

Pediatric Anatomy & Biomechanics

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*SAFER - Child occupant protection:
Latest knowledge and future opportunities
May 31, 2024*



INJURY BIOMECHANICS
RESEARCH CENTER



THE OHIO STATE UNIVERSITY

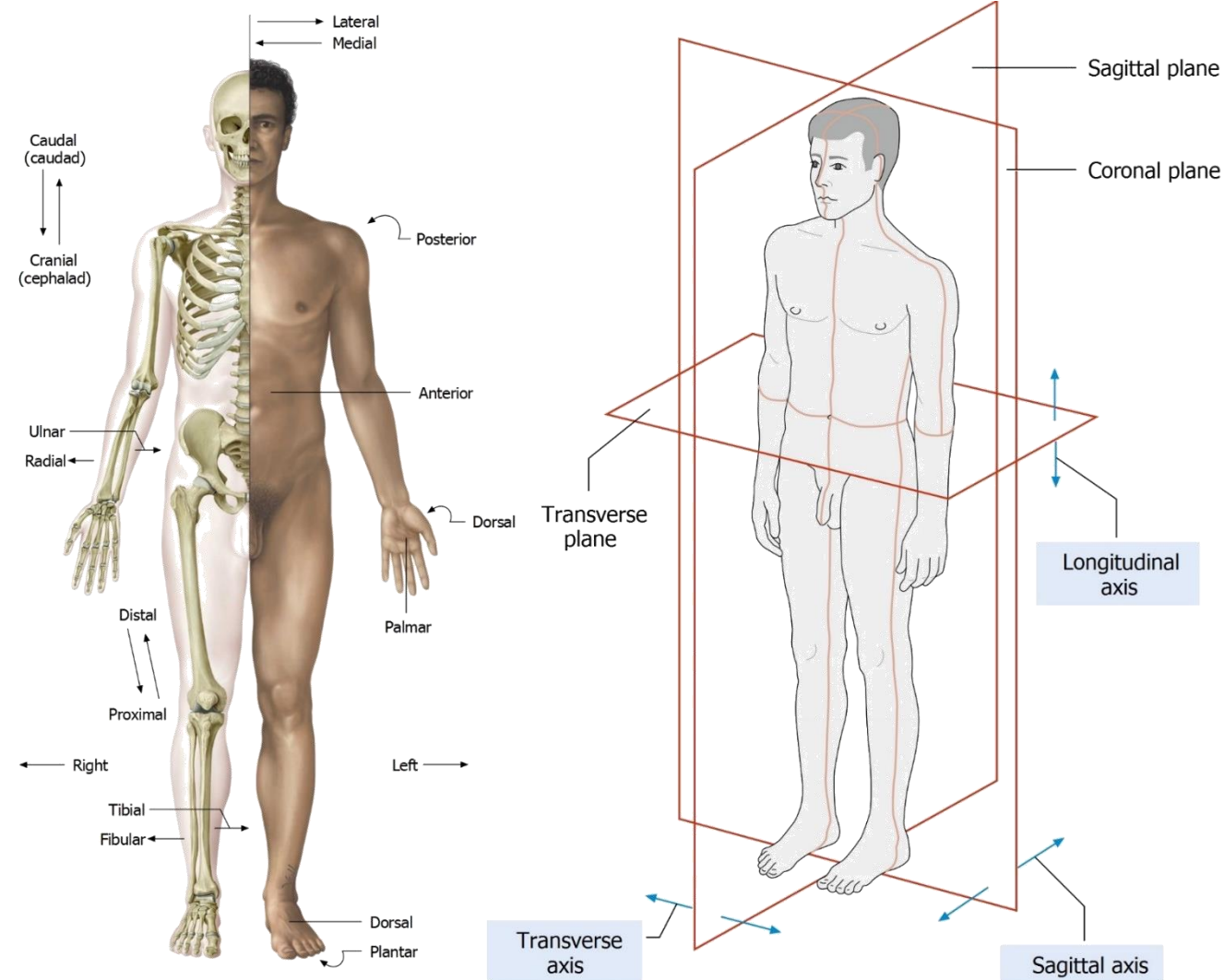
Anatomy in #s

206 ?

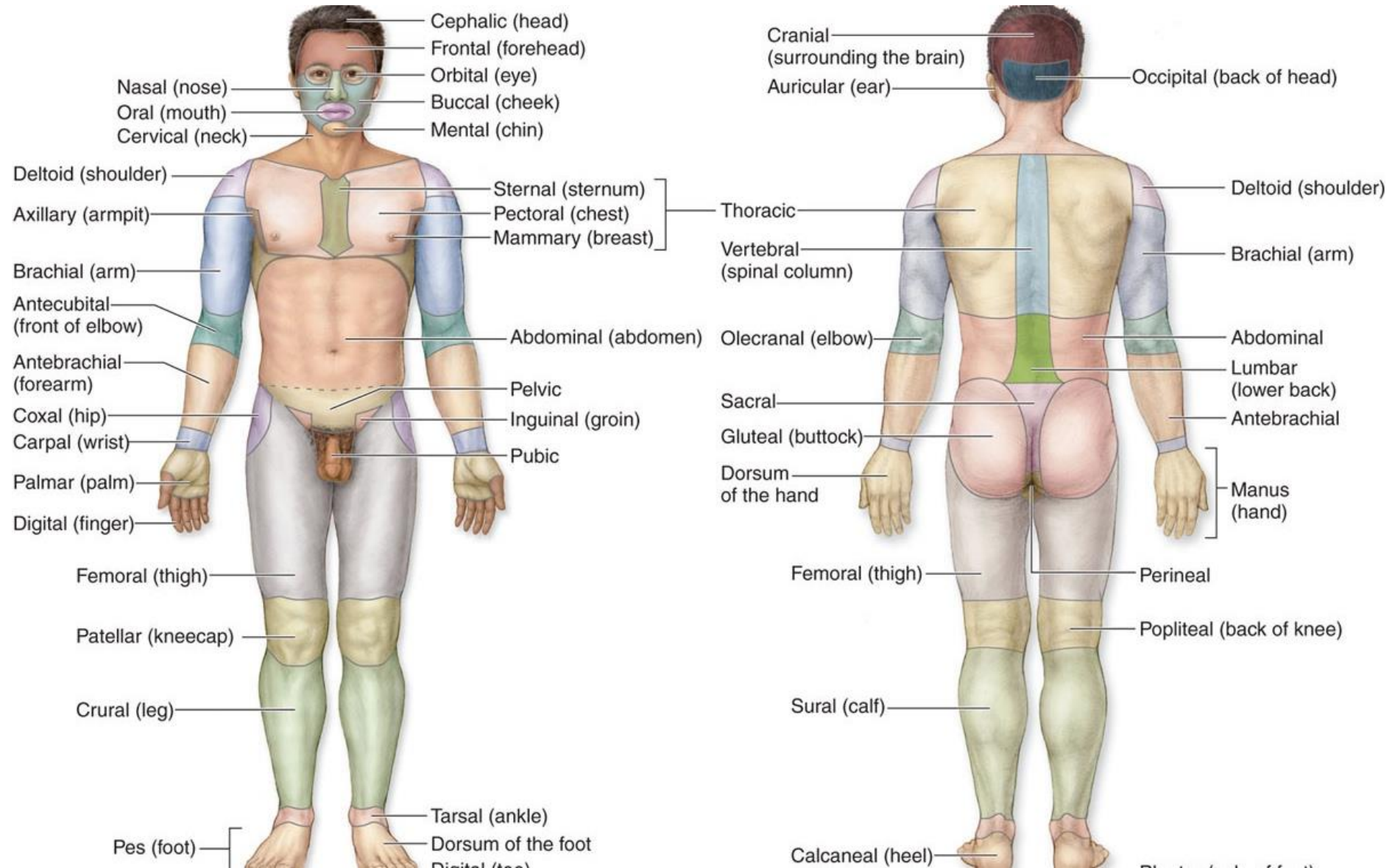


Introduction to Anatomy

- Anatomical position
 - Eyes & palms forward
- Anatomical planes
 - Transverse (axial)
 - Sagittal
 - Coronal
- Directional terms
 - Anterior/posterior
 - Superior/inferior
 - Medial/lateral
 - Proximal/distal
 - Palmar(plantar)/dorsal
 - Cranial/caudal

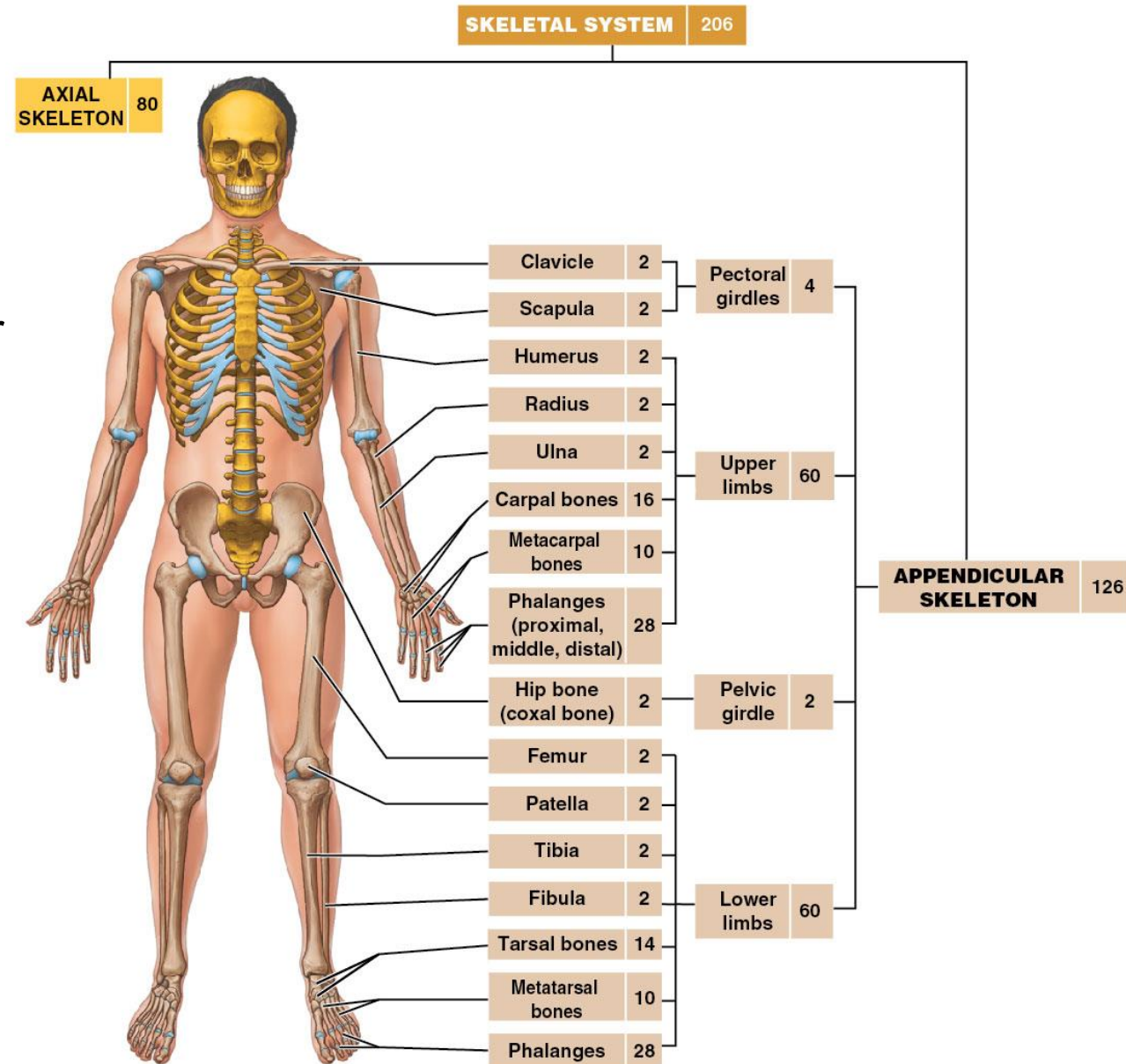


Language of Anatomy



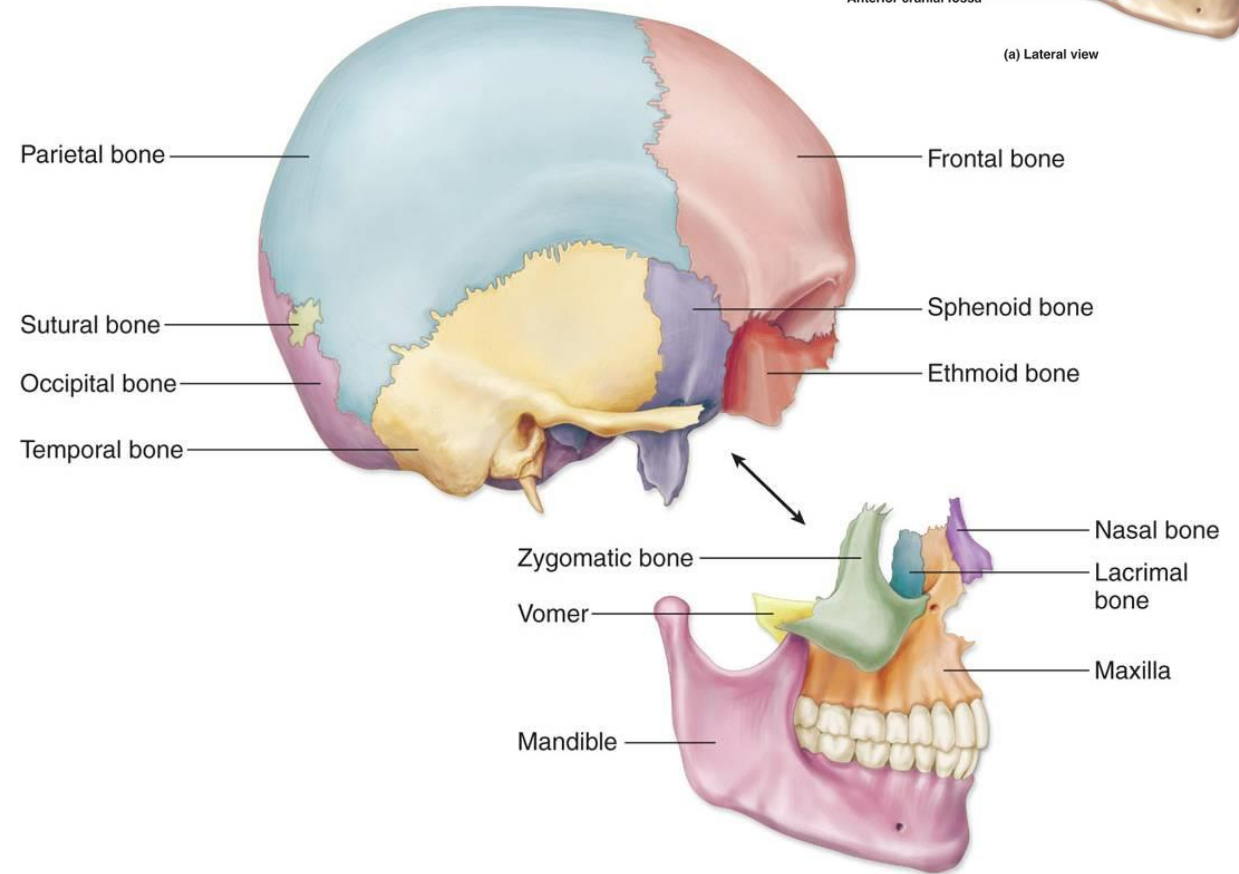
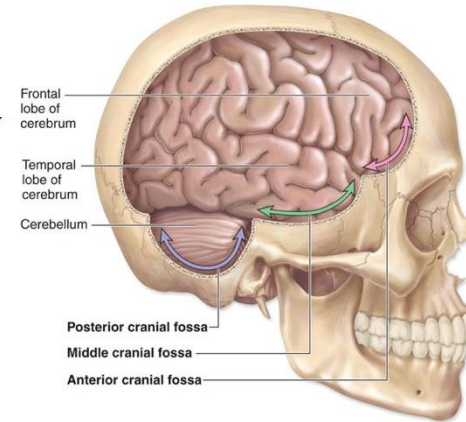
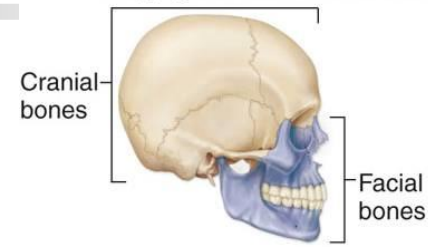
Adult Skeleton

