medially
- zygomatic bones are the cheekbones that articulate with zygomatic processes of maxilla, frontal bone, and temporal bone and also contribute to inferolateral margins of the orbit
- nasal bones are 2 tiny rectangular bones that fuse medially to form bridge of nose and articulate with the frontal bone superiorly and maxillary bones laterally
- lacrimal bones are 2 fingernail-shaped bones in the anterior-medial portion of the orbit, each with a depression (lacrimal fossa) for the lacrimal sac, and articulates with the frontal bone, ethmoid bone, and maxillae
- palatine bones are 2 L-shaped bones where the horizontal plates form part of the hard palate and the vertical plates form the nasal cavity and orbit
- vomer is a single thin bone forming the nasal septum

- h. inferior nasal conchae are thin curved bones that project medially and forms the largest of 3 pairs of conchae (the other 2 are the middle and superior nasal conchae of the ethmoid bone).



Facial/Orbit

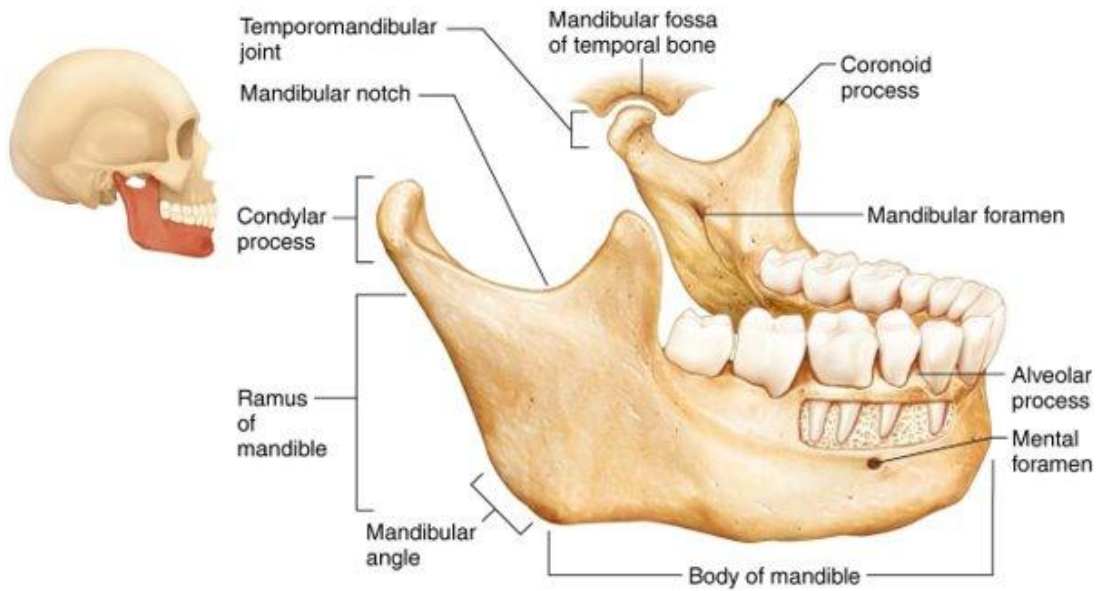
The bones of the orbits include the zygomatic, frontal, maxilla, ethmoid, lacrimal, sphenoid, and palatine bones.



(b) Contribution of each of the seven bones forming the right orbit

Facial / Mandible

The mandible has a body containing the chin and the left and right rami extend from the body at the mandibular angle and contain the following bone markings: mandibular notch, coronoid process (for insertion of temporalis muscle), mandibular condyle, alveolar margin (contains tooth sockets), mandibular foramina (passage of nerves to teeth in lower jaw), and mental foramina (blood vessels and nerves to chin and lower lip).

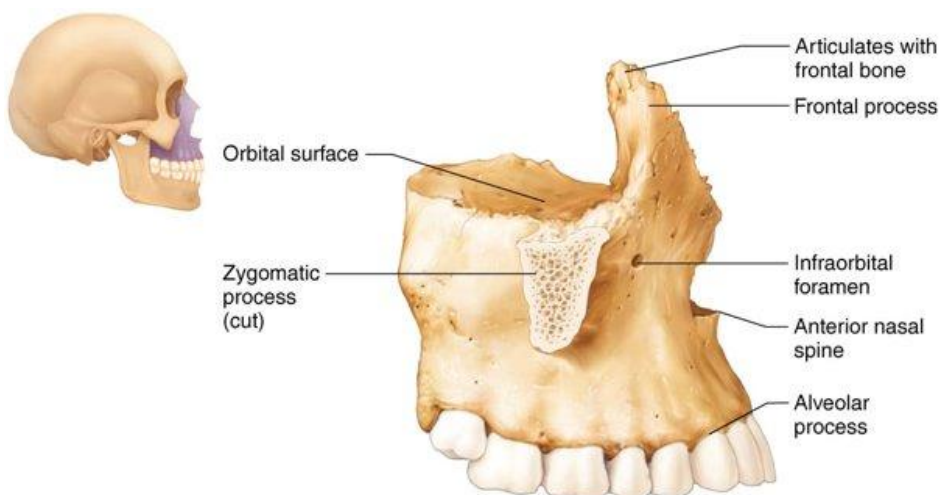


(a) Mandible, right lateral view

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Facial / Maxillary

The maxillary bones have alveolar margins to hold teeth of the upper jaw, palatine processes projecting posteriorly to form the anterior 2/3 of hard palate and contain the following bone markings: incisive fossa (passage of blood vessels and nerves), frontal processes, zygomatic processes, and maxillary sinus in main portion of bone on each side (common site of infection).

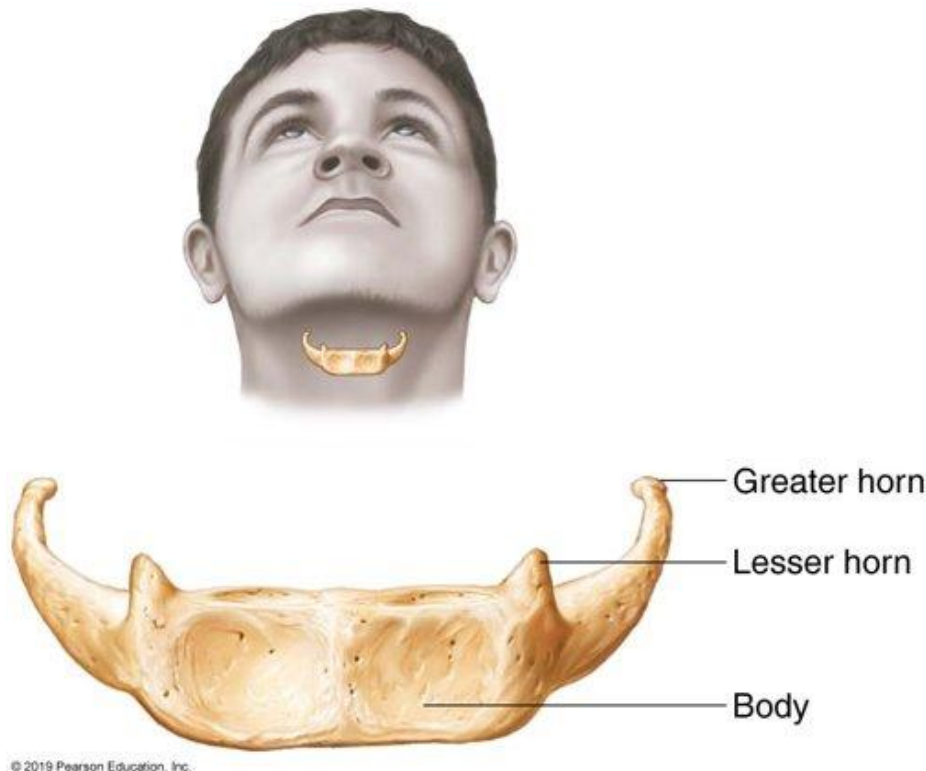


(b) Maxilla, right lateral view

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Tongue Bone

The tongue contains the hyoid bone (only bone of the body that does not articulate with any other bone) that is horseshoe-shaped with a body and 2 pairs of horns to support the tongue and other muscles for speaking, eating, and swallowing.

