Skeletal System

bones, **cartilage** and **ligaments** are tightly joined to form a strong, flexible framework

bone is active tissue:

→5-7% bone mass/week

daily Calcium requirement: 1200mg/day

Functions of Skeletal System:

1. **Support**
   strong and relatively light; 20% body weight
2. **Movement**
   framework on which muscles act
   act as levers and pivots
3. **Protection**
   brain, lungs, heart, reproductive system
4. **Mineral storage (electrolyte balance**
   99% of body's calcium is in bone tissue
   (1200-1400g vs <1.5g in blood, rest in cells)
   also stores phosphate
5. **Hemopoiesis**
   blood cell formation
6. **Detoxification**
   bone tissue removes heavy metals and other foreign materials from blood
   can later release these materials more slowly for excretion but this can also have bad consequences

Skeletal Anatomy

each individual bone is a separate **organ** of the skeletal system

~270 bones (organs) of the Skeletal System at birth

with age the number decreases as bones fuse

by adulthood the number is ~206 (typical)

even this number varies due to varying numbers of minor bones:

sesamoid bones – small rounded bones that form within tendons in response to stress

eg. kneecap (patella), in knuckles

wormian bones –bones that form within the sutures of skull

each skeletal organ is composed of many kinds of tissues:

bone (=osseous tissue)
cartilage
fibrous connective tissues
blood (in blood vessels)
nervous tissue

General Shapes of Bones

bones can be categorized according to their general shape:

1. **long:** cylindrical, longer than wide

   rigid levers for muscle actions eg crowbars

   eg. arms, legs, fingers, toes
2. **short:** length nearly equal width

   limited motion, gliding if any

   eg. carpals, tarsals, patella
3. **flat:** thin sheets of bone tissue

   enclose and protect organs

   broad surfaces for muscle attachments

   eg. sternum, ribs, most skull bones, scapula, coxa
4. **irregular:** elaborate shapes different from above

   eg. vertebrae, sphenoid, ethmoid

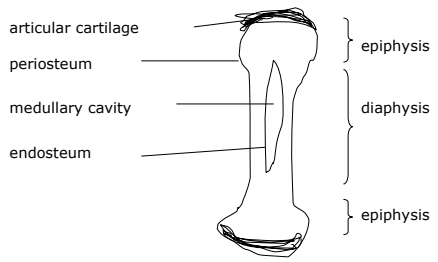
Bone Structure

bones have outer shell of **compact bone**

usually encloses more loosely organized bone tissue

= **spongy** (=cancellous) **bone**

the general structure of a typical longbone:



epiphyses

large surface area for muscle attachment and pivot

spongy bone with **trabeculae**;

contains **red marrow** (=hemopoietic tissues)

→ produces blood cells in delicate mesh of reticular tissues

in adults red marrow is limited to vertebrae, sternum, ribs, pectoral and pelvic girdles, proximal heads of humerus and femur

with age, red marrow is replaced by yellow marrow

articular cartilage

on surface of epiphyses

resilient cushion of hyaline cartilage

diaphysis

thick **compact bone** but light; hollow → medullary cavity

medullary cavity

yellow marrow – fat (adipose) storage

"fat at the center of a ham bone"

in event of severe anemia, yellow marrow can transform back into red marrow to make blood cells

periosteum

white fibrous connective tissue continuous with tendons
penetrates bone – welds blood vessels to bone

endosteum
fibrous CT that lines medullary cavity

Microscopic Structure (Histology)

A. bone:

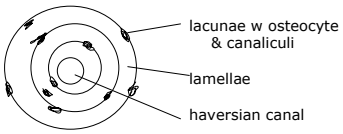
connective tissue; contains **cells** and **matrix**

bone cells = **osteocytes**

matrix predominates; ~ 1/3rd organic and 2/3rd's inorganic

matrix contains lots of **collagen fibers**

highly organized arrangement of matrix and cells



perforating canals (Volkmann canals) interconnect the haversian canals

periosteum provides life support system for bone cells

blood vessels penetrate bone and connect with those in haversian canals

B. cartilage

resembles bone:

large amount of matrix
lots of collagen fibers

differs:
firm flexible gel is not calcified (hardened)
no haversian canal system
no direct blood supply