- 206 bones in the adult body
- Axial Skeleton - 80
 - Skull – 22 (+ 7 associated ones)
 - Vertebral column – 26 (33 vertebrae)
 - Thoracic cage - 25
- Appendicular Skeleton - 126
 - Shoulder & Hip bones
 - Upper & Lower extremities



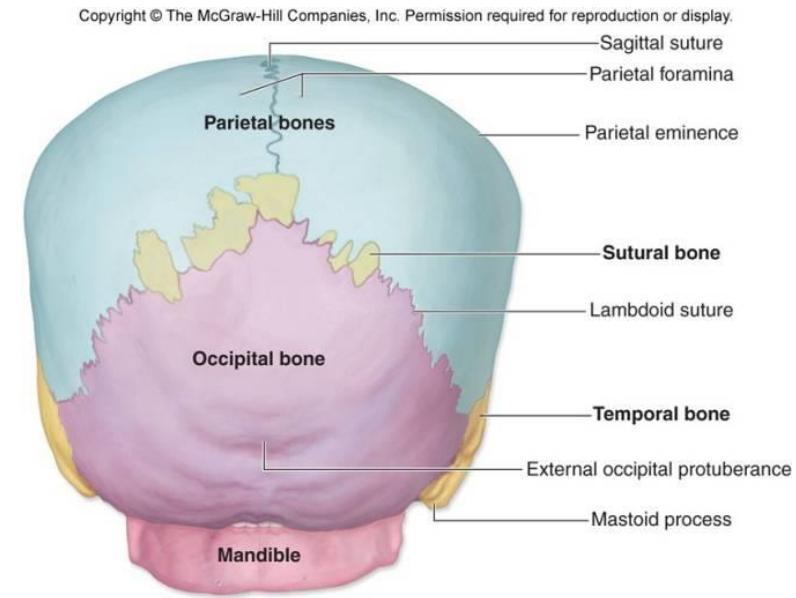
Head Anatomy

- 22 Bones
- Organized into 2 categories:
 - **Cranial bones** – those that make up the cranium (the bones that surround the brain) and have direct contact with the brain (8 bones)
 - **Facial bones** – those that do not make direct contact with the brain (14 bones)

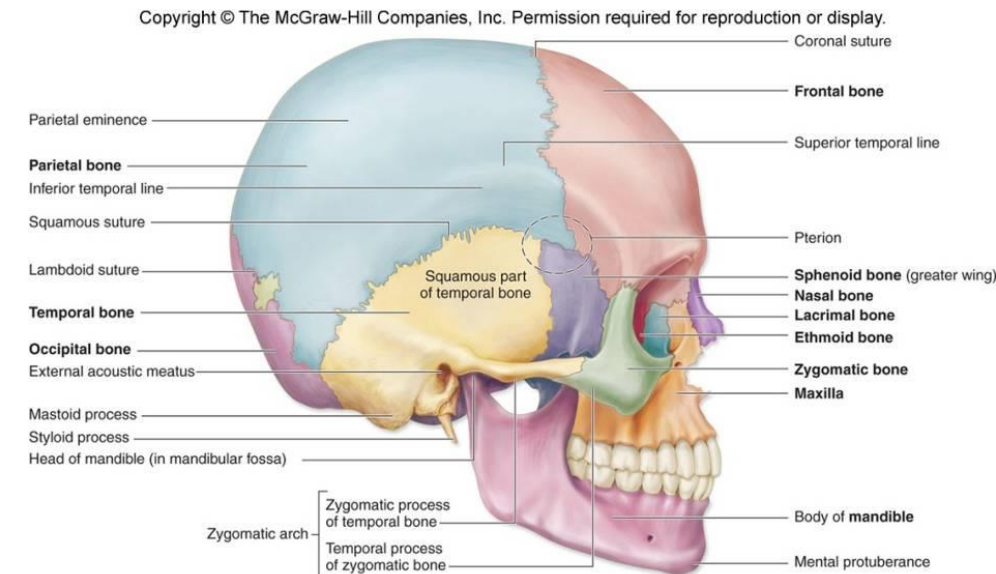


Head Anatomy - Sutures

- **Immovable FIBROUS** joints between skull bones
- 4 major sutures:
 - Coronal – between frontal and parietal bones
 - Lambdoid – between parietal and occipital bones
 - Sagittal – shared by the two parietal bones and runs along the mid-sagittal plane from the frontal bone to the occipital bone
 - Squamous – between the temporal and parietal bones



(b) Posterior View



Pediatric Head Summary

- Occipital bone
 - 5-7 YO: fusion of pars basilaris & partes laterals
 - 11-18 YO: fusion of spheno-occipital synchondrosis
 - 22-34 YO: closure of jugular growth plate
- Parietal bone
 - Fully ossified by age 6
- Frontal bone
 - Primarily formed by age 4, but grows in size through 16 YO
- Sutures?

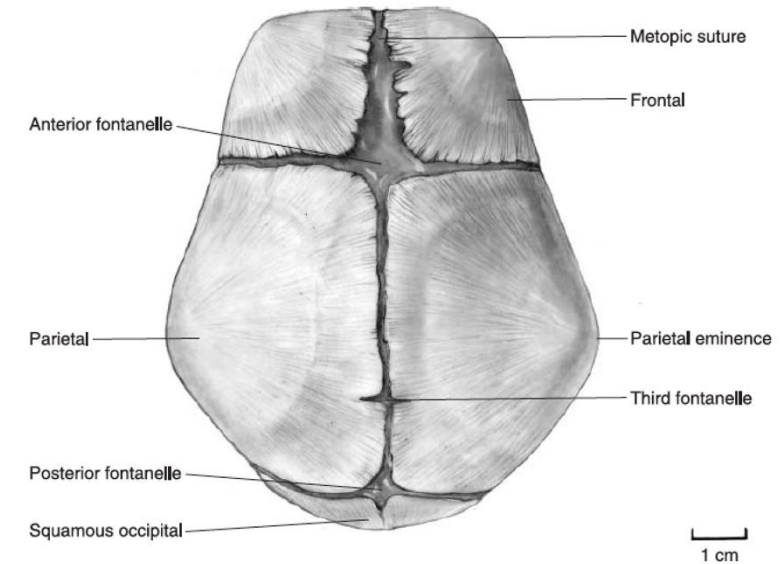


Figure 4.14 Superior view of fetal skull.

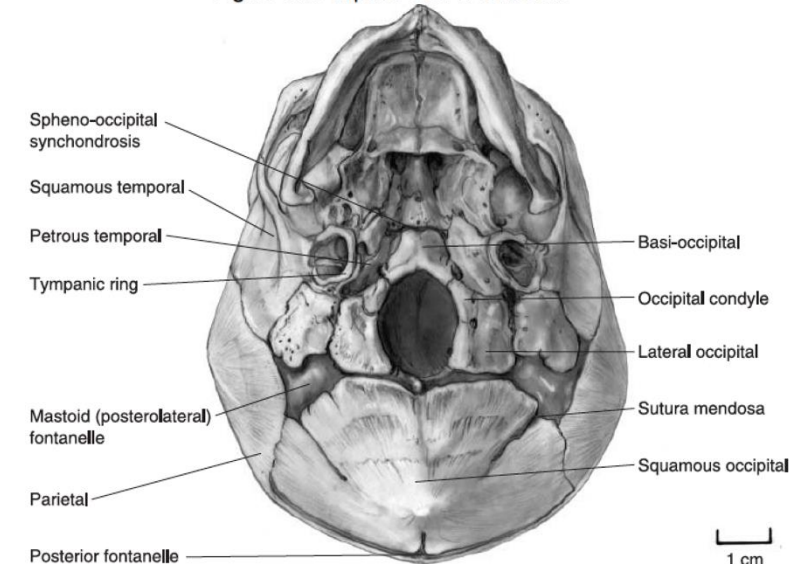
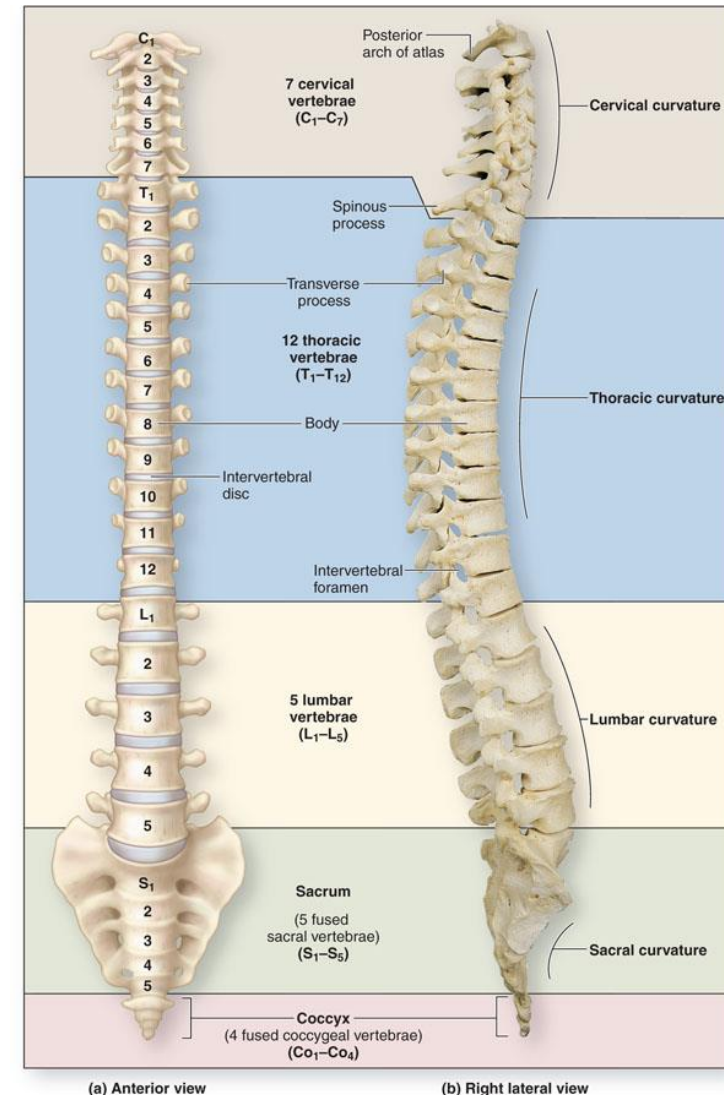


Figure 4.13 Basal view of fetal skull and mandible.



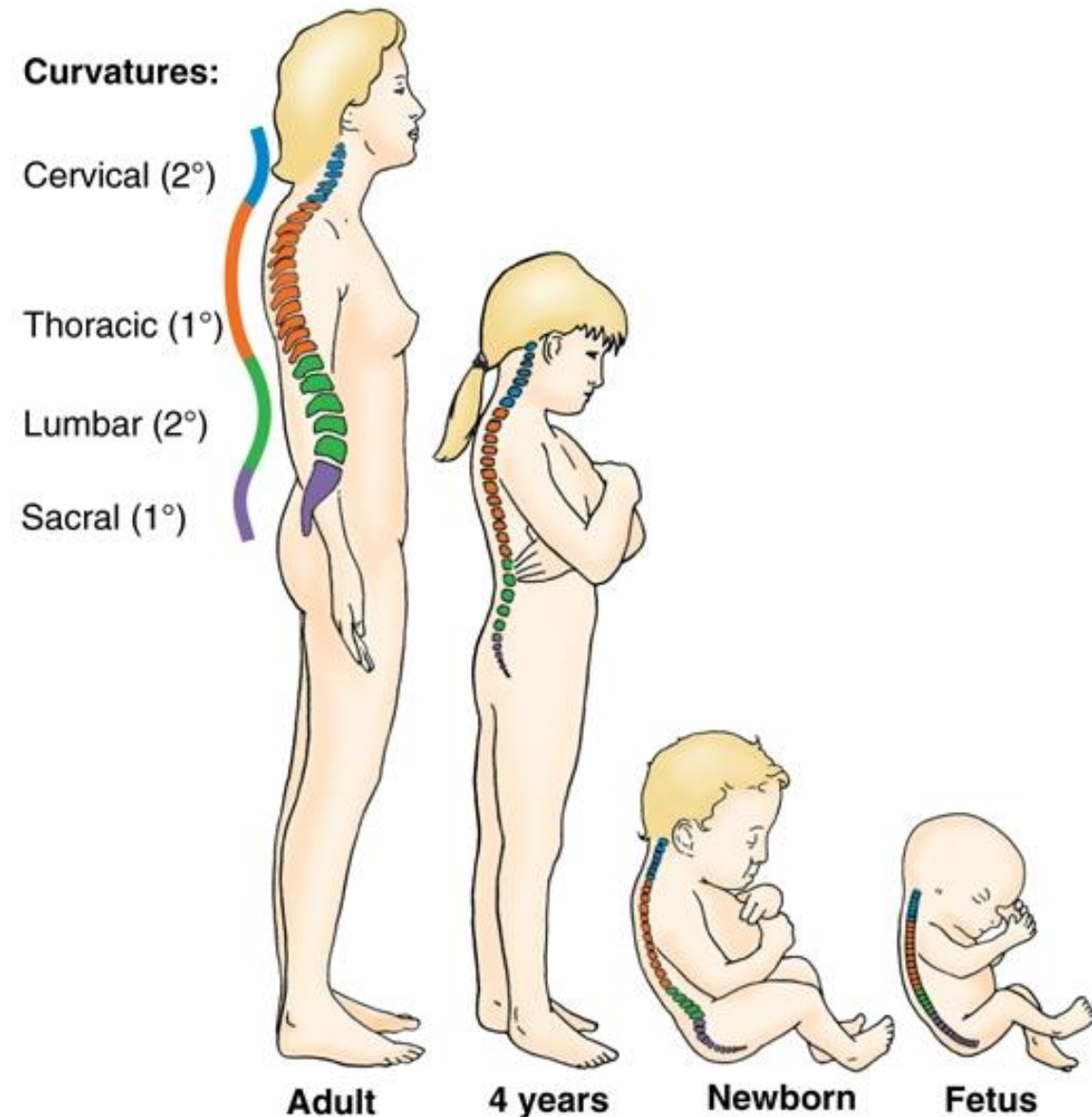
Vertebral Column

- Comprised of 33 vertebrae organized into 5 categories
 - (26 TOTAL)
- Cervical (7)
 - C1–C7
- Thoracic (12)
 - T1–T12
- Lumbar (5)
 - L1–L5
- Sacral (5)
 - Fused
- Coccygeal (4)
 - Fused



Vertebral Column

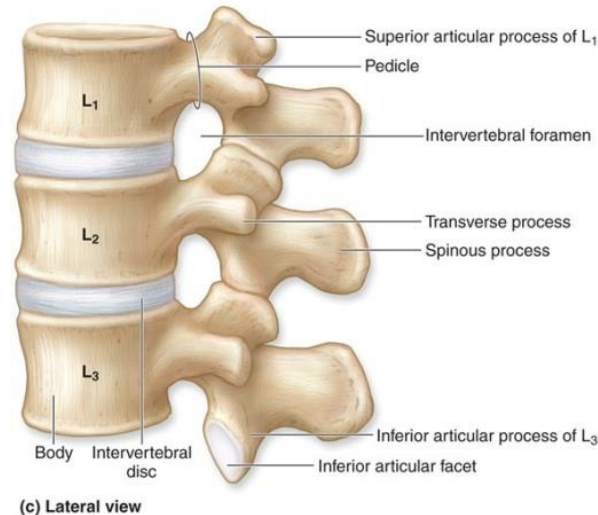
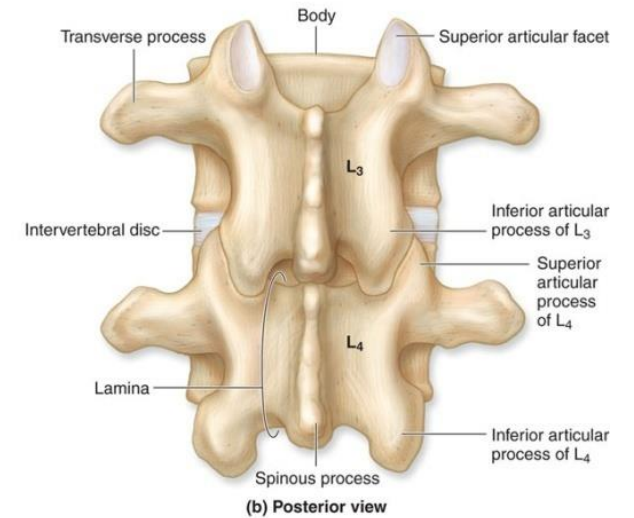
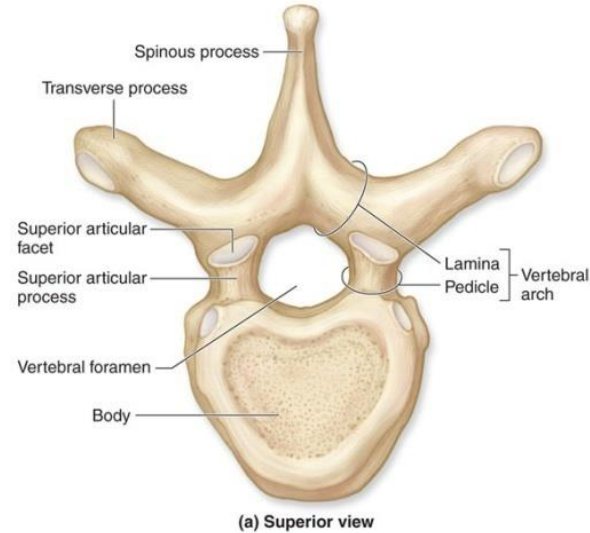
- Spinal Curvatures
 - Primary
 - Concave anteriorly
 - Thoracic
 - Sacrococcygeal
 - Secondary
 - Concave posteriorly
 - Cervical
 - hold head upright
 - Lumbar
 - Body erect