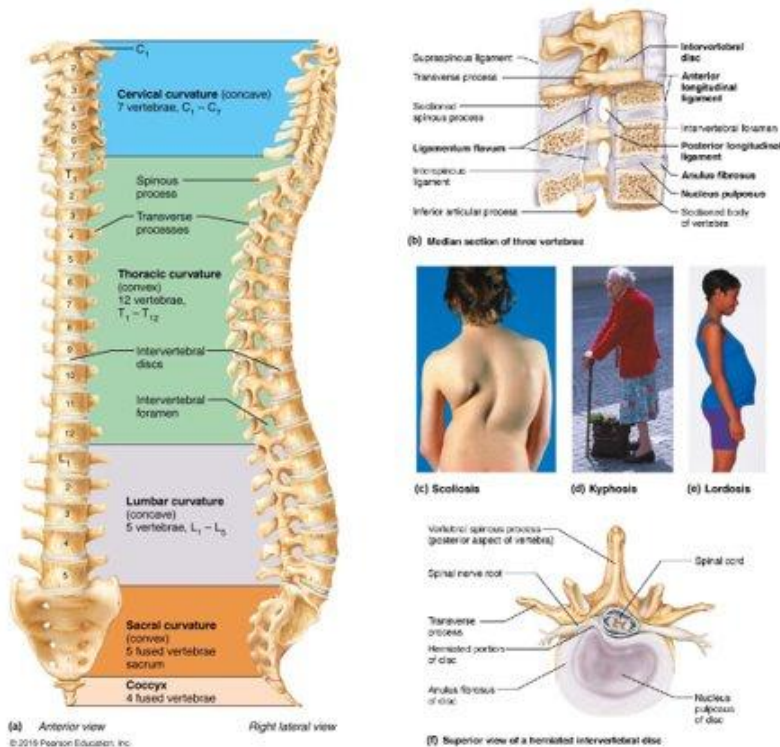


Vertebral Column

The vertebral column includes 32-33 bones (7 cervical, 12 thoracic, 5 lumbar, 5 sacral, 3 or 4 coccygeal) forming a column of 70 cm long in an adult of average height composed of 24 mobile bones to allow movement and the remaining 8-9 fuse to form 2 composite bones (sacrum and coccyx). The 3 main functions of the vertebral column are weight-bearing, anchor for muscles and ligaments, and protection of the spinal cord. The normal curvature alternates between concave (lateral view curves anteriorly) and convex (lateral view curves posteriorly): cervical (concave), thoracic (convex where it is exaggerated in kyphosis), lumbar (concave where it is exaggerated in lordosis) and sacral (convex) but in scoliosis the curvature is lateral instead of anterior or posterior. The supporting elements of vertebral column include:

1. ligaments of which the major supporting ligaments are anterior (broad and attached to bony vertebrae and discs to prevent hyperextension of spine) and posterior (narrow and attaches only to the discs to prevents hyperflexion of spine) longitudinal ligaments forming continuous bands down the front and back of vertebral bodies from the neck to the sacrum
2. intervertebral discs (forming 25% of the vertebral column length) which provide cushioning (shock absorbers) between bony vertebral bodies with each disc being circular with a central nucleus pulposus (elastic and compressible) and an annulus fibrosus around the periphery (attached to adjacent vertebrae) which is largest in cervical and lumbar regions.

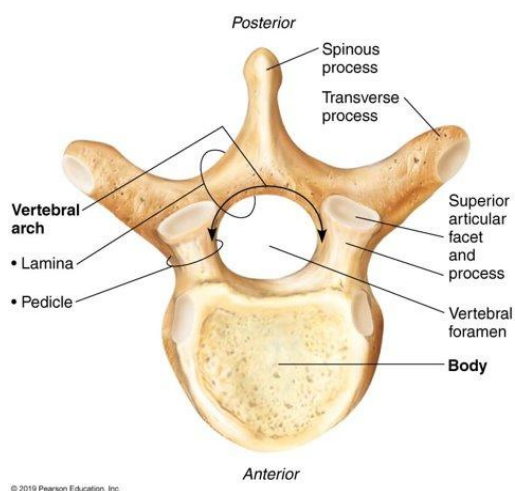
A herniated disk occurs when a portion of the nucleus pulposus pushes through a crack in the annulus and then may compress a spinal nerve.



Typical Vertebra

The following are typical features of vertebrae:

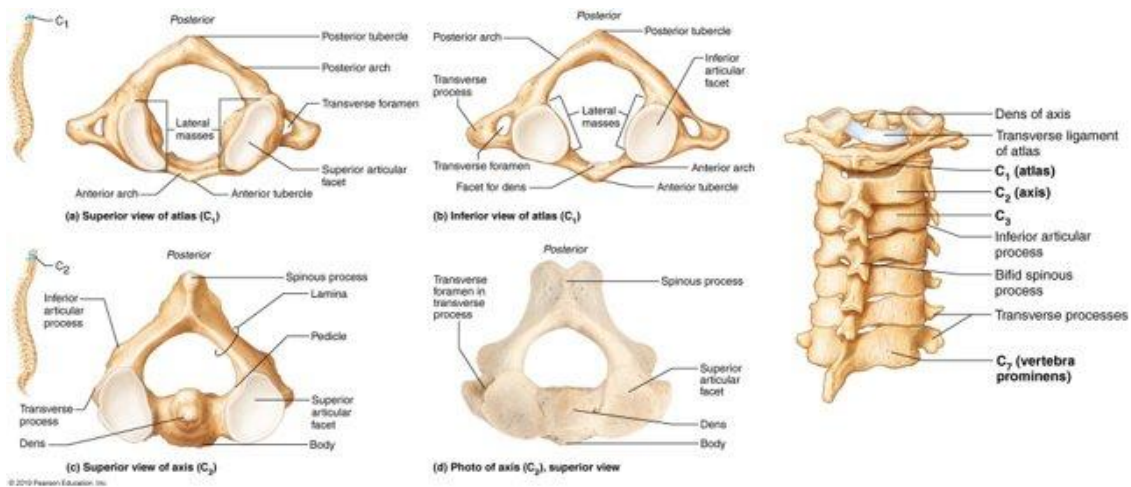
- gets larger as one descends column
- formed of weight-bearing body and vertebral arch (2 pedicles with notches on superior and inferior surfaces forming the intervertebral foramina between adjacent vertebrae for passage of nerves and 2 laminae) which enclose the vertebral foramen containing the spinal cord of the CNS
- 7 processes emerge from each vertebral arch: 1 spinous process for muscle attachment, 2 transverse processes (1 per side) for muscle attachment, and paired superior and inferior articular processes with facets covered in hyaline cartilage for articulation of adjacent vertebrae.



Cervical Vertebrae

Distinct features of the cervical vertebrae are:

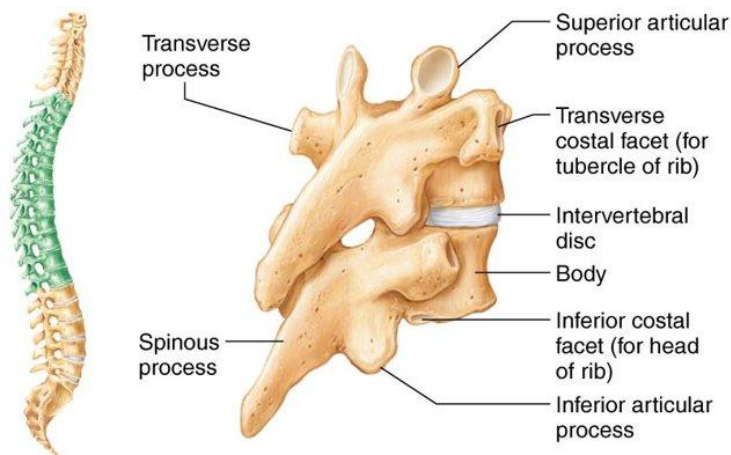
- a. vertebrae 1 (atlas) and 2 (axis) have no intervertebral disc and an unusual structure:
 1. the atlas has no body and no spinous process but has posterior and anterior arches extending from lateral masses containing superior articular facets for articulation with the occipital condyles and inferior articular facets for articulation with the axis
 2. the axis has a shape intermediate between the atlas and a typical vertebrae but with a dens (odontoid process) which allows rotation of the head left and right,
- b. vertebrae 3-7 are more typical but with spinous processes that are short and split at the end (except 7 which is long and non-split allowing it to be the first palpated) and each transverse process contains a transverse foramen for passage of the vertebral artery to the brain.



Thoracic Vertebrae

Distinct features of the thoracic vertebrae are:

- a. body has demi-facets on adjacent vertebrae for the head of ribs
- b. transverse processes have facets for articulation with the tubercles of ribs (except thoracic vertebrae 11 and 12)
- c. spinous process is long and angled caudally.



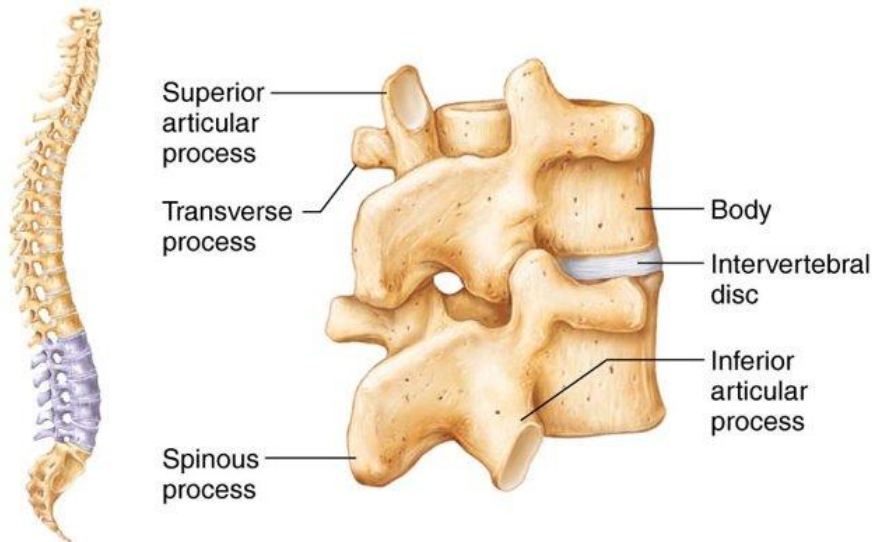
(b) Thoracic vertebrae

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Lumbar Vertebrae

Distinct features of the lumbar vertebrae are:

- pedicles and laminae are shorter and thicker
- spinous processes are flat, short, and project directly back
- inferior facets are oriented laterally while superior facets are oriented medially.