→ nutrients and O_2 by diffusion

all bone starts out as cartilage

in bone the matrix is hardened (= **ossified**) by **calcification** (or mineralization)

microscopic structure of cartilage:

chondrocytes in lacunae

kinds of cartilage:
(all similar matrix with lots of collagen fibers; differ in other fibers)

1. hyaline
most common
eg. covers articular surfaces of joints, costal cartilage of ribs, rings of tracheae, nose

2. fibrous
mostly collagen fibers
eg. discs between vertebrae, pubic symphysis

3. elastic
also has elastic fibers
eg. external ear, eustachian tube

Anatomy of Skeletal System

each individual bone has numerous holes, bumps, depressions and ridges

= Bone Markings

Foramen: opening in bone – passageway for nerves and blood vessels

Fossa: shallow depression – eg a socket into which another bone articulates

Sinus: internal cavity in a bone

Condyle: rounded bump that articulates with another bone

Tuberosity: small rough projection – point of attachment for muscle

Spine: sharp slender process

two main subdivisions of skeletal system:

axial : skull, vertebral column, rib cage

appendicular: arms and legs and girdles

The Axial Skeleton

A. Skull

most complex part of the skeleton

consists of **facial** and **cranial** bones

most bones are paired, not all

skull bones joined by **sutures**

Fontanels

ossification of skull begins in about 3rd month of fetal development

not completed at birth→bones have not yet fused

gaps = **fontanels**
- frontal (anterior)
- occipital (posterior)
- 2 sphenoid
- 2 mastoid

at this stage skull is covered by tough membrane for protection

bones eventually grow together and fuse to form solid case around brain

Sinuses (Paranasal Sinuses)

in 4 of the bones making up the face

in life sinuses are lined with **mucous membrane**

sinuses lighten bone, warm and moisten air

6 sinuses:
- **frontal** -2
- **maxillary** -2
- **ethmoid** -1
- **sphenoid** -1

Maxilla Bone

cheek bones, upper teeth cemented to these bones

hard palate: palatine process and palatine bones

cleft palate → when bones of **palatine process** of **maxilla bones** do not fuse properly

not only cosmetic effect
can lead to serious respiratory and feeding problems in babies and small children
today, fairly easily corrected

Temporal Bone

external auditory meatus - opening to ear canal leads to middle ear chamber

only bone that contains other bones:

=**ear ossicles** (part of sense of hearing)**:**

malleus = hammer
incus = anvil
stapes = stirrup

Mandible = lower jaw

largest, strongest bone of face
articulates at temporal bone

Occipital Bone

foramen magnum - large opening in base through which spinal cord passes

occipital condyles - articulation of vertebral column

Sphenoid Bone – irregular, unpaired bone

resembles bat or butterfly in shape

keystone in floor of cranium: anchors many of the bones of cranium

contains **sinuses**

sella turcica – depression for the pituitary gland

Ethmoid Bone – irregular, unpaired bone

honeycomed with **sinuses**

cribiform plate – perforated with openings which allow olfactory nerves to pass

nasal conchae – passageways for air; filtering, warming, moistening

crista galli – attachment of meninges

very delicate and easily damaged by sharp upward blow to the nose

can drive bone fragments through the cribriform plate into the meninges or brain itself

can also shear off olfactory nerves→ loss of smell

Hyoid bone – single "U" shaped bone in neck just below mandible and above larynx (voice box)

suspended from **styloid process** of temporal bone

only major bone in body that doesn't directly articulate with other bones

serves as point of attachment for tongue and several other muscles

B. Vertebral Column

main axis of body

vertebrae are separated by pads of fibrous cartilage

=**intervertebral discs**

make vertebral column flexible rather than rigid

permits foreward, backward, and some sideways movement

in the newborn the spinal column forms a "C" shaped curve

after ~ age 3 has a double "S" shape with 4 bends; cervical, thoracic, lumbar, pelvic

divided into 5 regions:
- **cervical**
- **thoracic**
- **lumbar**
- **sacral**
- **coccygeal**

all but last two are similar in structure:
- **body**
- **spinous process**
- **vertebral foramen**
- **transverse process**
- **superior and inferior articular process**
- **intervertebral foramen** between each pair separated by **intervertebral discs**