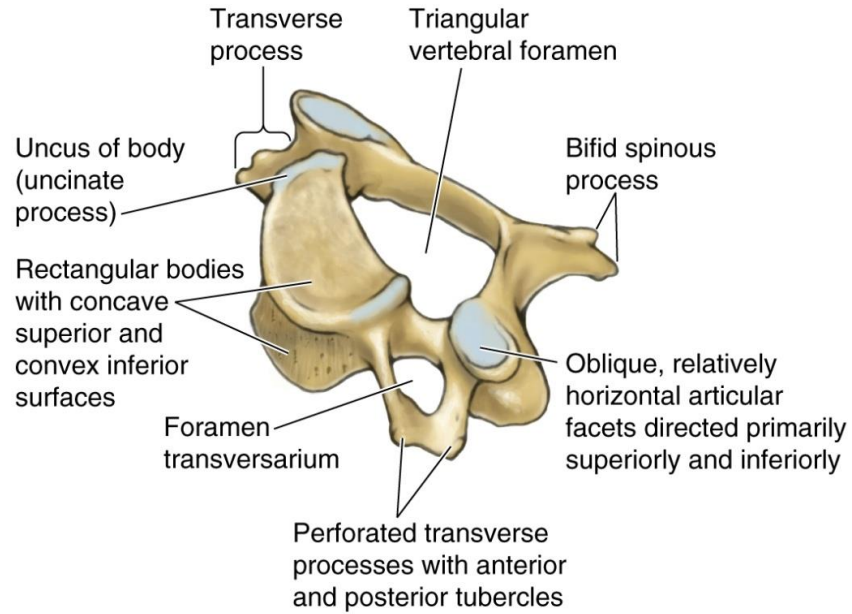
Vertebral Column

- Vertebrae = body + vertebral (neural) arch
- Vertebral arch
 - Pedicles (2)
 - Lamina (2)
 - Spinous Process
 - Transverse Process (2)
 - Articular Process
 - Superior (2)
 - Inferior (2)

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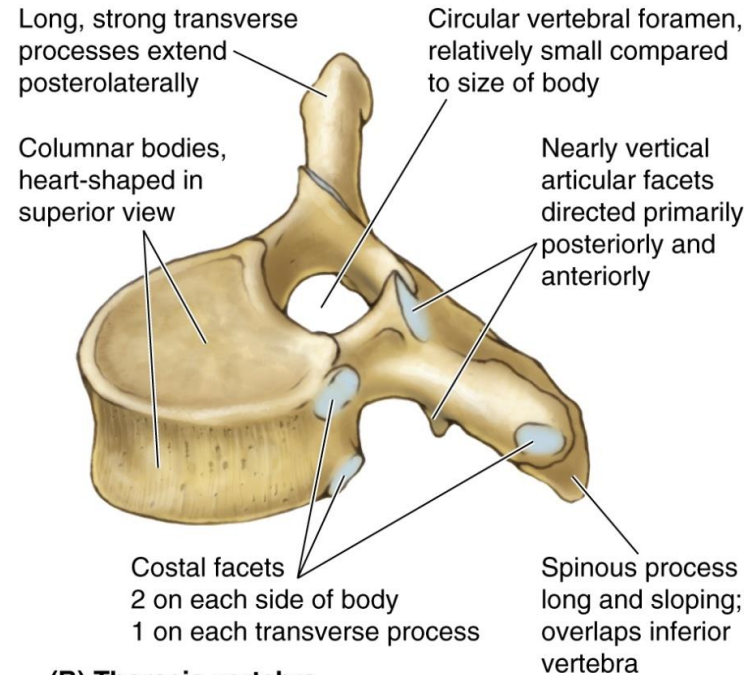


Vertebral Column

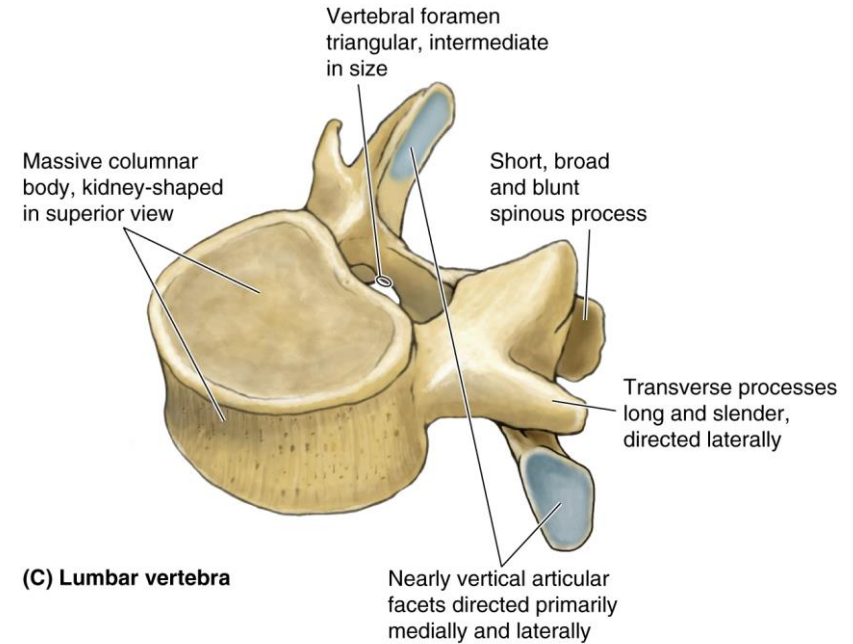


(A) Cervical vertebra

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(B) Thoracic vertebra



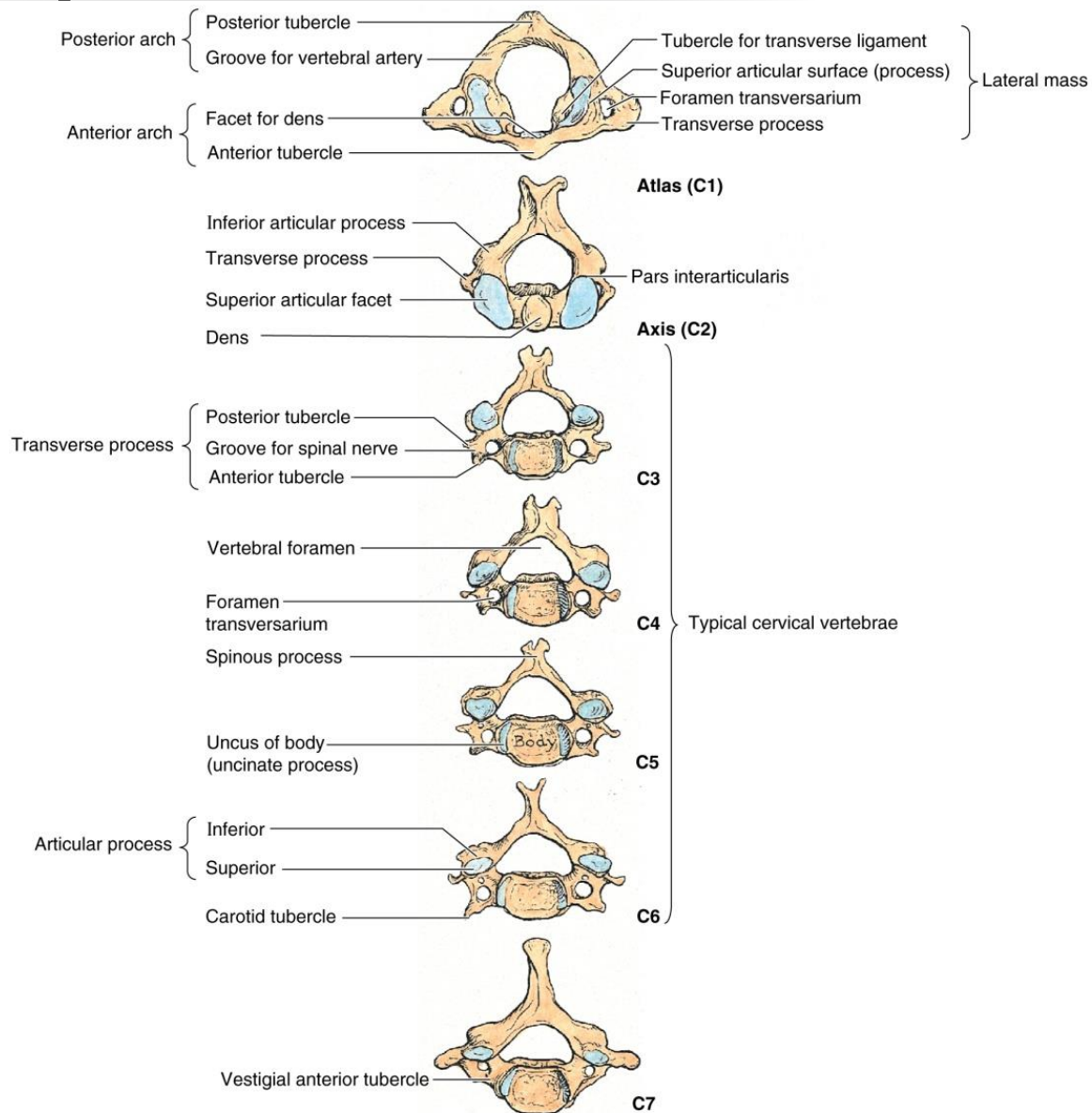
(C) Lumbar vertebra

Left anterior superior oblique views of "typical" presacral vertebrae

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Cervical Spine



(A) Superior views, vertebrae C1–C7



Cervical Spine

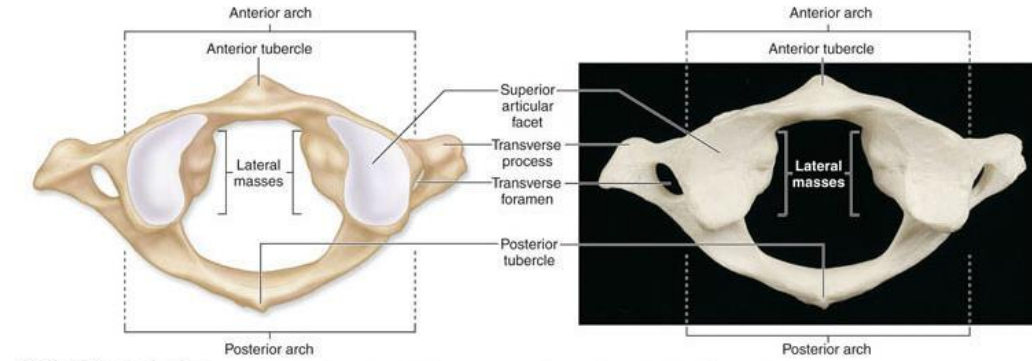
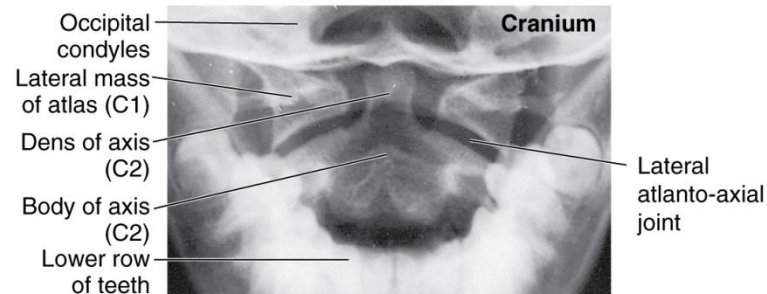
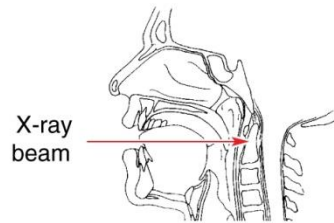
■ Atypical Vertebrae

■ C1 – Atlas

- Articulates w/condyles of the occipital bone
- Deep superior articular facets
- No Body

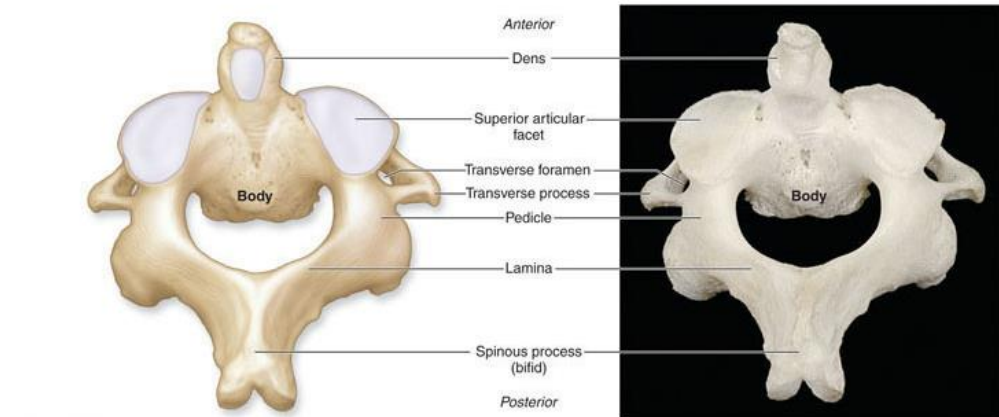
■ C2 – Axis

- Odontoid Process or Dens
- Axis of rotation between atlas and skull



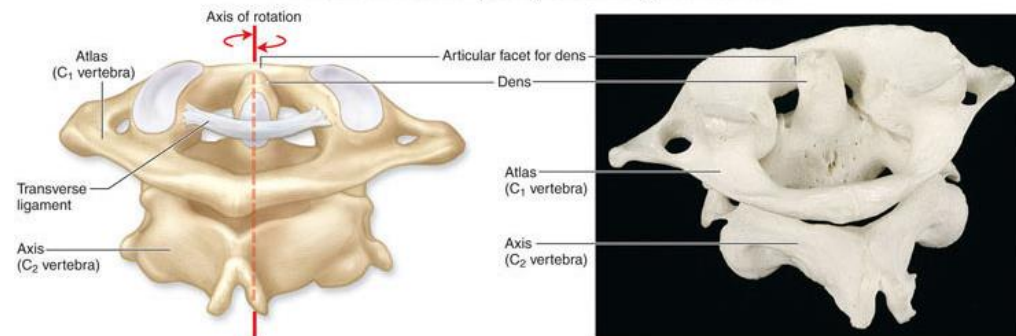
(a) Atlas (C₁), superior view

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(b) Axis (C₂), posterosuperior view

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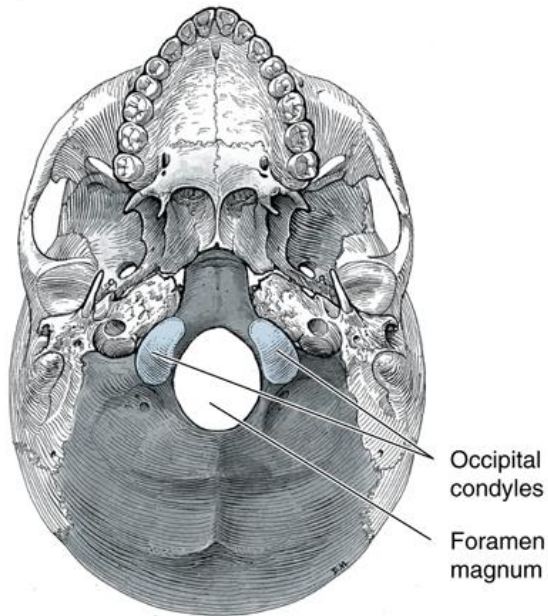
(c) Atlas and axis, posterosuperior view