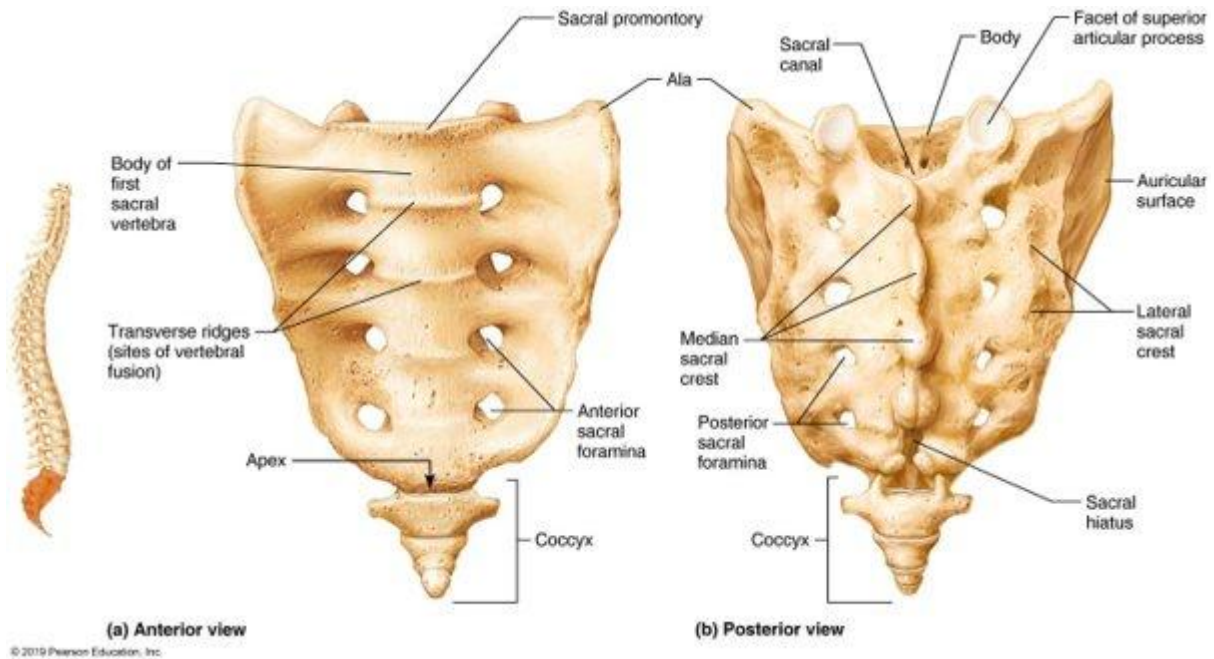
(c) Lumbar vertebrae

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Sacral and Coccygeal Vertebrae

Distinct features of the sacral vertebrae are:

- 5 separate sacral vertebrae are fused during adolescence (transverse lines indicate where adjacent vertebrae fused) into the sacrum with a sacral canal for the nervous tissue
- sacrum articulates superiorly with the 5th lumbar vertebra and laterally with the hip bones (sacroiliac joint)
- sacral promontory is a ridge found at the antero-superior aspect of the sacrum
- sacral foramina are the equivalent of intervertebral foramina for the passage of nerves
- median sacral crest is a dorsal midline ridge of bone formed by the fusion of the spinous processes
- sacral hiatus is a caudal opening of the vertebral canal. Distinct features of the coccygeal vertebrae are that it forms the tailbone from fusion of the 3-4 coccygeal vertebrae.



Thorax

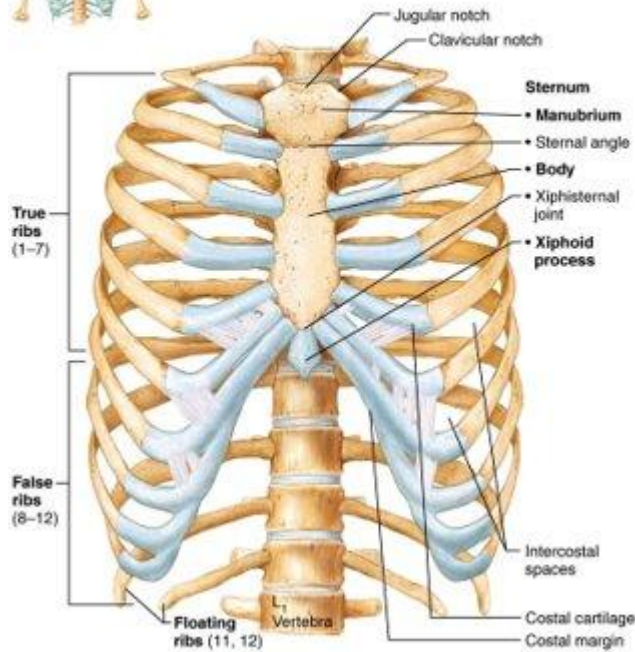
The thoracic cage is formed of thoracic vertebrae, ribs, costal cartilage, and the sternum to form a protective cage around the heart, lungs and major blood vessels. It provides support for the shoulder girdle and upper limbs, and provides surface area for attachment of back, chest and shoulder muscles. The sternum is anterior and midline in the thorax and is formed from the fusion of 3 bones:

1. manubrium (articulates with 1st pair of ribs and clavicles via clavicular notches)
2. body (has notches for articulation with ribs 2-7)
3. xiphoid process (attachment for some muscles) of the sternum.

Three important anatomical landmarks of the sternum are:

1. jugular notch which is the superior border of the manubrium that is aligned with T2-T3
2. sternal angle which is the cartilaginous hinge between the manubrium and body of sternum
3. xiphisternal joint which is the fusion of the sternal body with the xiphoid process (aligned with T9).

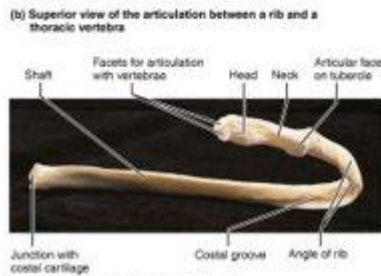
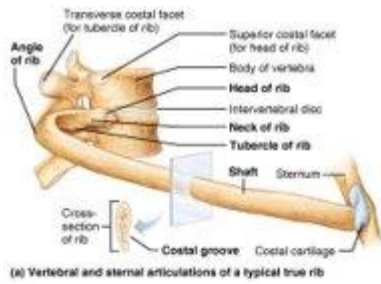
There are 12 ribs per side, all attached at the back to the vertebral column, and curve inferiorly and anteriorly. Seven are true ribs that attach to the sternum independently while the remaining 5 are false ribs with ribs 8-10 attaching to the sternum indirectly via costal cartilages and rib 7 while ribs 11 and 12 are not attached anteriorly (floating ribs).



(a) Skeleton of the thoracic cage, anterior view
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Ribs

A typical rib is a bowed flat bone with a head (has 2 facets where 1 articulates with the demi-facet on the body of the same-numbered thoracic vertebra and the other facet articulates with the demi-facet on the body of the adjacent vertebra above), neck, tubercle (articulates with transverse process of same-numbered thoracic vertebra) and shaft (has a groove on the inferior inner surface of the body of the rib to accommodate the intercostal neurovascular bundle).



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Pectoral Girdle

The pectoral girdle includes the scapula and the clavicle. Scapula (shoulder blade). It is a thin, triangular and flat bone located dorsally between ribs 2 and 7 with the following bone markings:

- superior, medial and lateral borders
- coracoid process (site for origin of biceps muscle)
- socket of shoulder joint (glenoid cavity) for arm which is shallow and relatively unstable
- acromion (articulates with acromial end of clavicle). Clavicle (collarbone). It is slightly S-shaped (curvature promotes outward fracture away from subclavian artery), sets lateral position of shoulder and has insertion points for muscles.