Cervical (7):

have **transverse foramena**

1st and 2nd cervical vertabrae are highly modified for movement of the head:

atlas – holds head up
no body or spinous process
"yes" movement of head

axis -- **dens** (odontoid process) – forms pivot
"no" movement

Thoracic (12):

distinguished by **facets** smooth areas for articulation of ribs

each rib articulates at two places:
one on body of vertebrae
one on transverse process

Lumbar (5):

short and thick spinous processes

modified for attachment of powerful back muscles

Sacrum (5 fused):

triangular bone formed from fused vertebrae

sacroiliac joint – lots of stress

Coccyx (4-5, some fused):

tailbone

painful if broken

sometimes blocks birth canal, must be broken

C. Ribcage

sternum { **manubrium**, **body** (=gladiolus), **xiphoid process**

ribs: most joined to sternum by **costal cartilages**

true ribs (7prs)

false ribs (5 prs)

include floating ribs (2prs)

Appendicular Skeleton

arms and legs plus the bones that attach each to the axial skeleton (=**girdles**)

both have similar structure but:

arms sacrifice strength for dexterity and freedom of motion

legs sacrifice freedom of motion for strong support of the body

A. Upper Extremeties

shoulder (=pectoral girdle)
upper and lower arm
wrist and hand

Pectoral Girdle:

scapula & **clavicle**

only attached to trunk by 1 joint (between sternum and clavicle)

scapula is very moveable – acts as almost a 4th segment of limb

scapula rides freely and is attached by muscles and tendons to ribs but not by bone to bone joint

extensive flat areas of scapula are used as origins for arm muscles and trunk muscles

very shallow joint cavity (= glenoid cavity) for articulation of upper arm

clavicle is the most frequently broken bone in the body, sometimes even during birth

Upper Arm:

humerus: longest and largest bone of arm

loosely articulates with scapula by **head** – **glenoid cavity**

"ball and socket joint": allows movement in all directions

large processes of scapula, **acromium** and **coracoid**

→have muscles which help to hold humerus in place

Forearm:

consists of two bones: **radius** & **ulna**

very mobile; adds to flexibility of hand

they are attached along their length by **interosseous membrane**

ulna:

main bone of forearm

firmly joined to humerous at elbow

"hinge joint": allows only flexion and extension

large process = **olecranon process**, extends behind elbow joint

acts as lever for muscles that extends forearm

radius:

main attachment of lower arm to hand

more moveable of two

can revolve around ulna to twist lower arm and hand

Hand:

attached by muscles mainly to radius provides great flexibility

made of three kinds of bones:

carpals

large # of rounded bones allows movement of fingers in all directions

provide flexibility and ability to grasp things

metacarpals

form the "palm" of the hand

rounded at proximal ends for flexibility

attached to fingers as hinge joint

phalanges

simple hinge joints for grasping

B. Lower Extremeties

number and arrangement of bones in the lower limb are similar to those of the upper limb

lower limb they are adapted for weight bearing and locomotion, not dexterity

Pelvic Girdle

coxa (os coxa, innominate bones)

pelvis consists of a pair of **coxa** that articulate with sacrum

rigid connection to axial skeleton; strength, not flexibility

the two coxal bones forms large basin of bone

→receptacle for many internal organs

as bipedal animals the pelvis must support most of the body weight

→viscera bear down on pelvic floor (common site of herneas)

pelvis is funnel shaped; yet must remain large enough for the birth canal

large flaring portion of pelvis = **false pelvis**

smaller actual opening = **true pelvis**

→in women it is the actual space child must fit through

pelvis is easiest part of skeleton to distinguish between sexes

pelvic bones are also the origin of thigh muscles and trunk muscles

each coxa is produced by fusion of three bones:

ilium – upper, fan shaped

ischium – bottom, the actual bone you sit on

pubis – front

the 2 pubic bones are joined by a pad of fibrous cartilage = **pubic symphysis**

in women before birth it softens to allow expansion of birth canal

Upper Leg = Thigh

femur the largest bone in body

like the upper arm, the articulation between the pelvis and upper leg is a "ball and socket" joint

head of femur fits in large deep socket = **acetabulum** of pelvis

great strength, much less flexibility than humerous

patella (=kneecap)

a **sesamoid** bone (= bones found where tension or pressure exists; also in thumb and large toe)

in tendons at knee joint; does not articulate directly with any other bone

acts as kind of a bearing

→allows tendon to slide smoothly across knee joint

if patella is lost through accident or injury get ~30% loss of mobility and strength due to > friction

Lower Leg

consists of two bones: tibia and fibula

tibia (=shinbone)

main bone, articulates with <u>both</u> femur and foot

→more strength, much less mobility than lower arm bones

fibula

thin & narrow, offers extra support for lower leg and foot

Foot

like hand, made of three types of bones:

tarsals

thick angular bones; must support all the weight of the

locked together and immoveable

greatly limits the movement of the rest of the foot

almost no dexterity compared to the hand

metatarsals

support most of the structure of the foot

much less movement than metacarpals

phalanges

simple hinge joints

arches: the tarsals and metatarsals are strung with ligaments to provide double arches

act as shock absorbers

arches also furnish more supporting strength than any other type of construction →more stability

if ligaments and muscles weaken, arches are lost = flatfootedness = fallen arches,

→ more difficult walking, foot pain, back pain

high heals redistribute the weight of foot

→throw it foreward; ends of metatarsals bear most weight of the body instead of the arches

→sore feet

Articulations (joints)

Articulations = any place where 2 or more bones meet

joints hold bones together

some allow for some degree of movement

joints can be categorized into three general kinds by the **degree of movement** & their **structure:**

A. Immoveable Joints (= Synarthroses; "joined together")

bones are joined by **fibrous connective tissue**

eg. sutures – only in skull

eg. gomphoses =teeth in socket

B. Slightly Moveable Joints (=Amphiarthroses; "on both sides")

bones are joined by some kind of **cartilage**

eg. symphysis pubis

eg. intervertebral discs

eg. costal cartilage between ribs & sternum

C. Freely Moveable Joints (= Diarthroses; "through a joining")

most complex joint structure; are actually **organs**, consisting of several tissues:

→ entire joint is connected by a **joint capsule** that continuous with the **periosteum** of each bone

→ end of each bone is padded with **articular cartilage**

→ the ends of both bones are enclosed by **synovial membrane**

→ joint cavity is filled with **synovial fluid**

→ often supported by **ligaments**

= cords of fibrous connective tissue that join bone to bone

ligaments bind bones together across joints but limit their range of motion

more elastic than tendons

→ sometimes includes fluid filled **bursae**

= synovial sacs spaced around joints between tendons or ligaments to cusion, reduce tension & friction

eg. hinge joint (fingers, toes, elbow)

eg. ball and socket joints (shoulder, hip)

Exercise and Synovial Joints

synovial fluid is warmed by exercise and becomes thinner

→this is more easily absorbed by articular cartilage

→provides more effective cushion against compression

this warmup and compression also helps to distribute nutrients to cartilage cells (nonvascular tissue) and squeeze out metabolic wastes

→ **warm up is good for you**

Skeletal Physiology

Composition of Bone

bone is active tissue:

→5-7% bone mass/week

mature haversian canal systems are replaced up to 10x's during a lifetime

→equiv. of skeletal mass is replaced every 7 years

bone is the densest tissue in the body

→ only 20% water

bone has a grain just like wood:

grain runs longitudinally for greatest strength

as bone is remodeled old bone is eroded to accommodate new bone but grain is preserved

matrix of bone consists of:

2/3rd mineral salts; mainly calcium & phosphorus

($CaPO_4$, CaOH, $CaCO_3$, also Mg, Na, K)

this matrix tends to accumulate toxic metals:lead & radium

→ bone cancer, leukemia

1/3rd collagen and proteins

this mixture of organic and inorganic components allow bone to be strong without being brittle

osteocytes = the cells of bone tissue

cells that secrete the matrix

2 kinds of bone cells:

osteoblasts = bone building cells

osteoclasts = bone destroying cells

Skeleton in Infancy & Childhood

parts of skeleton begin to form in 1st few weeks of development

begins in fetus as **cartilage** template

once the cartilage is laid down, it begins to turn into bone by **ossification**

Ossification = conversion of cartilage or other connective tissue into bone by depositing calcium and other minerals

in longbones ossificaton begins 3rd month of development

centers of ossification in longbones:

begins in **diaphysis**

at birth additional centers in **epiphyses**

early development mainly involves an increase in size and length

effects of length are primarily in long bones of arms and legs

growth hormone plays a major role in fetal and childhood bone development

→ stimulates cartilage cells between zones of ossification

as long as the cartilage is growing faster than the process of ossification, the bones will continue to lengthen

when **epiphyseal cartilage** disappears the bone has completed its growth (in length)

deficiency of GH: dwarfism

excess of GH: gigantism, acromegaly -hands, feet, jaw enlarge

thyroid hormone helps bones to develop the proper proportions during this time

head becomes proportionately smaller
facial bones more prominent
thorax more elliptical
pelvis larger and wide

legs proportionately longer
vertebral column develops two additional curves
(already had thoracic and pelvic curves)
cervical curve ~3mo; lifts head
lumber ~1 yr; standing, walking

Puberty

at puberty the sex hormones (**estrogen** & **testosterone**) begin to affect the process of ossification

leads to masculinizing and feminizing features of skeleton

facial features develop especially rapidly

also:

male	deep and funnel shaped pelvis;
	whole skeleton larger and heavier
female	shallow, broader and flaring pelvis
	limbs grow more slowly

estrogen and testosterone continue to help maintain skeletal health throughout adulthood

in teen years your skeleton gains about 50% of total bone accrual

smoking, especially in girl, dramatically slows that rate making them more susceptable to hip and vertebral fracture (~5% middle schoolers smoke)

Adulthood: Bone Maintenance and Remodeling

by early adulthood the skeleton has reached its maximum height

the skeletal system is strongest in early adulthood

bones continue to grow and remodel themselves throughout life

even after bone growth has stopped, osteoblasts and osteoclasts continue working

→ bones constantly adapting to stresses
reaction to mechanical stresses

→ weak areas are strengthened

→ old bone is removed to reduce bulk

in adult these opposing processes balance each other out so bone neither grows nor shrinks

The Skeleton as a Calcium Reservoir

most calcium in body is contained in teeth and skeleton

→ acts as a mineral **reservoir**, esp for calcium, and phosphate

calcium is used in body for:

muscle contractions
nerve impulses
synapses
heart beat
secretions
blood clotting
cofactors for enzymes

a supply of calcium must be constantly available for all these activities

blood calcium homeostasis is maintained by depositing or dissolving bone tissue via osteoblast & osteoclasts

Ca^{++} deficiency:

severe neuromuscular problems
hyperexcitability
loss of function

Ca^{++} excess:

Calcium deposits in blood vessels, kidneys and soft organs

vitamin D

needed for absorption of calcium by small intestine

deficiency: poor calcification
deformed bones

rickets
osteomalachia

found in eggs and milk

also formed from precursors produced by cells of digestive tract
carried in blood to skin
UV converts precursor to Vit D.

two **hormones** involved in bone maintenance and blood calcium homeostasis

Calcitonin →stimulates bone formation (osteoblasts)

→ lowers blood Calcium levels

PTH →stimulates bone destruction (osteoclasts)