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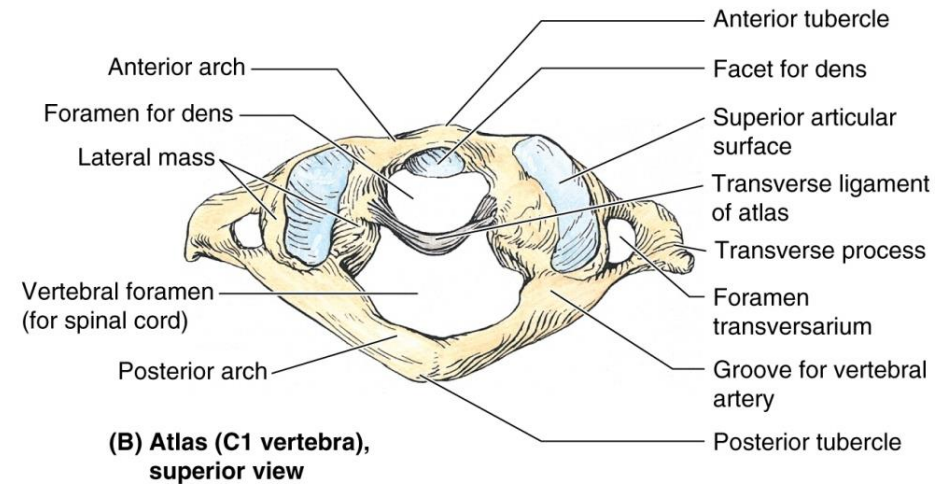


Craniovertebral Joints

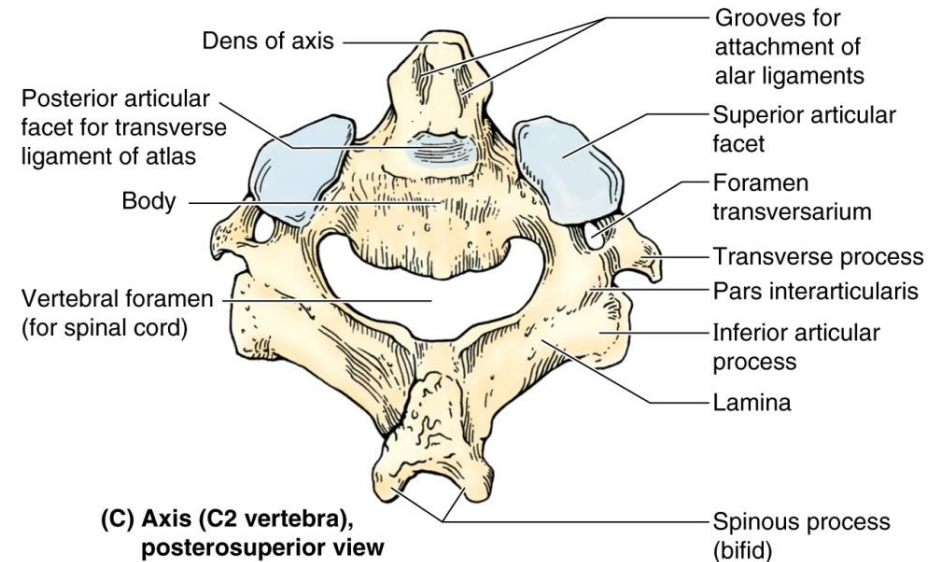
- Atlanto-occipital joints
 - Atlas to occipital
- Atlanto-axial joints
 - Atlas to axis
- No IV discs!



(A) Cranial base, external surface (inferior view)



(B) Atlas (C1 vertebra), superior view

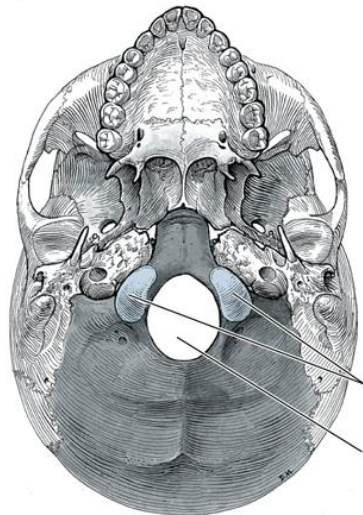
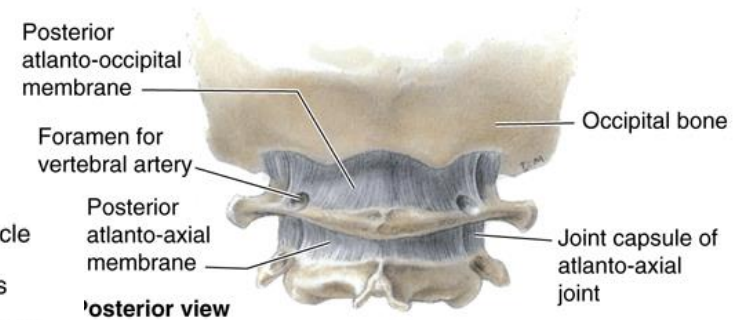
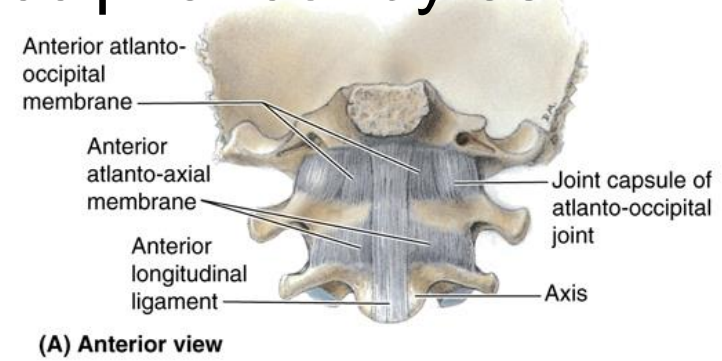


(C) Axis (C2 vertebra), posterosuperior view

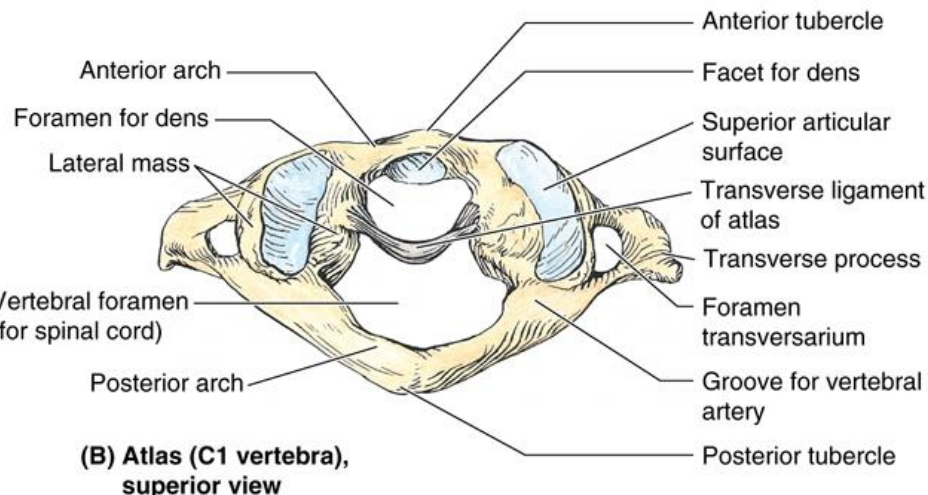


Atlanto-Occipital Joint

- Superior articular surfaces of C1 to occipital condyles
- “yes” movement
- Atlanto-occipital membrane
 - Anterior (ALL)/posterior (weaker)
 - Arches of C1 to foramen magnum
 - Help prevent excessive movement

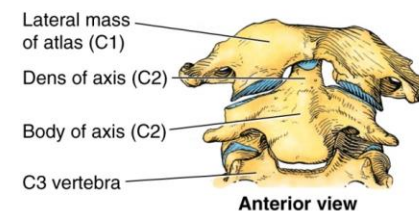
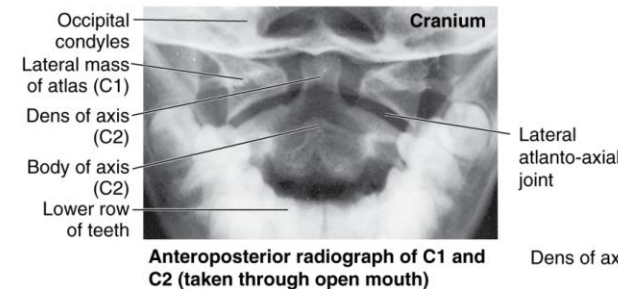
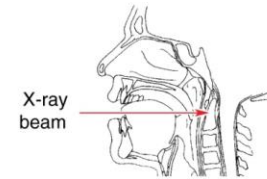
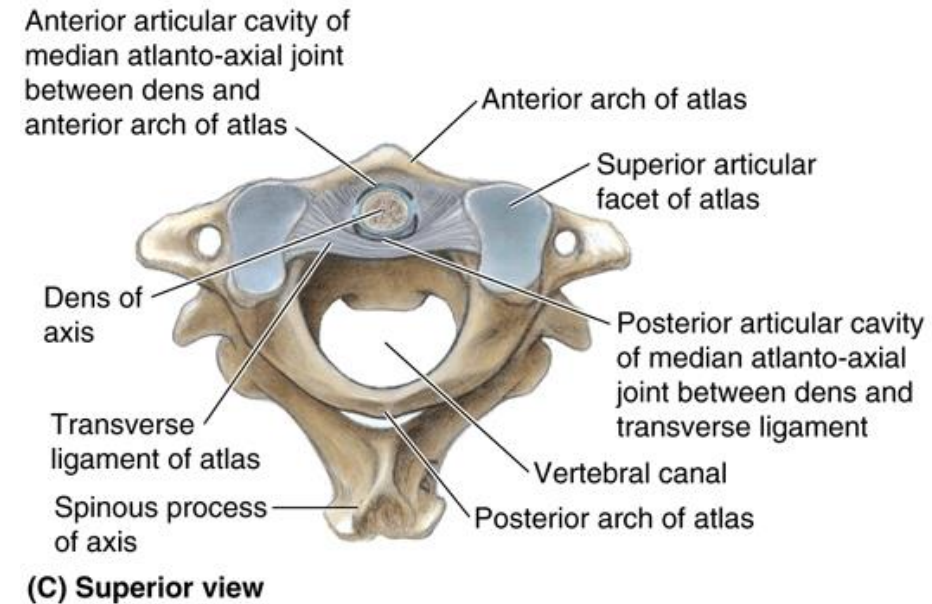


(A) Cranial base, external surface (inferior view)

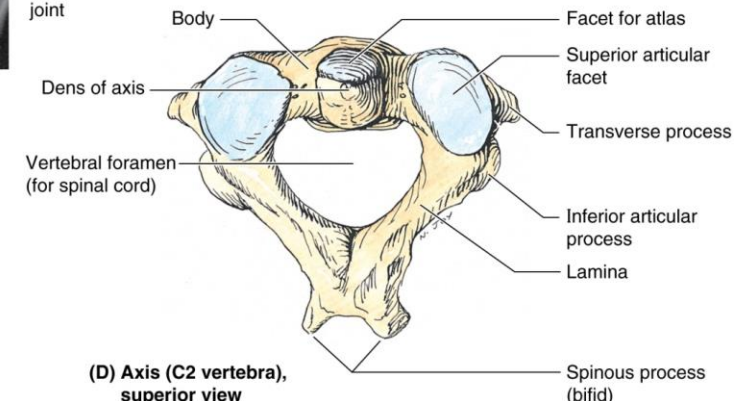


Atlanto-Axial Joints

- Atlanto-axial joints
 - 2 lateral
 - Inferior articular facets of C1 and superior of C2
 - Gliding
 - 1 median
 - Dens of C2 and anterior arch of C1
 - Pivoting
 - “no” movement
 - Cranium and C1 rotate on C2
- Transverse ligament of the atlas
 - Holds dens against C1
 - Strong



(E) Articulating atlas and axis (C1 and C2 vertebra) as viewed radiographically



Vertebral Column

- Atypical Vertebrae

- Sacrum

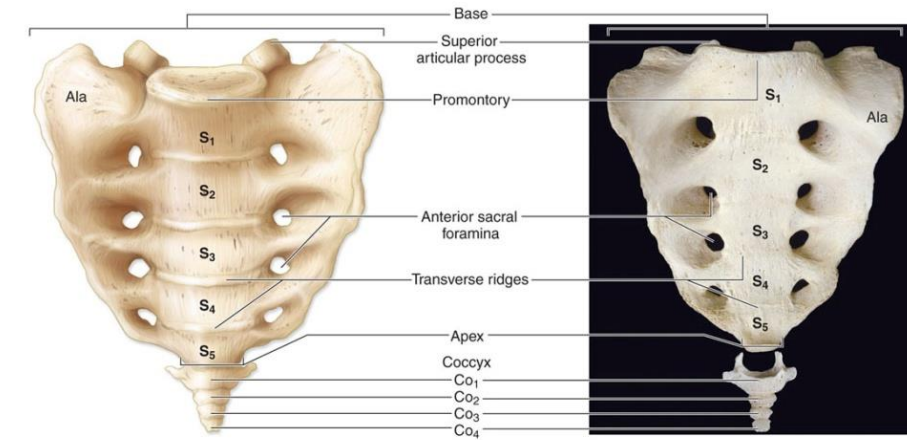
- 5 vertebrae that fuse in the third decade of life

- Coccyx

- 4 vertebrae that fuse in the third decade of life

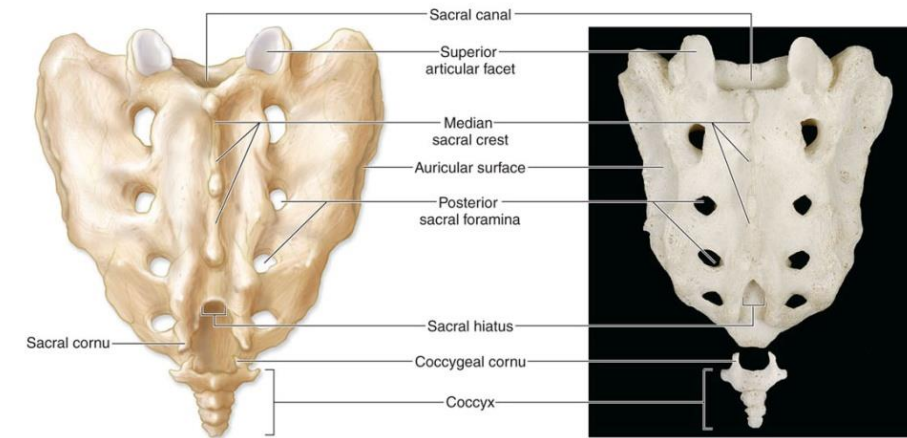


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(a) Sacrum and coccyx, anterior view

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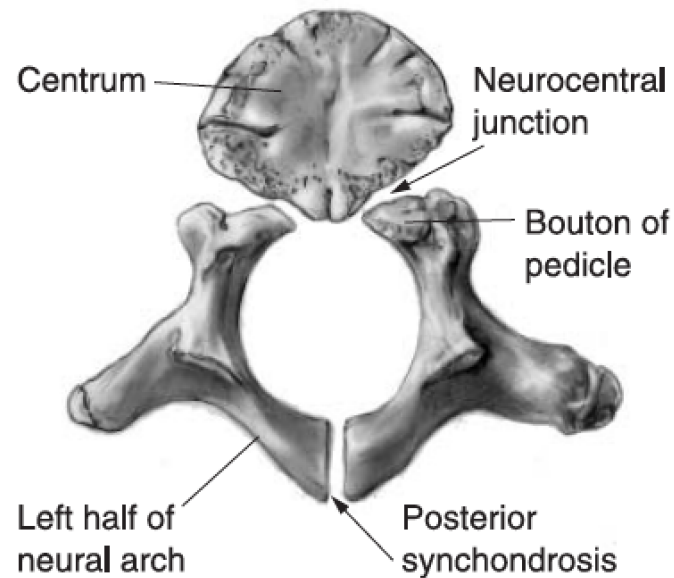
(b) Sacrum and coccyx, posterior view