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(a) Right scapula, anterior aspect (b) Right scapula, posterior aspect

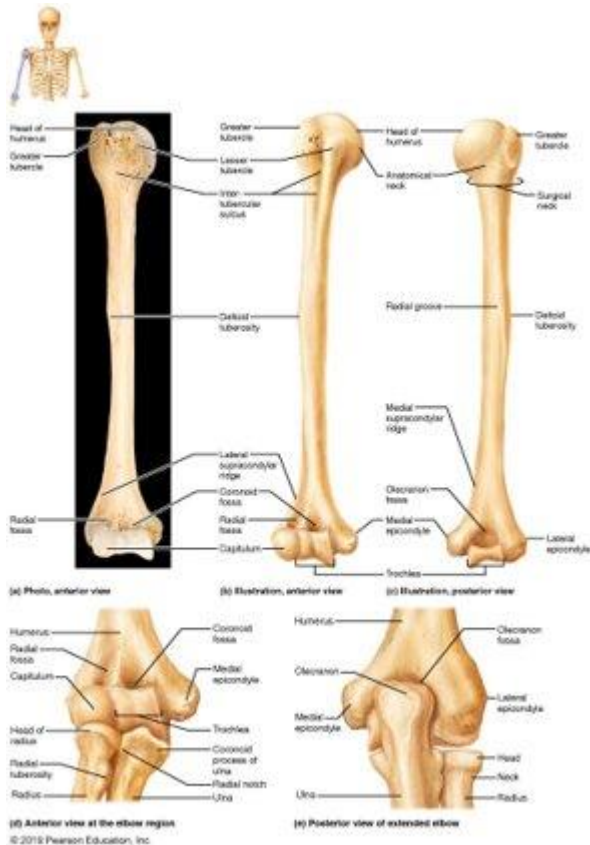


(c) Right scapula, lateral aspect

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Arm

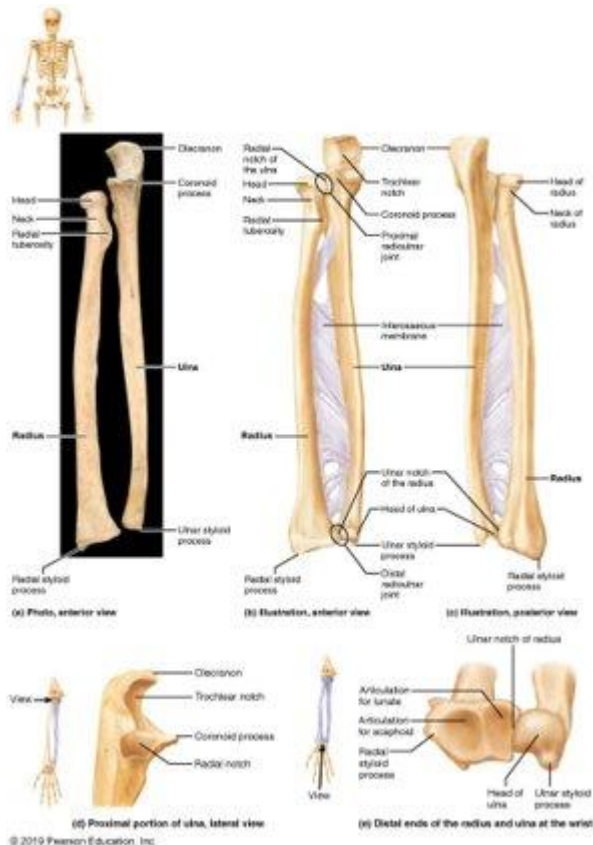
The arm (humerus) is part of the upper limb together with the forearm and hand. It is the only bone of the arm and the longest bone of the upper limb. It articulates with the scapula proximally (humerus head inserts into glenoid cavity of scapula) and forearm (radius and ulna) distally. The proximal end of the humerus has the anatomical neck, greater tubercle, lesser tubercle, intertubercular sulcus, and surgical neck (most common fracture site). The shaft has the deltoid tuberosity. The distal end of the humerus has 2 condyles (medial has the trochlea for articulating with ulna and lateral has the capitulum for articulating with the radius) and 2 epicondyles (medial and lateral). The ulnar nerve runs behind the medial epicondyle and gives the perception of pins and needles when struck.



Forearm

The forearm includes 2 parallel long bones, radius and ulna, that articulate with each other at the proximal and distal radio-ulnar joints and include an interosseous membrane to maintain their proximity during movements.

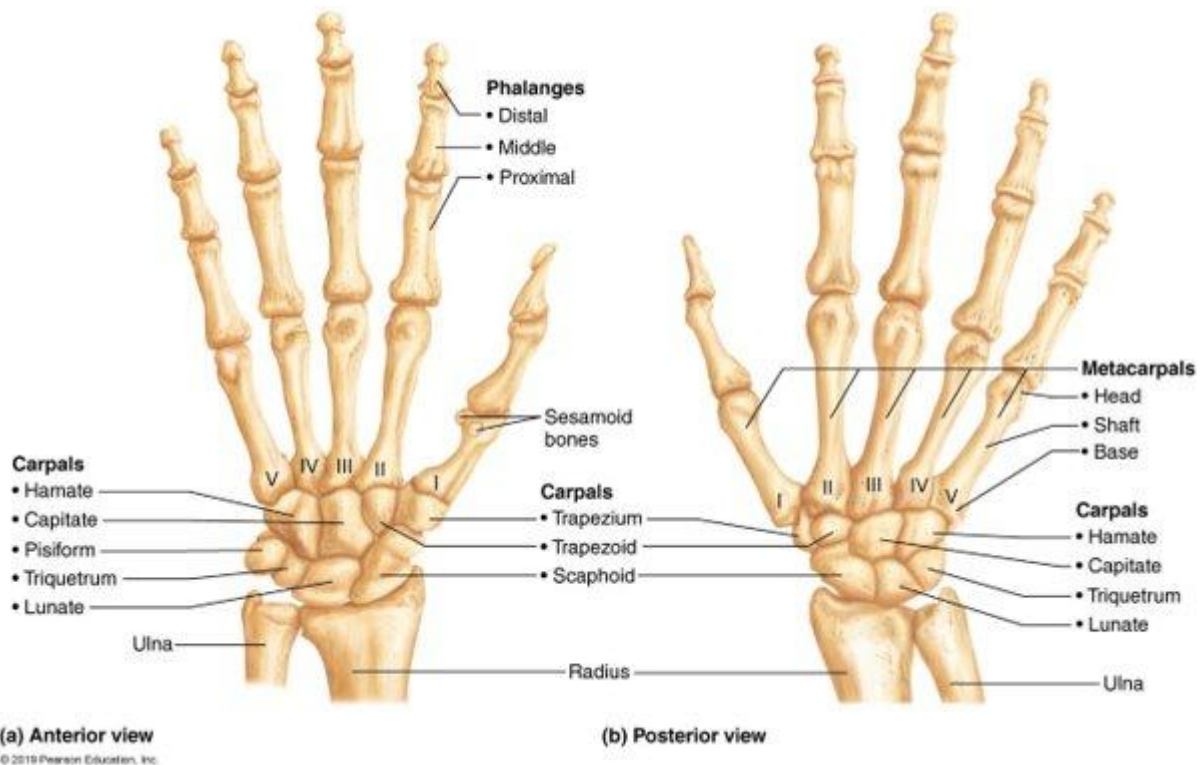
1. ulna at proximal end forms elbow joint and has olecranon process (prevents elbow hyperextension) and coronoid process containing radial notch for articulation with radius while at distal end has ulna styloid process for ligament attachment to wrist,
2. radius is slightly shorter than ulna with head at proximal end while distal end forms wrist joint, has radial styloid process for ligament attachment to wrist and has ulnar notch for articulation with ulna.



Hand

The hand includes 27 bones comprising the carpus, metacarpus and phalanges:

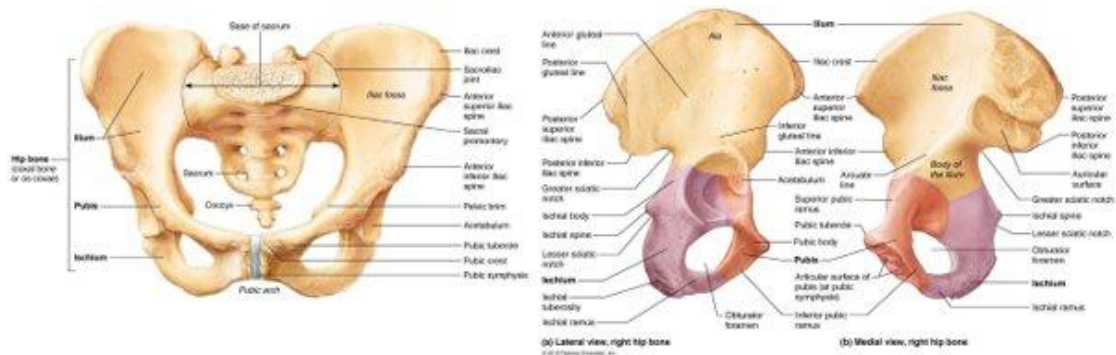
1. carpus (wrist) includes 8 carpal bones (scaphoid, lunate, triquetrum, pisiform, trapezium, trapezoid, capitate, hamate) but only scaphoid and lunate articulate with radius
2. metacarpus (palm) includes 5 long bones numbered 1-5 from thumb (pollex) to little finger where the proximal ends articulate with wrist bones and distal end articulates with phalanges
3. phalanges (fingers) include the 5 fingers numbered 1-5 from thumb to little finger where each finger has 3 phalanges (proximal, middle and distal) except for thumb which has only 2 (proximal and distal).