→ raises blood calcium levels

The Skeleton in Old Age

as we age sex hormones gradually decline

sex hormones stim bone deposition, and decrease osteoclast activity

reabsorption outweighs growth

→ bone become brittle

shaggy margins, spurs, joint problems

cartilage keeps growing: big ears

too much bone loss may lead to **Osteoporosis**

= a group of diseases in which bone reabsorption outpaces bone deposition

bones lose mass and become more brittle

affects entire skeleton but esp spongy bone of vertebrae and neck of femur

most serious consequence is pathologic fractures esp in hip, wrist and vertebral column

also, as bones become less dense they compress like marshmallows

→ results in **kyphosis**

→ exaggerated thoracic curve

(widow's hump, dowager's hump)

bone loss is especially severe in post menopausal women (esp caucasian women)

menopause causes sharp reduction in **estrogen**

smoking also reduces estrogen levels

by 70 yrs the average white woman has lost 30% of her bone mass (some up to 50%)

not as drastic in men

→ bone loss begins ~60 yrs and seldom exceeds 25% loss

suggestions:
need good bone mass by 35 or 40
plenty of weight bearing exercise, esp before menopause
good calcium uptake (850-1000 mg/d) early in life, esp 25-40
fluoridated water helps harden bones
don't smoke
hormone replacement therapy only slows loss, doesn't replace lost bon -No longer recommended, too dangerous

Disorders of Skeletal System

1. Fractures

repairs more slowly than skin; up to 6 months

a. clot (hematoma) formation

hours
broken blood vessels, damaged tissues, bone cells die

b. soft callus (fibrocartilage)

days
growth of new capillaries
disposal of dead tissue

c. bony callus

weeks
spongy bone tissue grows around area and replaces fibrocartilage
join two pieces firmly together

d. remodeling

months
dead portions of original area reabsorbed
compact bone replaces spongy bone
ends are remodeled to blend in
usually thickened area remains
misset bones may heal crooked
but weight bearing bones usually reassume proper shape
elec current speeds calcification and repair

new synthetic materials may soon be useful in replacing missing bone

also bone grafts

2. Vertebral curvature

normally spine has two "S" shaped curves

provides flexibility and resilient support

several types including:

scoliosis – abnormal lateral curvature
may appear spontaneously
or be result of polio, rickets or TB

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low body fat reduces estrogen production by ovaries in young female runners and dancers

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4. Rickets

childhood disease: bowed legs, deformed pelvis,
due to Vit D (or Ca^{++}) deficiency during growing years
body unable to absorb calcium from intestine
reduces calcification – bones stay soft

5. Osteoarthritis

most common age change is degeneration of joints
=wear and tear arthritis
rarely occurs before age 40; affects 85% of those over 70
as joints age get gradual softening and loss of articular cartilage
bone formation at margin of articular cartilage
as cartilage becomes roughened by wear, joint movements may be accompanied by crunching or cracking sounds (=**crepitus**)

affects especially fingers, intervertebral joints, hips and knees
bony spurs may form as cartilage wears away →deform joint
interfere with movement, pain

6. Rheumatoid Disease

far more severe than OA
is an autoimmune attack against synovial membrane
inflammation of synovial membranes and degeneration of cartilage
synovial membranes fill with abnormal tissue growth = granulation tissue
may erode articular cartilage, bones and ligaments
mainly small joints of body; wrists, ankles
tends to flare up and subside periodically
affects women far more than men
typically begins between age 30 – 40
no cure, but can be slowed with steroids, cortisone, etc

7. Osteomyelitis

any infection of bone, cartilage or periosteum
localized or general
usually bacterial

8. Ruptured (herneated) disc

intervertebral discs pad vertebrae
with age outer layer thins and cracks; inner layers less firm
extra pressure can cause rupture
= herneated disc: pain, numbness, partial paralysis

9. Gout

group of diseases characterized by elevated **uric acid** in blood
forms sodium urate crystals in synovial fluid causing severe pain
exacerbated by alcoholism

10. Bursitis

inflammation of bursal sacs around joints
fills with fluid
usually caused by blow or friction
="housemaids knee"
="water on the knee"

11. Tendonitis

inflammation, usually due to overuse

12. Achondroplastic Dwarfism

spontaneous mutation of genes, not necessarily from parents
long bones of limbs stop growing in childhood while growth of other bones is not affected
→ results in short stature but normal sized head and trunk
not same as pituitary dwarfism, only certain cartilage cells are affected

13. Polydactyly & Syndactyly

too many or too few fingers and toes

14. Hip Fractures

329,000/yr in US (2007)