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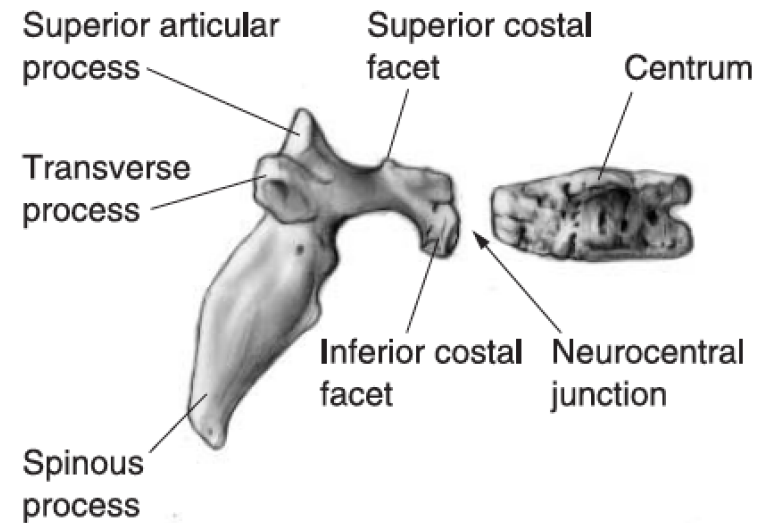


Neurocentral Fusion

- 1st in Lumbar Spine
- 2nd in Cervical Spine
- 3rd in Thoracic Spine
- Puberty – Complete Fusion



(a) SUPERIOR



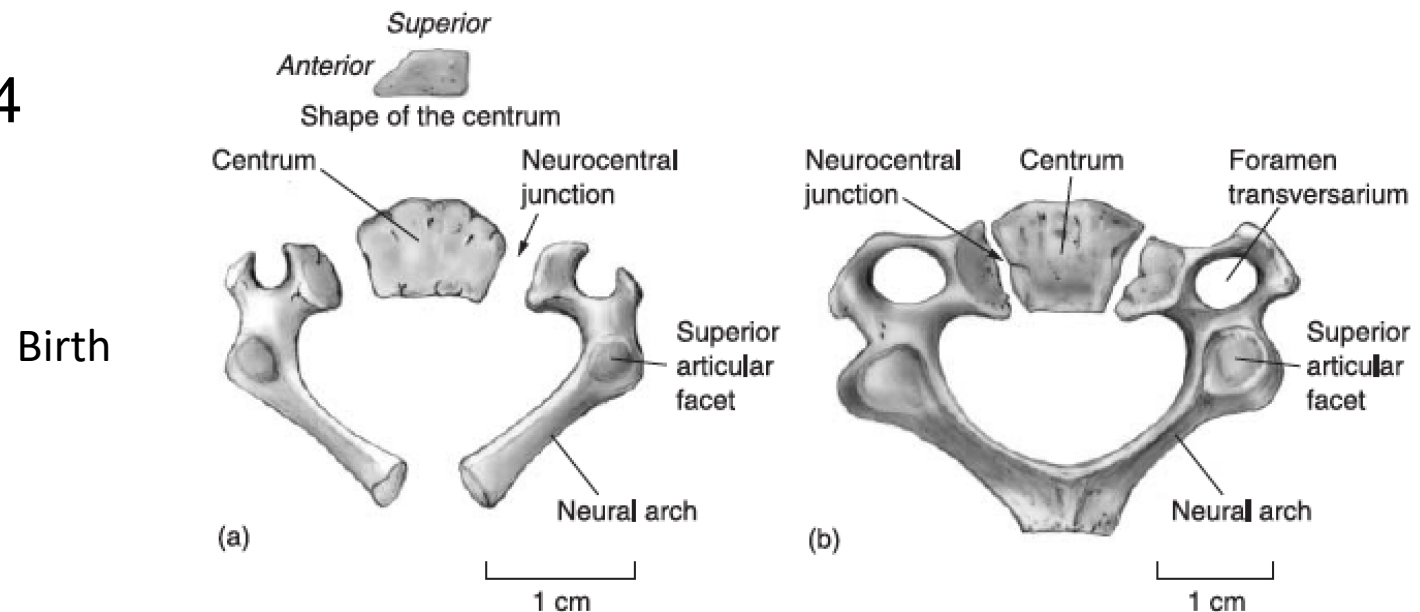
(b) LATERAL

1 cm



Typical Cervical - Development

- 3 primary centers of ossification
- Body
 - Inferior surface area > superior surface area
- Transverse foramen -
- Times of fusion (in years)
 - Posterior: 2
 - Transverse: 3-4
 - Anterior: 3-4

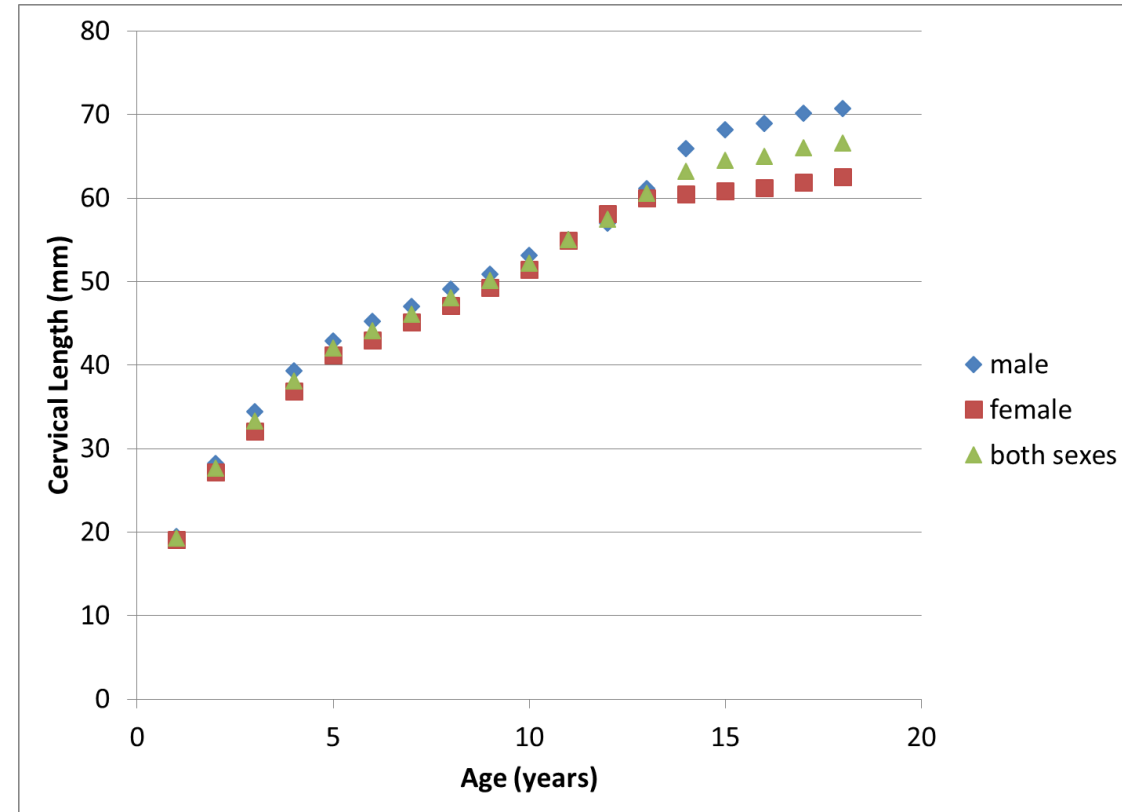


Male – 3 years



Cervical Development

- Vertebral bodies from C3-C7 are not fully developed until age 6
 - Vertebral bodies anteriorly wedged
 - Little restriction of flexion-rotation forces



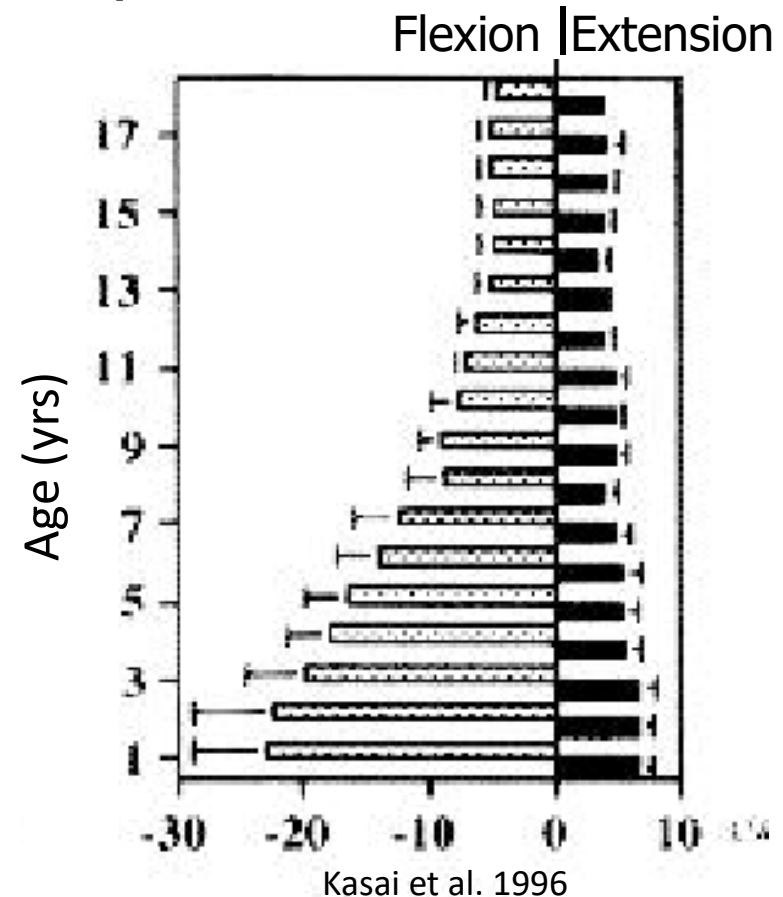
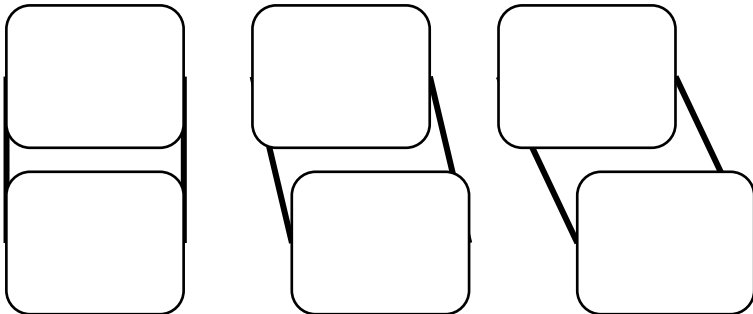
Data adapted from Kasai et al (1986)



Cervical Development

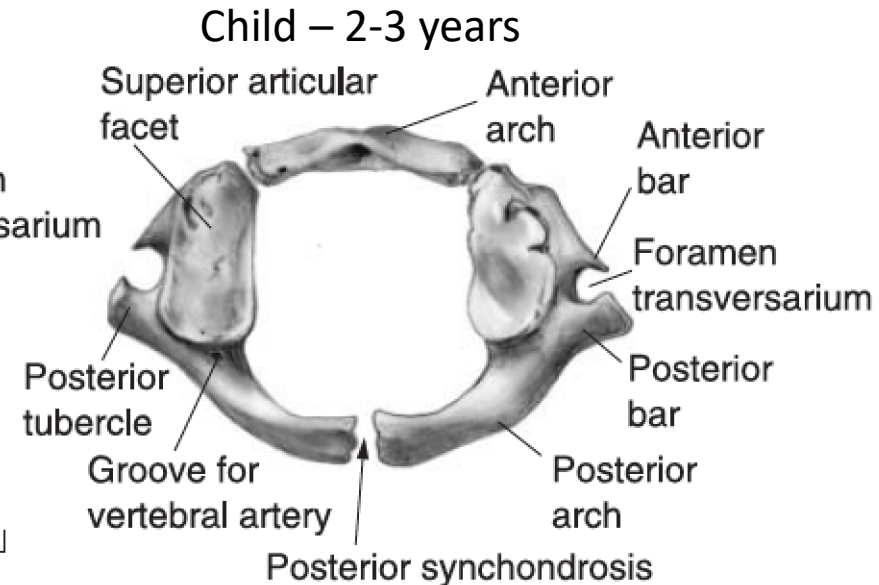
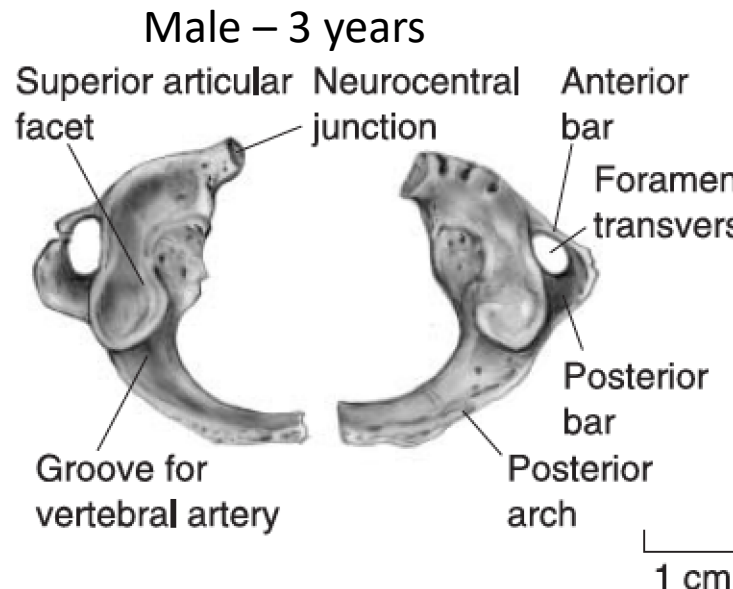
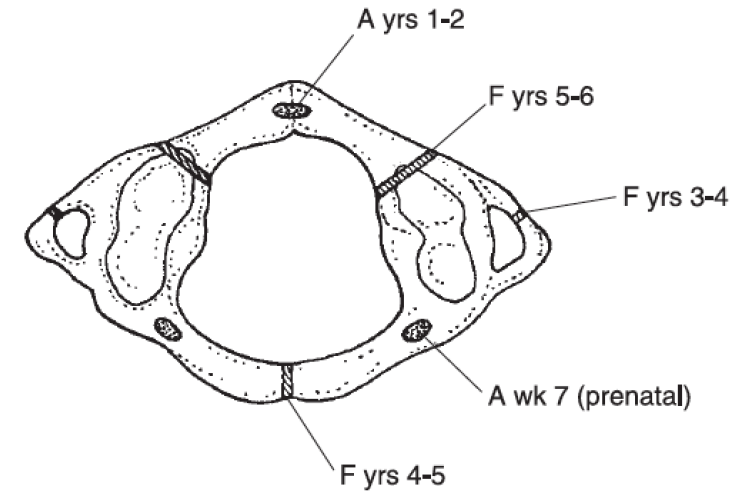
- Differences in anatomy culminate in increased sliding of cervical vertebrae
- Forward sliding relevant for frontal impacts

Vertebral Sliding



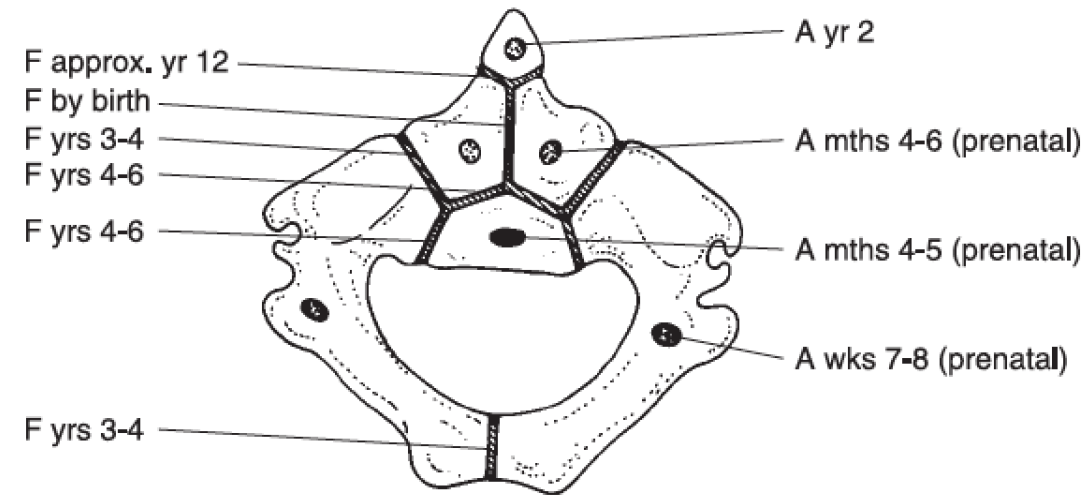
Atlas - Development

- Times of fusion (in years)
 - Transverse: 3-4
 - Posterior: 4-5
 - Anterior: 5-6