Pelvic Girdle

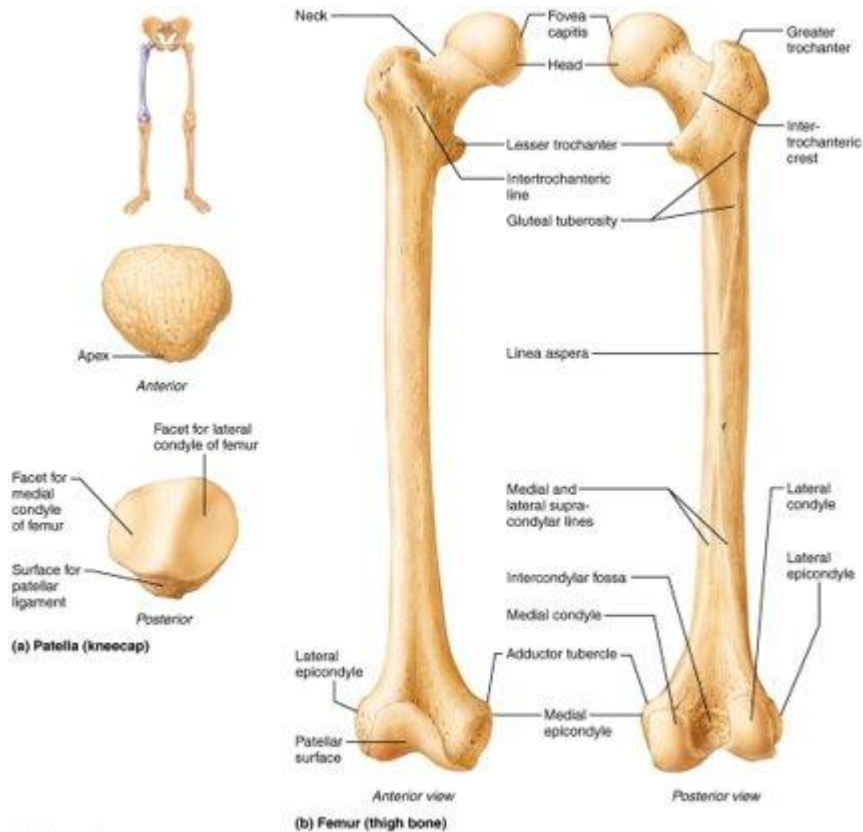
The pelvic girdle is formed of the left and right hip bones (coxal bones) which meet each other anteriorly but meet with the sacrum posteriorly to form a complete circle (pelvic brim or superior margin of true pelvis) which provides support for visceral organs of the pelvis and attaches to lower limbs at the acetabulum (hip joint). Each os coxa consists of 3 bones that fuse at the acetabulum during puberty:

1. ilium has the iliac crest (superior border) and iliac spines for attachment of muscles
2. ischium is at the postero-inferior part of the hip bone with an ischial tuberosity (anatomical part providing support when sitting)
3. pubis is at the antero-inferior part of hip bone with a pubic crest (antero-superior border near where the 2 pubic bones meet anteriorly at pubis symphysis) and a part of the obturator foramen (for passage of blood vessels and nerves) together with the posteriorly located ischium.



Thigh (femur)

The thigh is part of the lower limb together with the leg and foot. The thigh includes 1 bone called femur (largest, longest and strongest bone) with proximal end containing the head (articulates with hip joint), fovea capitis (for ligament from femur head to hip acetabulum), greater and lesser trochanters (sites of muscle attachment), neck (between head and trochanters), a shaft containing the linea aspera (site of muscle attachment), and a distal end containing the medial and lateral condyles (articulate with tibia), medial and lateral epicondyles (sites of muscle attachment), and the patellar surface between the condyles.

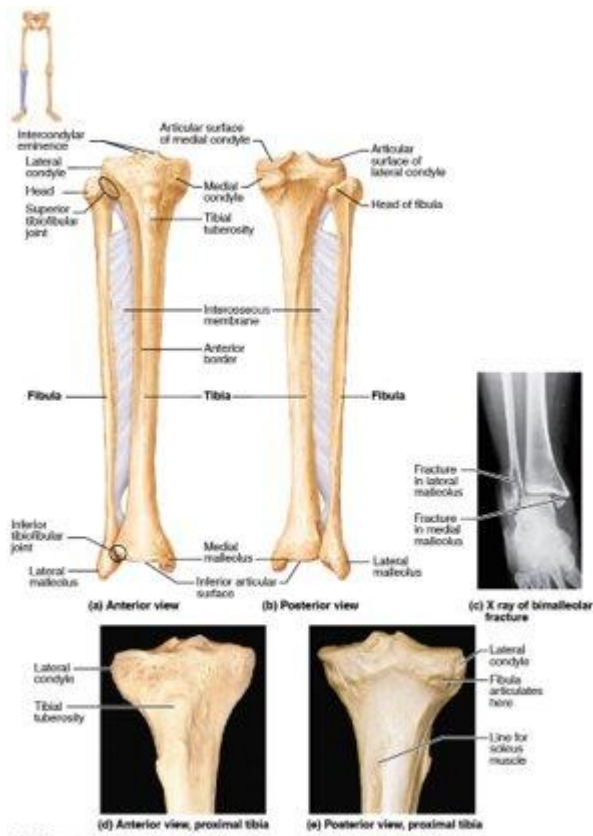


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Leg

The leg includes 2 parallel bones, tibia and fibula, which are held firmly together by an interosseous membrane plus proximal and distal tibio-fibular joints but only the tibia is part of the knee joint to transfer weight from the femur to the leg:

1. tibia at proximal end has medial and lateral condyles (articulates with femur) and the tibial tuberosity (site of patellar ligament insertion), a shaft with a defined anterior border (wedge shaped bone devoid of muscles) and a distal end containing the medial malleolus
2. fibula has a head at the proximal end and lateral malleolus at the distal end.

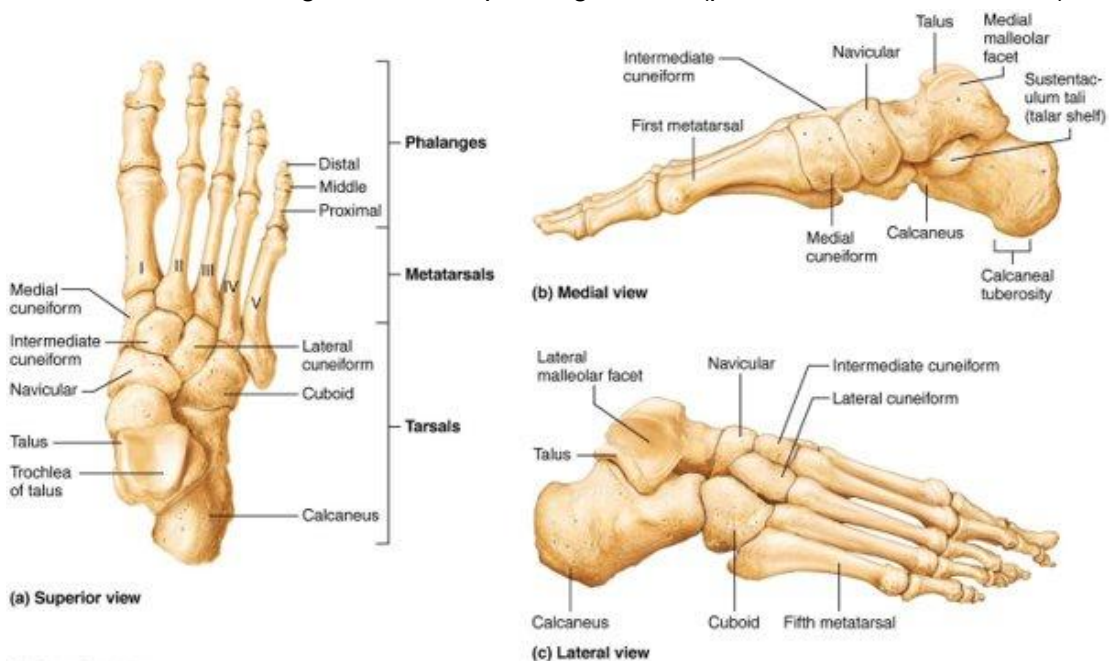


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Foot

The foot includes 26 bones comprising the tarsus, metatarsus and phalanges:

1. tarsus (ankle) includes 7 tarsal bones where the largest is the calcaneus (heel bone) and second largest is the talus (part of ankle joint)
2. metatarsus (sole) includes 5 miniature long bones numbered 1 (medial) to 5 (lateral)
3. phalanges (toes) where the big toe (hallux) has two phalanges (proximal and distal) but the remaining toes have 3 phalanges each (proximal, middle and distal).