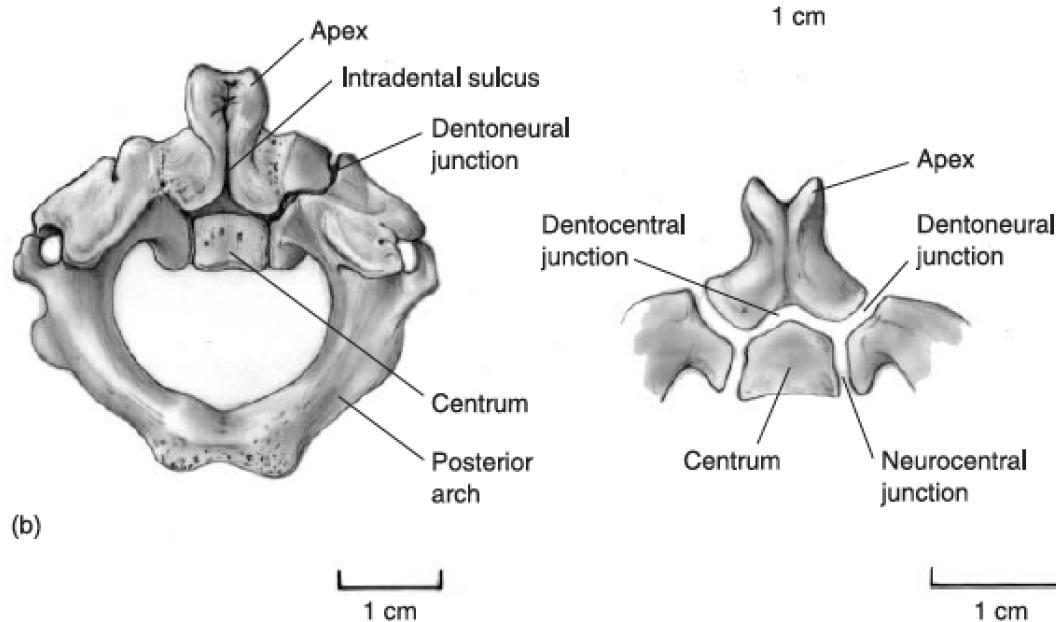


Axis - Development

- Times of fusion (years)
 - Transverse: 3-4
 - Dens to neural arches : 3-4 years



Male – 3 years

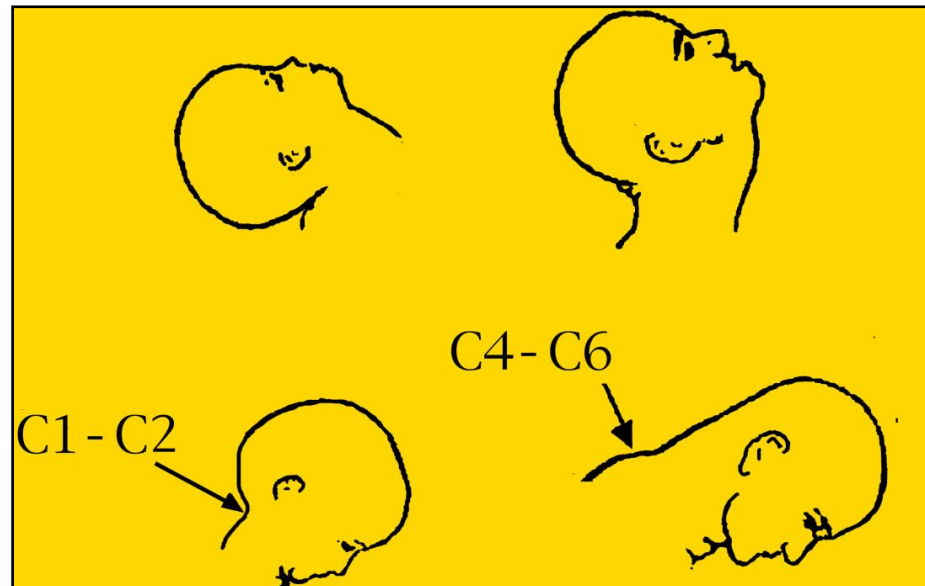


(b)



Development & Biomechanics

- Changing anatomy through age ~9 predispose children to spinal cord and ligamentous injury @ more rostral levels
 - Head is proportionally larger than the body
 - Results in higher torque
 - Fulcrum of flexion and extension is shifted to the ~C2 level from the lower cervical spine in adults
 - Stabilizing ligaments in children have more laxity



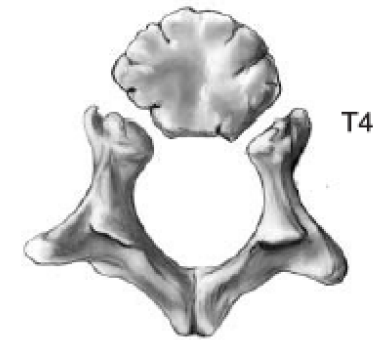
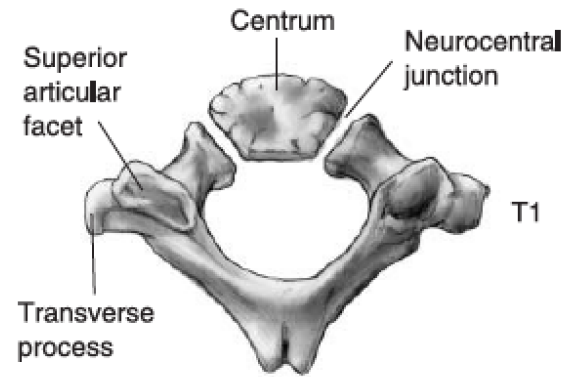
Craniovertebral Injury

- MVCs most common cause of spinal cord & spinal column injuries in children
 - 20-72% of all cases of spinal injury
 - Upper cervical spine have very high mortality rates (50-80%)
- Recent study by Brown et al documented 103 pediatric trauma cases
 - 68% sustained injuries to c1-c4
 - 20% dislocations at c1 all from MVC

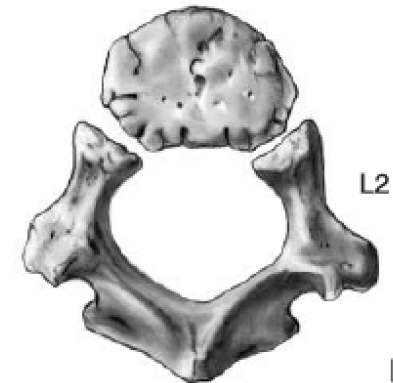
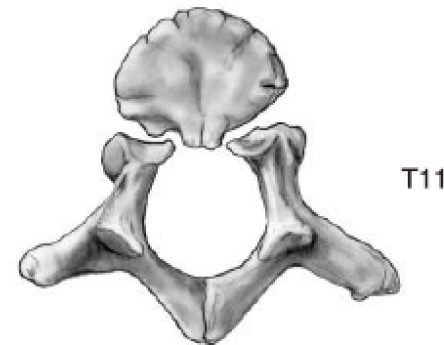


Thoracic & Lumbar - Development

- Similar to typical cervical vertebrae
- Times of fusion (in years)
 - Posterior: 2
 - Anterior: 3-4
- Puberty
 - Fusion completed



Child – 2-3 years

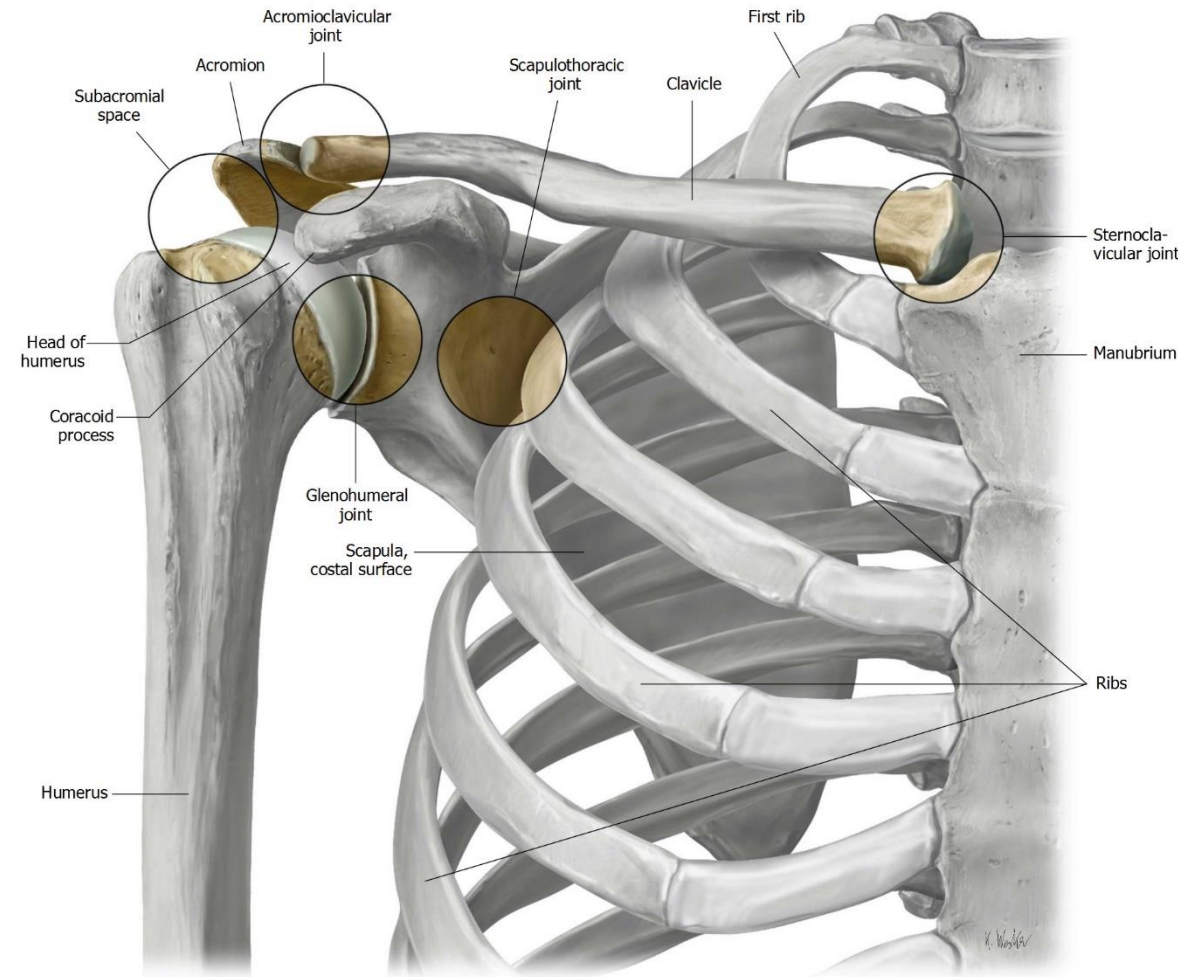


1 cm



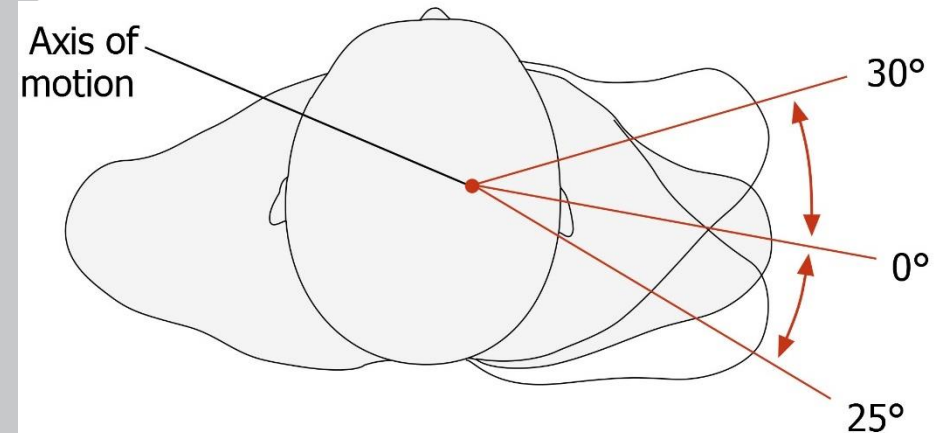
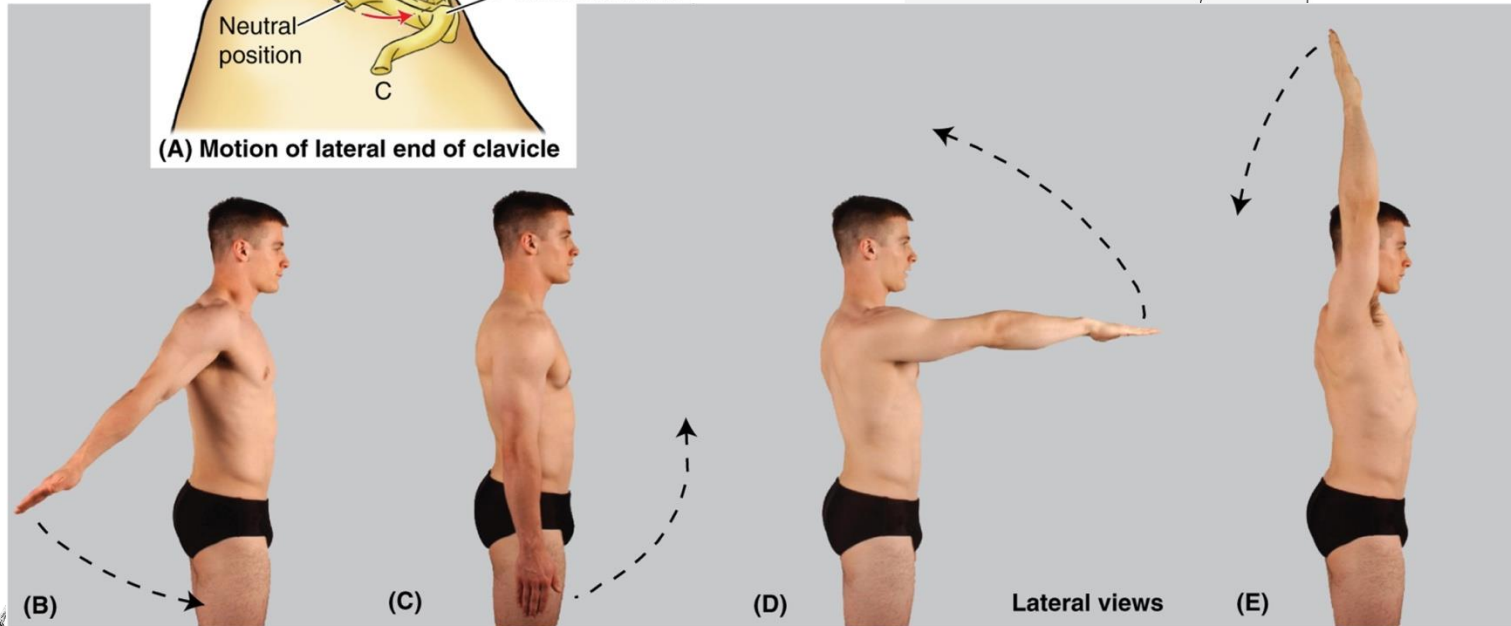
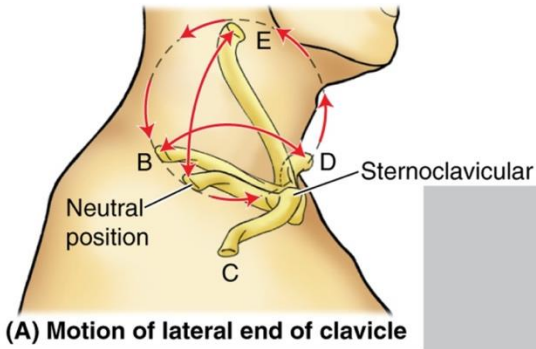
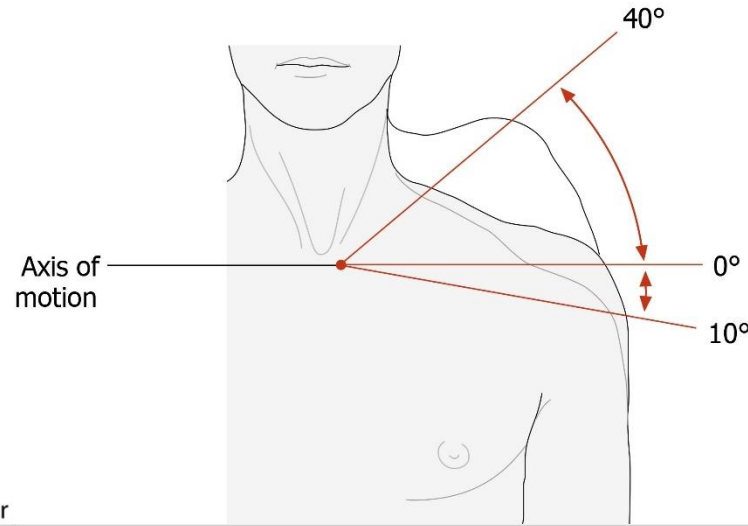
Joints of the Pectoral Girdle

- Sternoclavicular joint
 - Articulation between the sternum and clavicle
- Acromioclavicular joint
 - Articulation between the acromion process of scapula and lateral end of clavicle
- Glenohumeral joint
 - Articulation between the head of the humerus and the glenoid fossa of the scapula
- Scapulothoracic joint
 - Physiologic joint between the scapula and the thorax



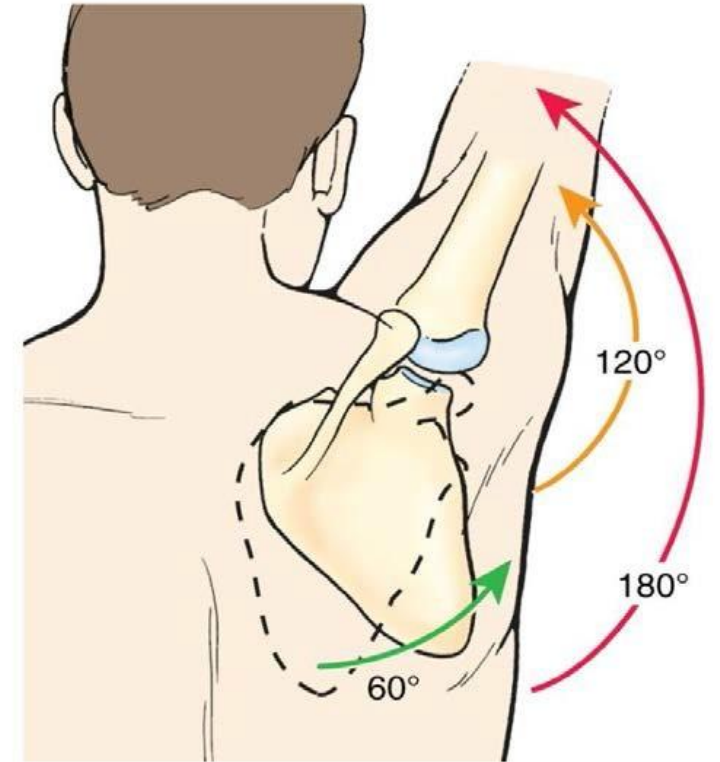
Movements of the Sternoclavicular Joint

- Elevation / Depression
 - 30 – 50 Deg (ROM)
- Protraction (ant) / Retraction (post)
 - 30 – 55 Deg
- Rotation
 - 40 – 50 Deg



Scapulo-Humeral Rhythm

- Scapulo-humeral rhythm
 - 2:1 Ratio of movement between the humerus and scapula during abduction
 - 2 degrees at glenohumeral joint
 - 1 degree at scapulothoracic articulation
 - This relationship is critical for normal function



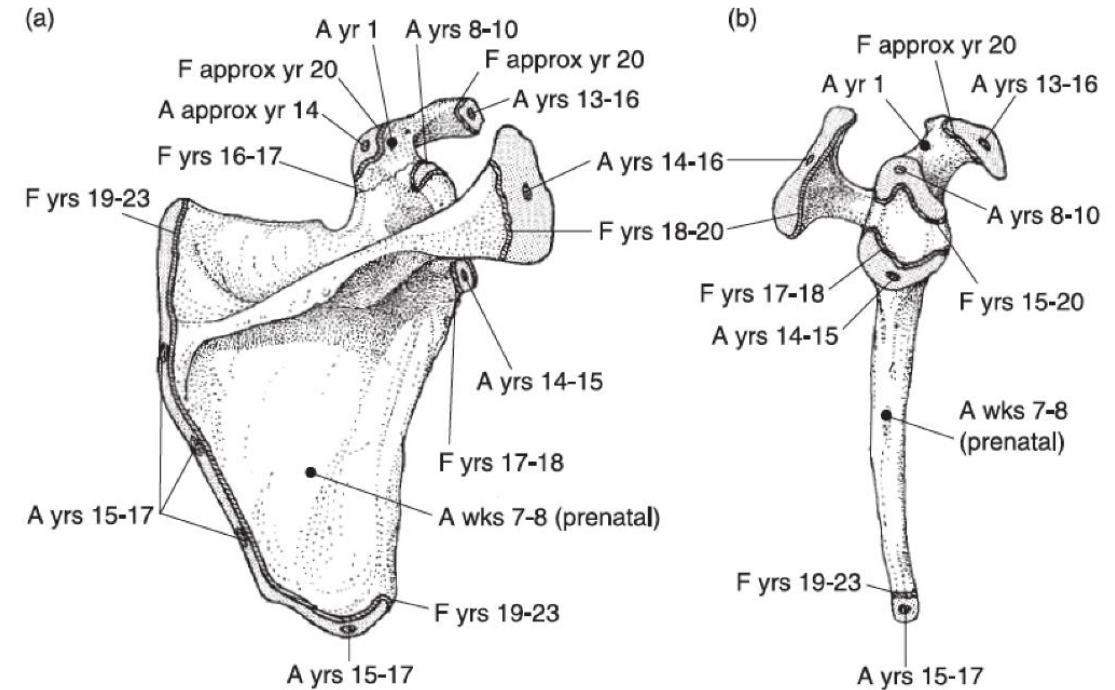
(C) Scapulo-humeral rhythm. The scapula and humerus move in 1:2 ratio. When the arm is abducted 180 degrees, 60 degrees occurs by rotation of the scapula, and 120 degrees by rotation of the humerus at the shoulder joint.



Scapula - Development

■ Scapula Morphological Summary

- Coracoid not visible until 3 YO
- 13-16 YO: coracoid and body of scapula begin to fuse
- Full fusion not complete until ~ 23 YO

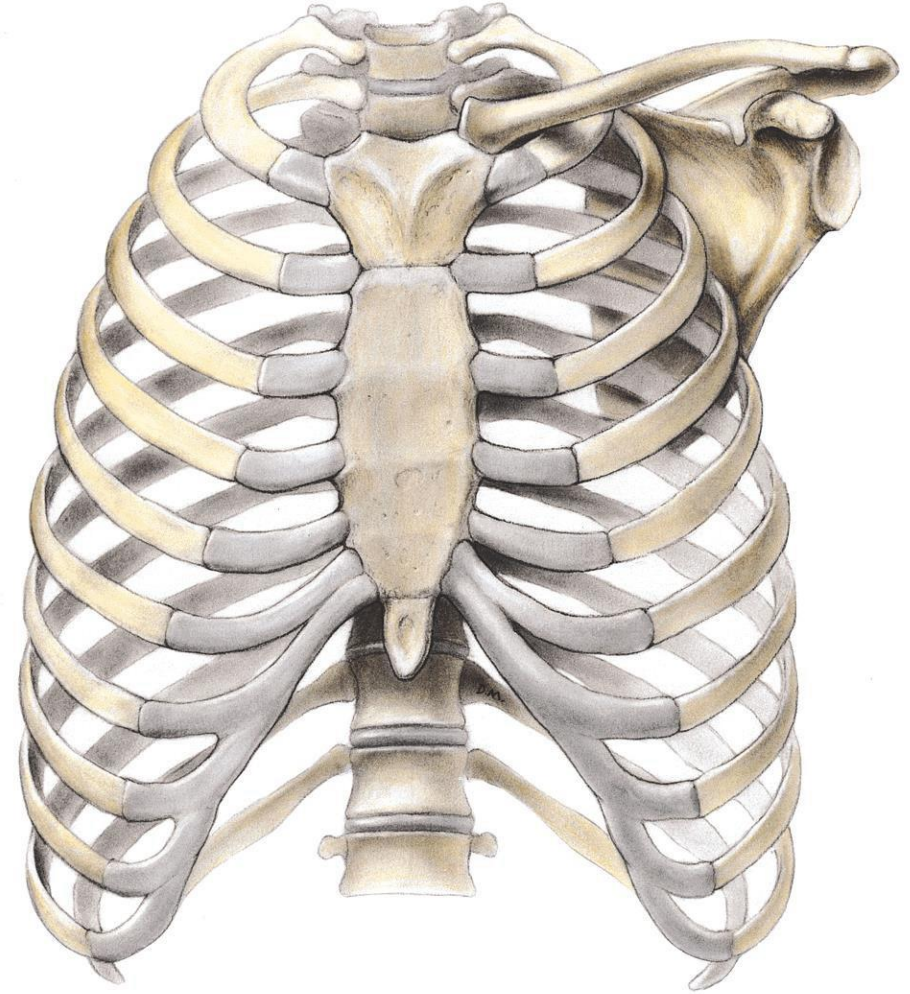


- What is the critical motion of the shoulder to ensure realistic belt fit when testing ATDs?



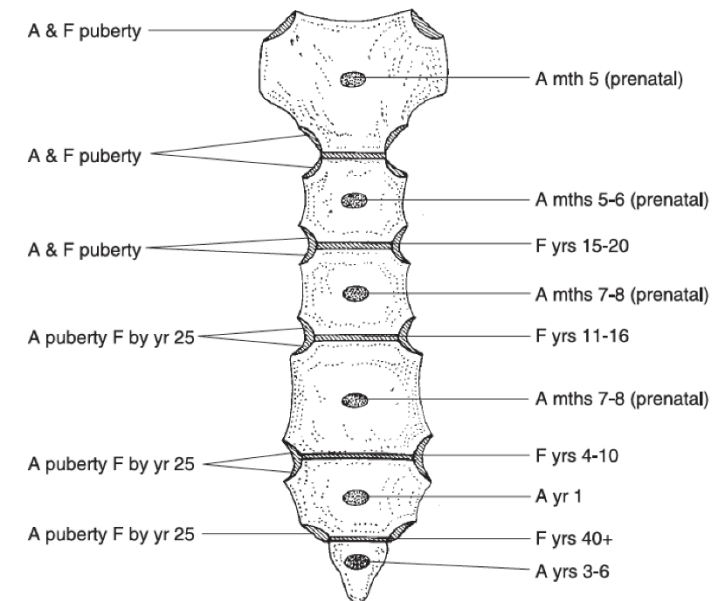
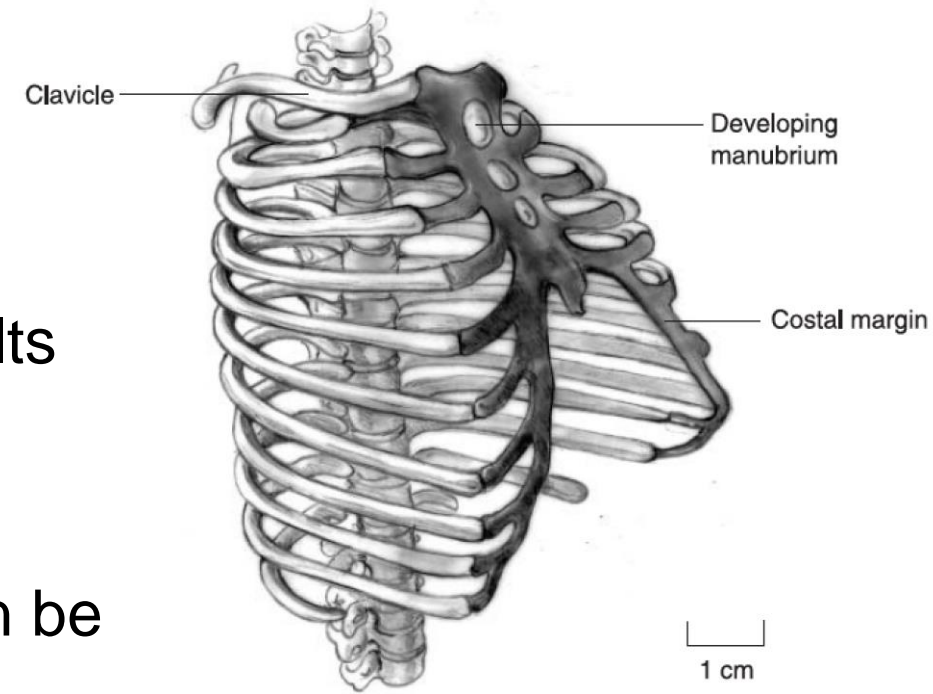
Thorax Anatomy

- 12 Thoracic vertebrae
- 24 ribs total / 12 pairs
 - 1-7 true ribs
 - 8-10 false ribs
 - 11-12 floating ribs
- Sternum
 - Manubrium
 - Sternal body
 - Xiphoid process



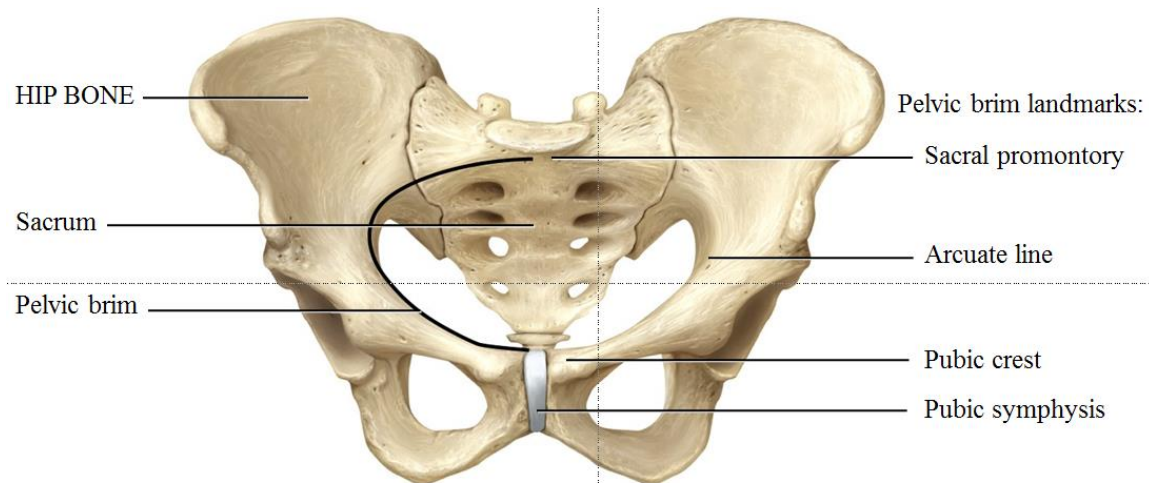
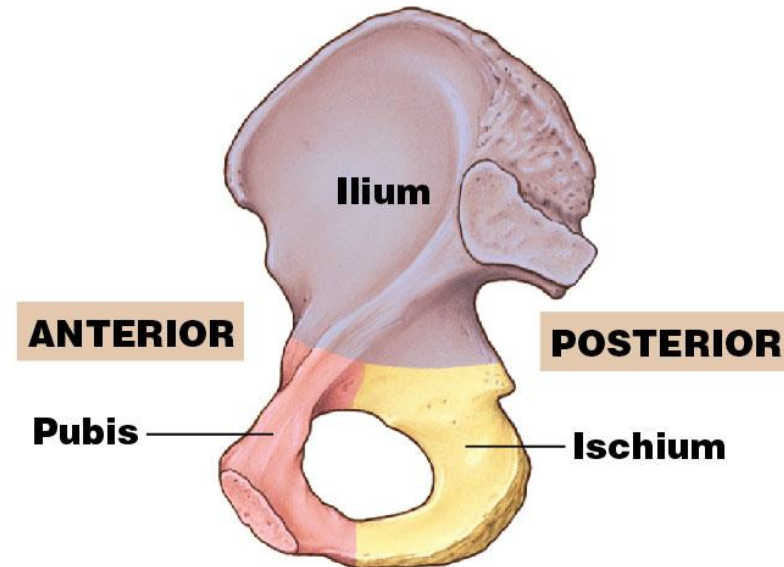
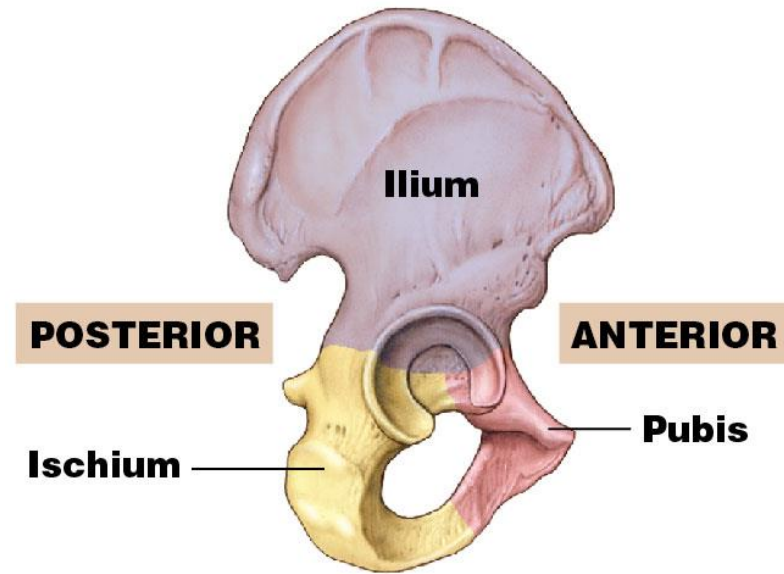
Pediatric Thorax Anatomy