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JOINTS

Joints

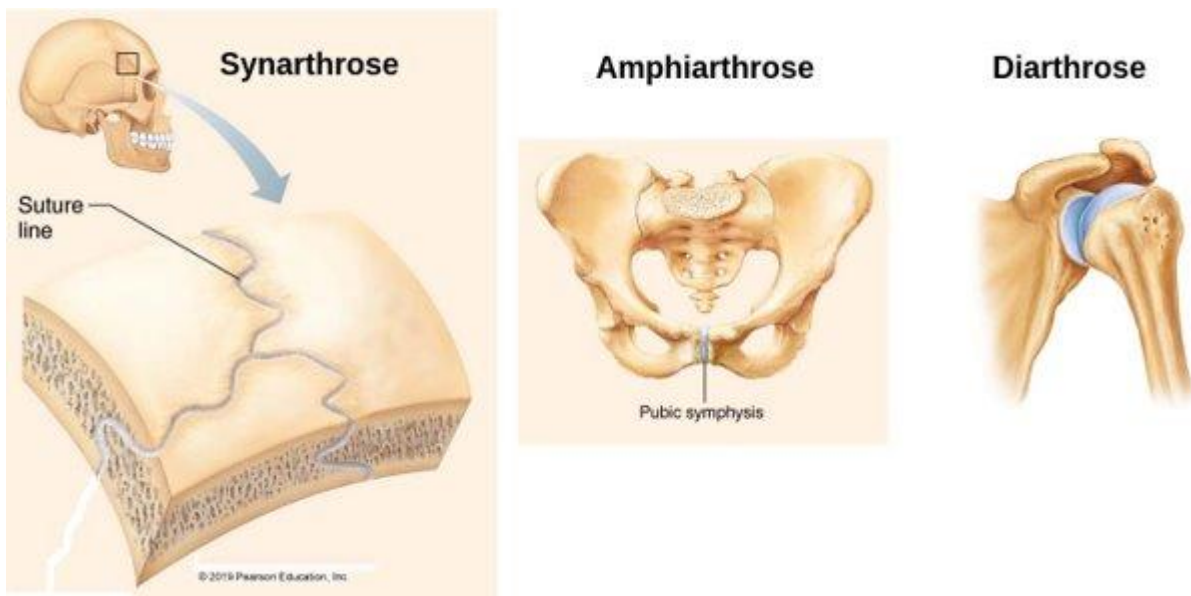
A joint is a site where 2 or more bones meet and is classified by function (movement possible) and structure (tissues of joint).

There are 3 functional types:

1. synarthrose is an immovable fixed joint between bones connected by fibrous tissue as for the sutures of the skull
2. amphiarthrose is a joint allowing slight movement such as the distal joint between the tibia and the fibula and the pubic symphysis of the pelvic girdle
3. diarthrose is a joint that is freely mobile as for all synovial joints.

Furthermore, there are 3 structural types based on the tissues within the joints:

1. Fibrous
2. cartilaginous
3. synovial.

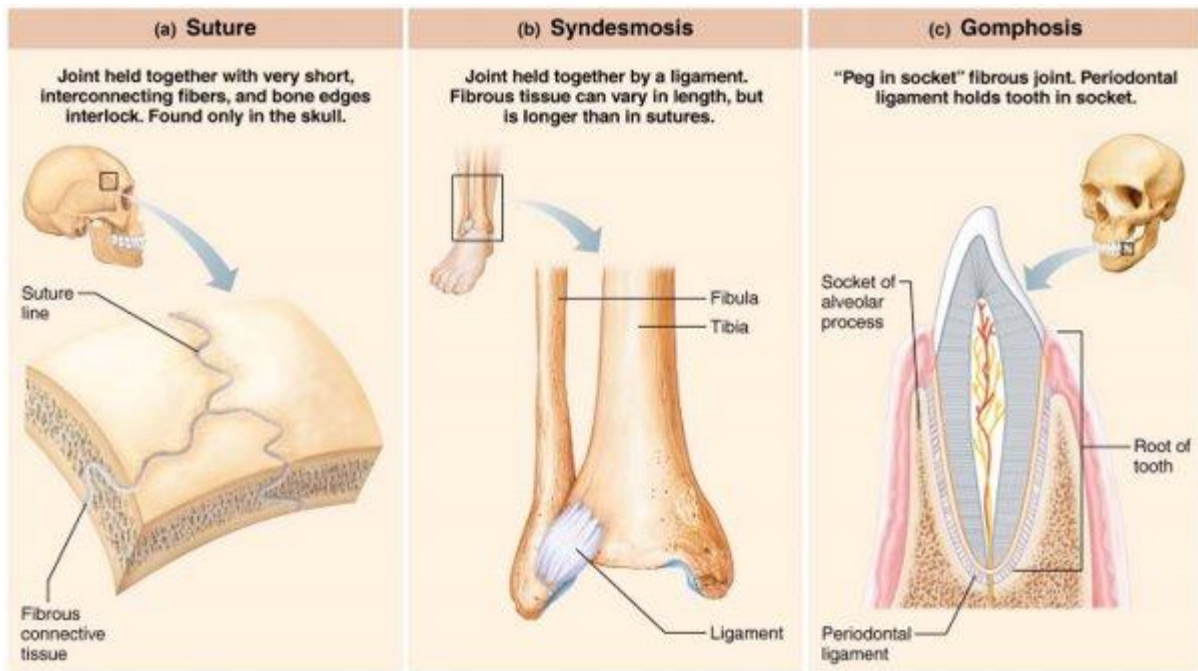


Fibrous

Fibrous joints include bones joined by fibrous connective tissue so there is no joint cavity and very little to no joint movement.

There are 3 types:

1. synostose or suture (no movement) is a joint formed by the interlocking of 2 bones held with very short connective tissue fibers found between bones of skull as sutures
2. syndesmose (little movement) is a joint held by a ligament or an interosseous membrane of fibrous connective tissue
3. gomphoses (no movement) is a joint that holds a tooth.



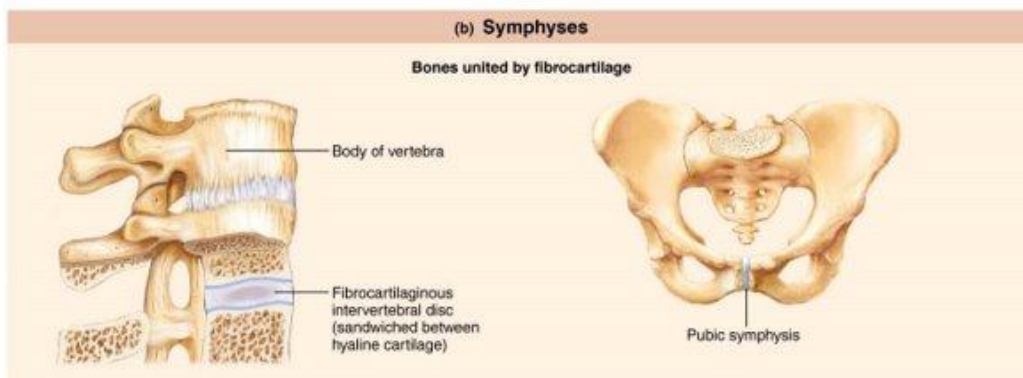
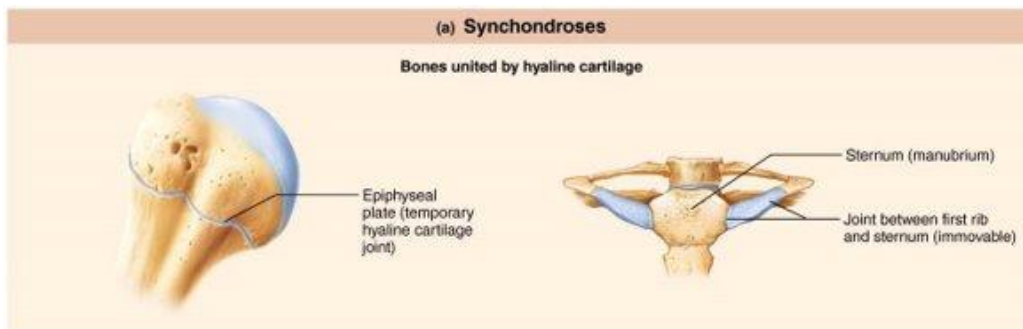
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Cartilaginous

Cartilaginous joints are bones joined by cartilage with no joint cavity.

There are 2 types:

1. synchondroses which are joints at areas of growth such as epiphyseal plates plus between the sternum and each of the first 7 ribs
2. symphyses are bones joined by fibrocartilage with hyaline cartilage on the articular surfaces to provide strength and some flexibility (e.g. pubic symphysis and intervertebral joints).



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Synovial / Features

Synovial joints are the most common joints designed for movement which can be nonaxial (gliding as between the proximal ends of the ulna and radius), monoaxial (movement in one plane as for elbow joint), biaxial (movement in two planes as for wrist), or multiaxial (movement in all planes as for hip due to ball and socket joint).

Common Features (found everywhere):

1. (1) articular cartilage that covers opposing bone surfaces so that it is slippery and cushioned,
2. (2) joint cavity called the synovial cavity,
3. (3) synovial fluid fills the joint cavity to reduce friction,
4. (4) articular capsule formed of 2 layers where the external is connective tissue to provide strength and the inner layer is a synovial membrane which secretes synovial fluid into the joint cavity
5. (5) reinforcing ligaments to confine movement of joint.

Exclusive Features (found at some joints):

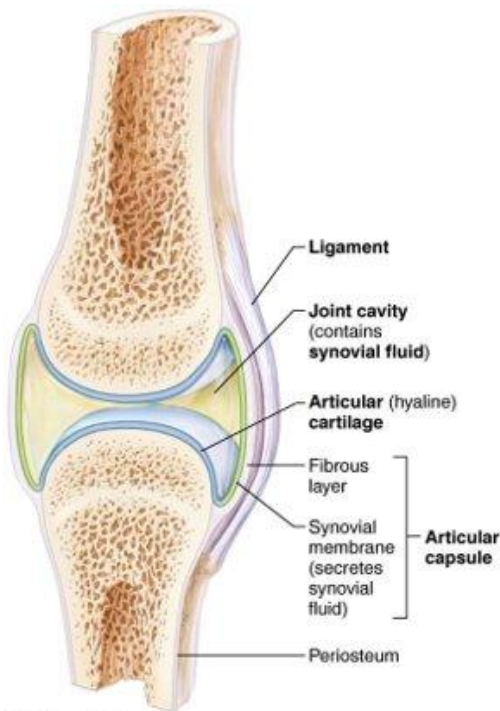
1. (1) articular discs to improve fit (e.g. knee and jaw joints)
2. (2) may have fatty pads for cushioning (e.g. hip and knee joints)
3. (3) bursa or sac lined internally with synovial membrane and containing a thin film of synovial fluid to reduce friction between tissues during movement (n.b. a bunion is an enlarged bursa at the base of the big toe)
4. (4) tendon sheaths can be thought of as elongated bursas that wrap around a tendon to reduce friction.

Factors determining stability:

1. (1) articular surfaces such as deep ball and socket joints (e.g. hip joint) have good stability but not shallow joints (e.g. shoulder joint)
2. (2) ligaments provide stability by resisting stretch (stretched ligaments stay stretched and break when stretched beyond 6% of length)
3. (3) muscle tone is the most important factor in providing stability (primary rehabilitation strategy) by pulling the bones together.

Common joint injuries:

1. dislocations are bones forced out of their normal positions at a joint (reduction is the treatment where the bones are relocated in their normal position) often because of ligament or joint capsule stretching which leads to repeat dislocations
2. sprains are torn ligaments without joint dislocation which repair slowly due to poor vascularization or require surgery for complete tears
3. cartilage injuries are common at the knee joint where it cracks (repairs slowly because cartilage has no blood supply) or pieces can break off interfering with joint movement (requires arthroscopic surgery).

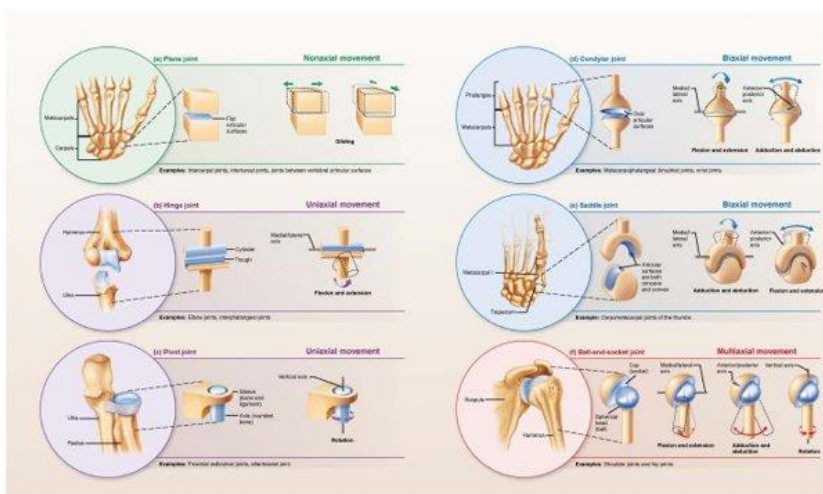


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Synovial / Shape

The shape of a synovial joint determines movements possible:

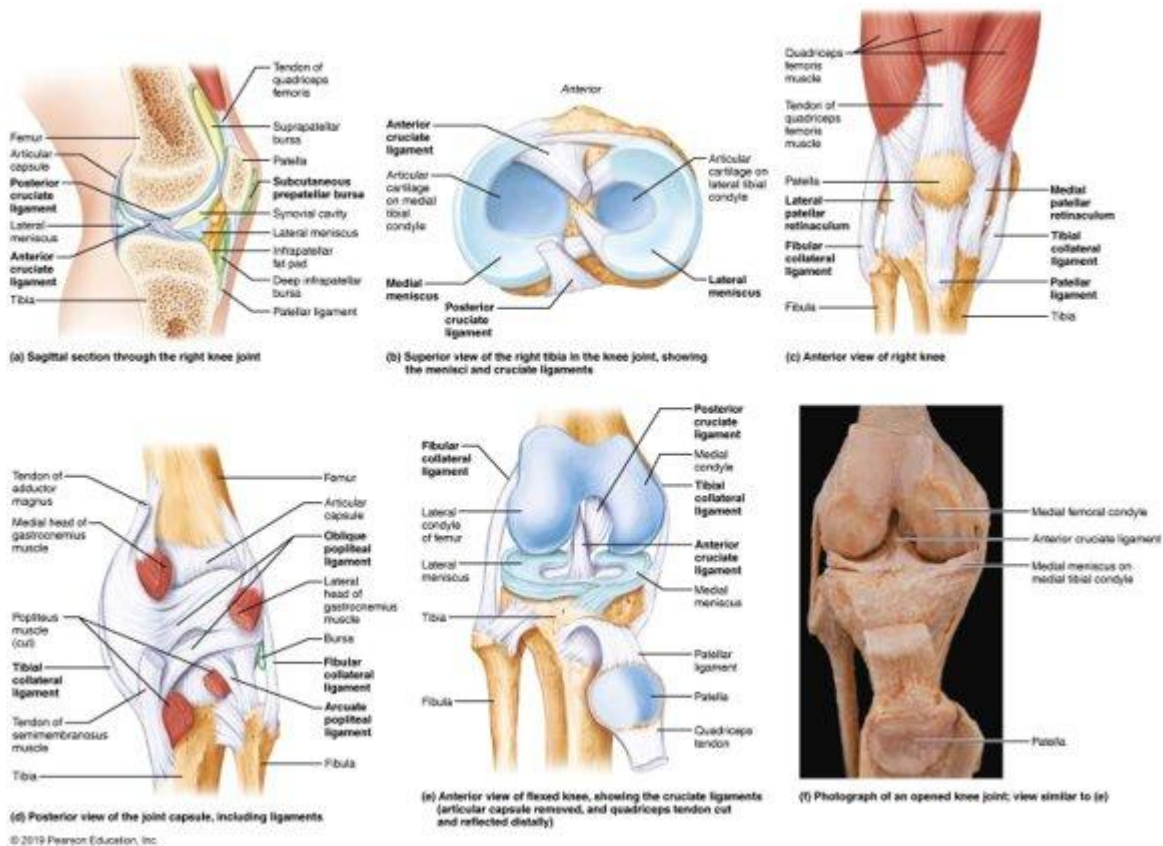
- plane joint consisting of 2 flat opposing surfaces that allow gliding (e.g. intercarpal joints)
- hinge joint as cylinder into trough to allow flexion and extension (e.g. elbow joint)
- pivot joint where there is insertion into a ring or sleeve (e.g. between atlas and dens of axis)
- condylar joint where both articulating surfaces are oval to allow some motion in all planes (e.g. knuckles)
- saddle joint which is similar to condylar but has a saddle shape to permit even more range of motion (trapezio-metacarpal joint at the base of thumb)
- ball-and-socket joint which offers the greatest freedom and range of motion (e.g. shoulder and hip joints).



Synovial / Knee

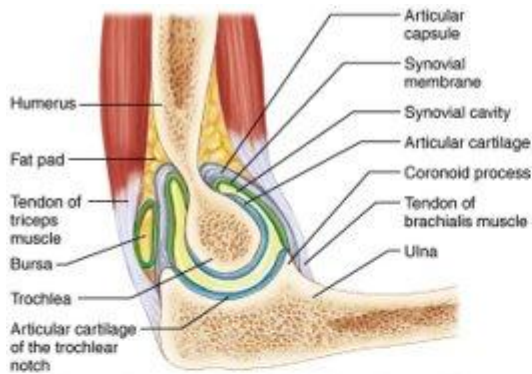
The knee joint allows flexion, extension and slight rotation when the knee is partially flexed. It has 3 articulating surfaces:

- femoro-patellar, lateral tibio-femoral, and medial tibio-femoral.
- The joint capsule anterior to the joint is replaced by 3 broad ligaments that are continuous with the quadriceps tendon (patellar ligament plus the medial and lateral patellar retinacula).
- There are 2 menisci (medial and lateral) attached to the fibrous capsule and 2 extracapsular ligaments (fibular collateral and tibial collateral), and 2 intracapsular ligaments (anterior and posterior cruciate).
- The cruciate ligaments, while inside the capsule, are covered by synovial membranes forming the synovial cavity so they are outside the synovial cavity.

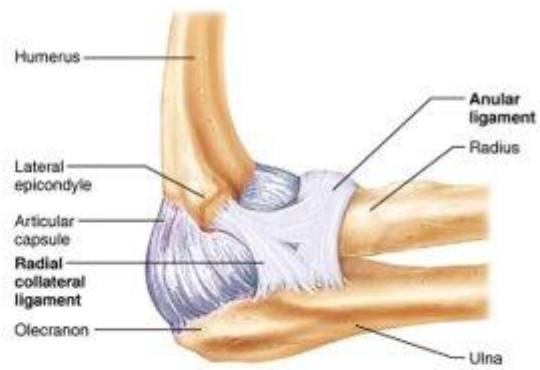


Synovial / Elbow

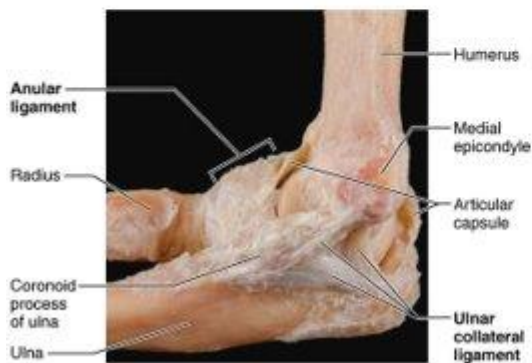
The elbow joint allows flexion, extension, pronation and supination. It has a hinge joint for movements primarily via the articulation of the trochlea of the humerus with the trochlear notch of the ulna. The joint is stabilized by collateral ligaments. The annular ligament around the radius head allows rotation of the radius for pronation and supination.



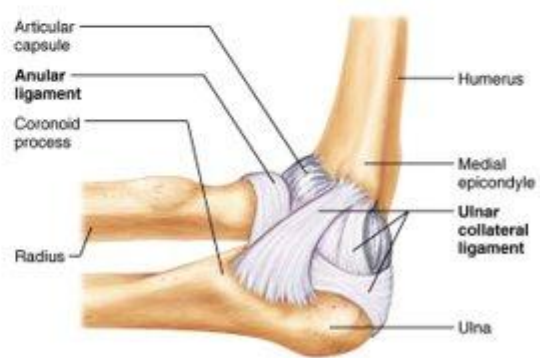
(a) Median sagittal section through right elbow (lateral view)



(b) Lateral view of right elbow joint



(c) Cadaver photo of medial view of right elbow
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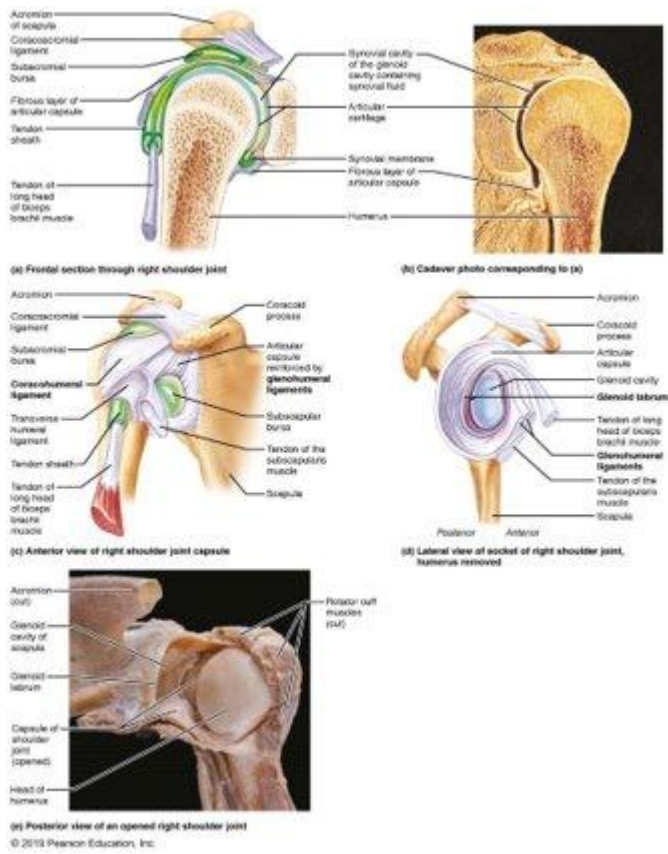


(d) Medial view of right elbow

Synovial / Shoulder

The shoulder joint allows movements in all 3 dimensions:

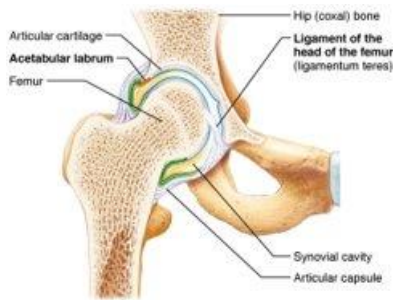
- flexion, extension, adduction, abduction, internal and external rotation at the glenohumeral joint, as well as elevation, depression, protraction and retraction due to the sternoclavicular joint.
- The glenohumeral joint includes the glenoid cavity which is broadened slightly by the glenoid labrum (fibrocartilagenous rim) but is still only one third the size of the head of the humerus so it is unstable.
- The main ligament holding the scapula and humerus together is the coracohumeral ligament. The stability of the shoulder joint largely derives from the tendons of the rotator cuff muscles.



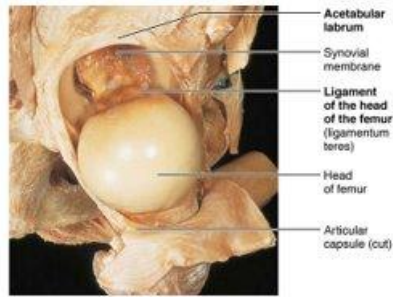
Synovial / Hip

The hip joint allows flexion, extension, adduction, abduction, and internal and external rotation.

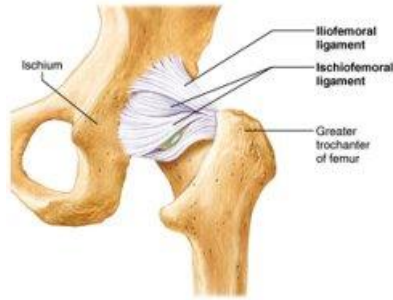
- It is a deep ball and socket joint.
- There is an intracapsular ligament (ligamentum teres) that extends from the fovea capitis of the head of the femur to the acetabulum of the hip bone.
- Damage to the artery coursing along the ligamentum teres may lead to arthritis of the hip joint (inflammation or degeneration).
- Extracapsular ligaments that provide support are the iliofemoral, pubofemoral and ischiofemoral.



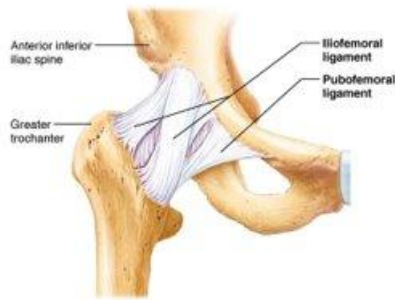
(a) Frontal section through the right hip joint



(b) Photo of the interior of the hip joint, lateral view



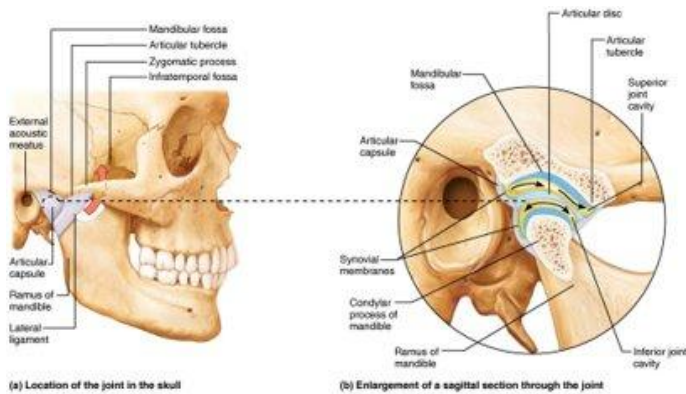
(c) Posterior view of right hip joint, capsule in place
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(d) Anterior view of right hip joint, capsule in place

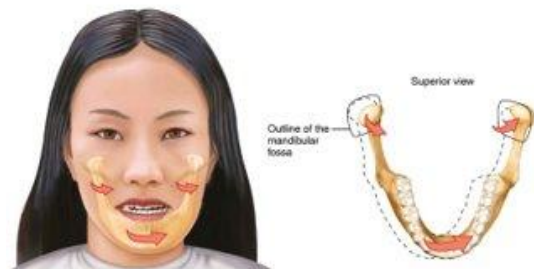
Synovial / Jaw

- The jaw joint allows flexion and extension plus gliding movements for grinding food. The temporomandibular joint includes articulation of the mandibular condyle with both the mandibular fossa and the articular tubercle of the temporal bone.
- It is stabilized by a lateral ligament.
- The initial 20 mm of mouth opening is due to rotation but further opening is due to translation or sliding permitted by an articular disk within the synovial cavity (see <https://www.youtube.com/watch?v=mB468Jh9aAY>).



(a) Location of the joint in the skull

(b) Enlargement of a sagittal section through the joint



(c) Lateral excursion: lateral (side-to-side) movements of the mandible
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