- Thoracic rib angle more horizontal
 - Cage more circular in kids vs an oval in adults
- Sternum
 - 3-6 YO: All sternebrae including xyphoid can be identified
 - 4-10 YO: Sternebrae 3 and 4 fuse
 - 11-16 YO: Sternebrae 2 fuses to 3 & 4
 - 15-20 YO: Sternebra 1 fuses to the rest
- Ribs are not fully fused until ~ 25 YO
 - Buckle type failures are more common & difficult to detect



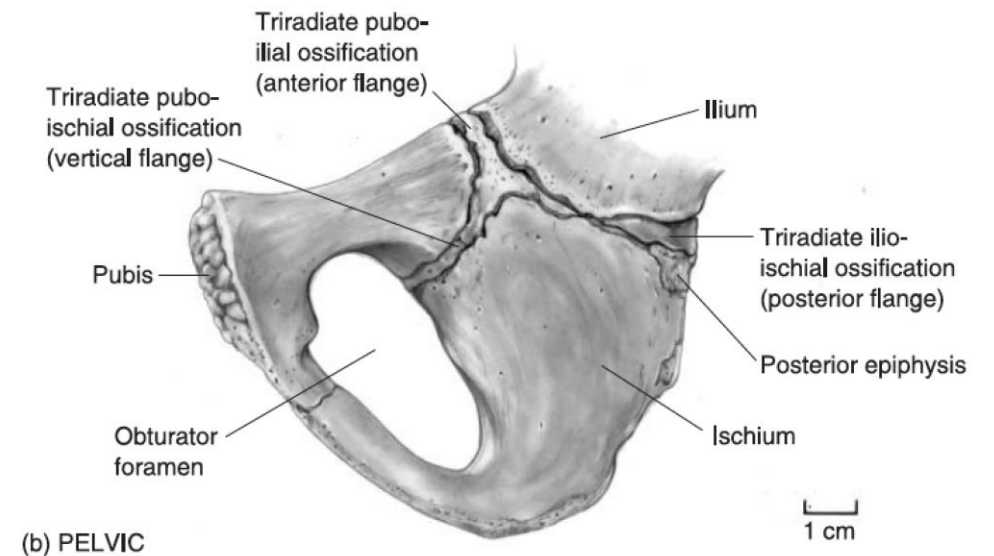
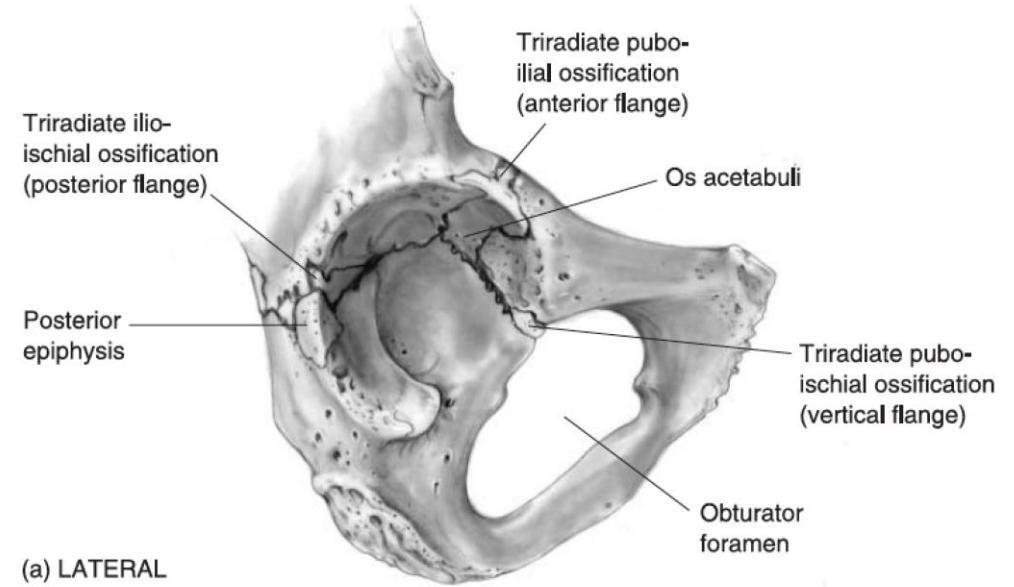
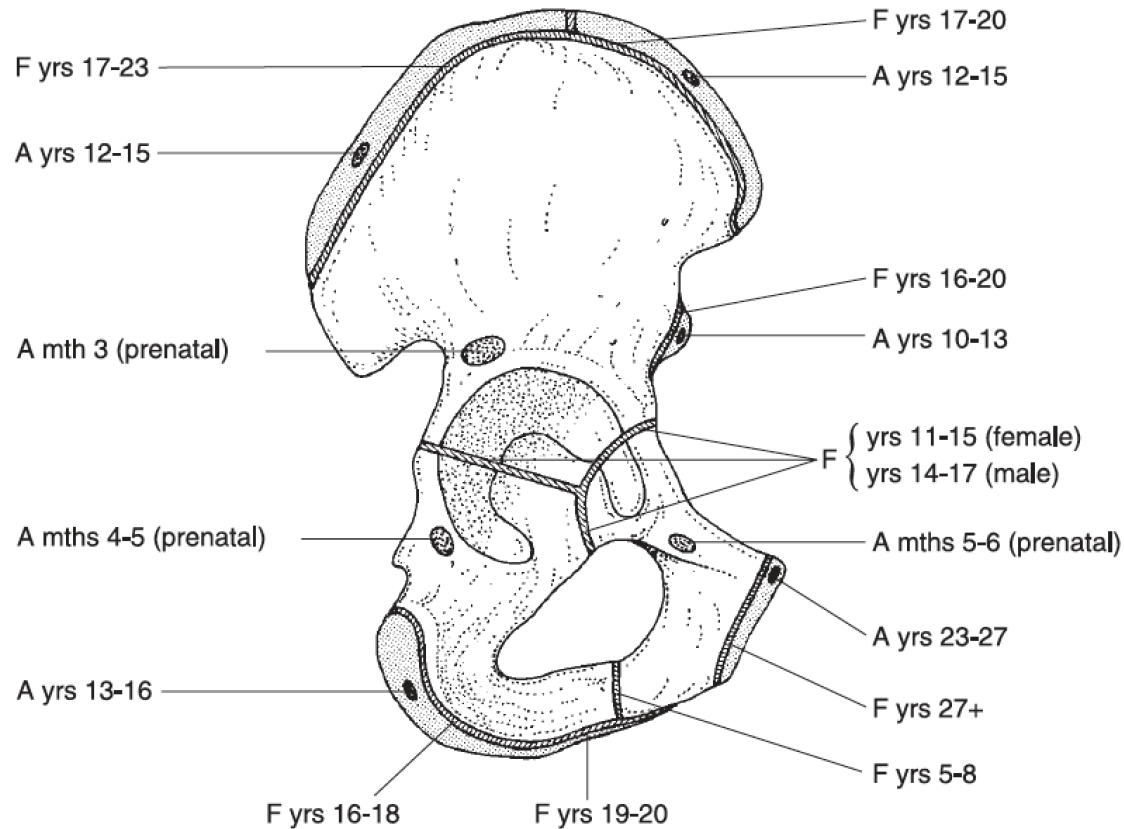
Pelvis Anatomy

- Os Coxae (Hip Bone)
 - Formed by the fusion of three separate bones (ilium, ischium and pubis)
- Acetabulum: a depression on the lateral surface where the head of the femur articulates



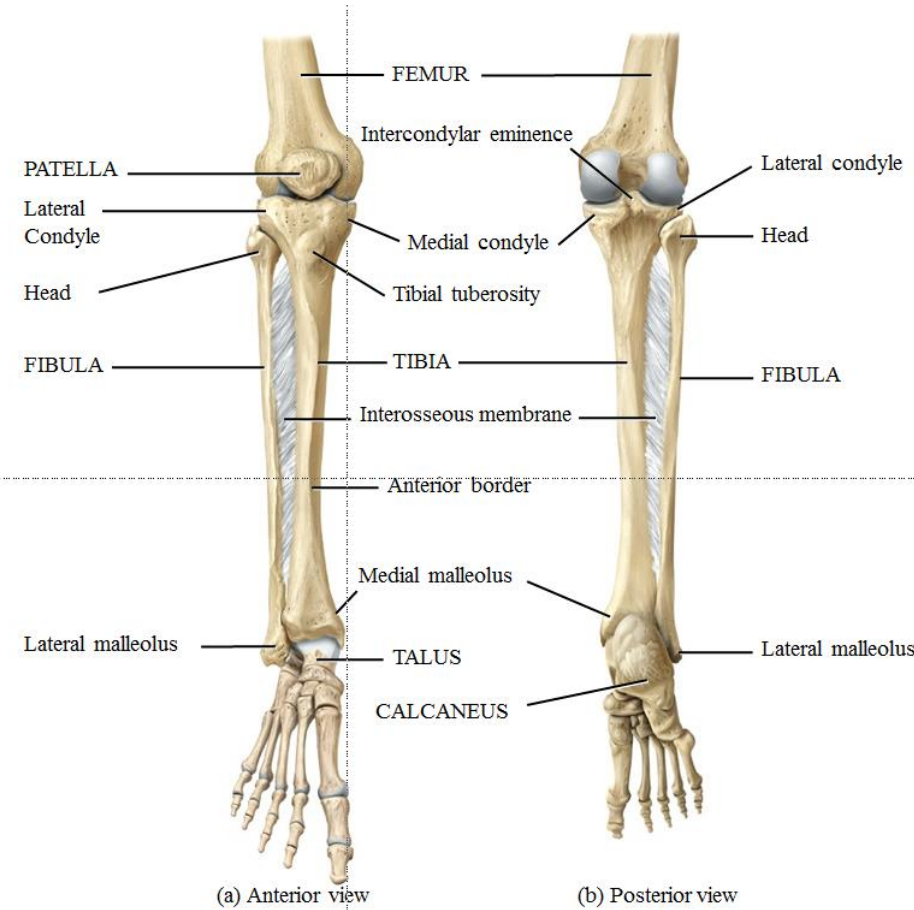
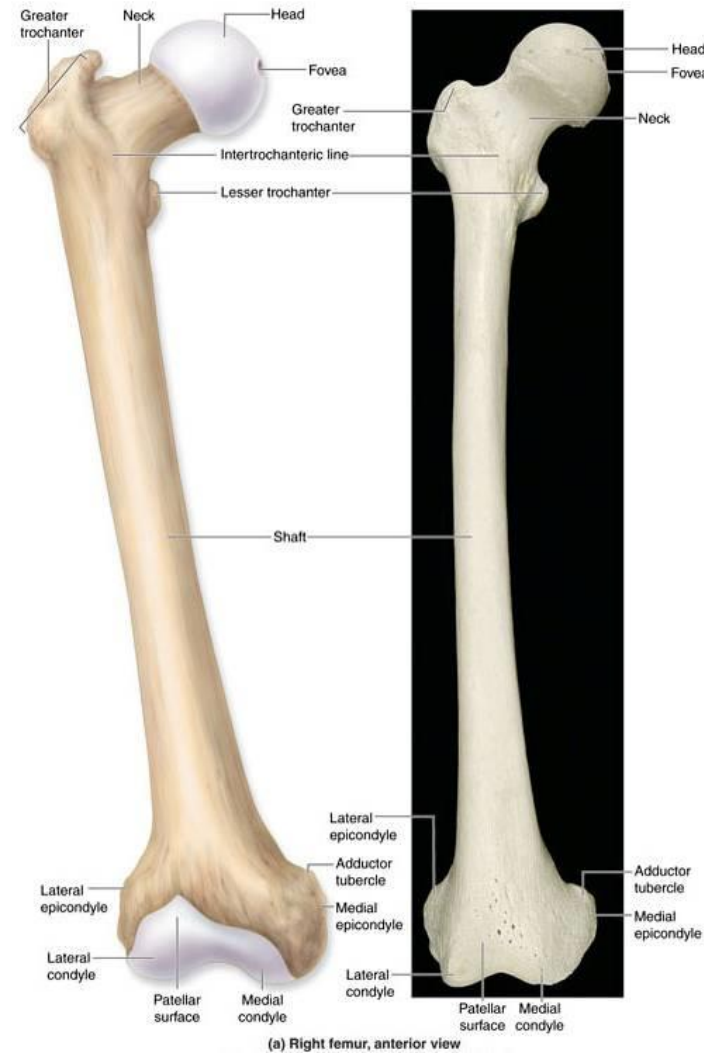
(a) Anterosuperior view of pelvic girdle

Pelvis Morphological Summary

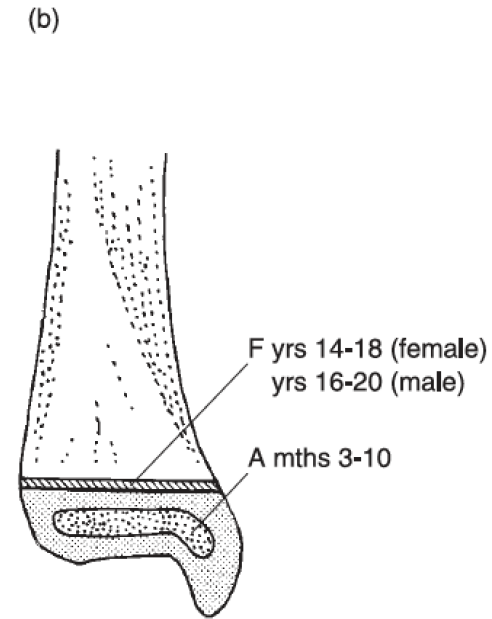
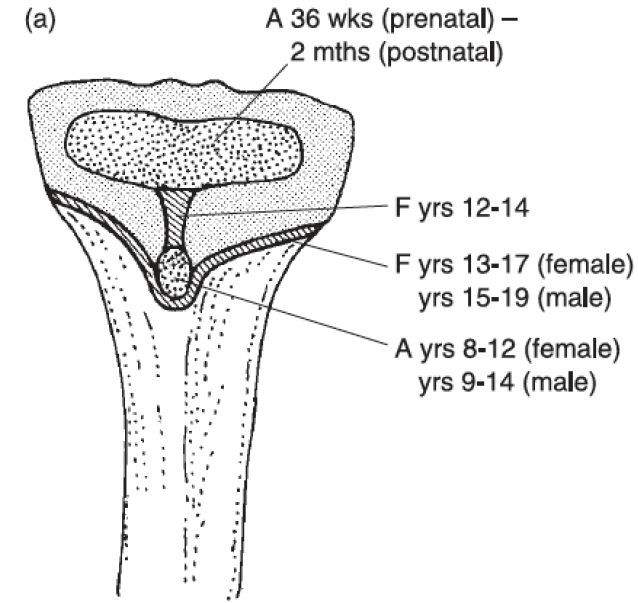
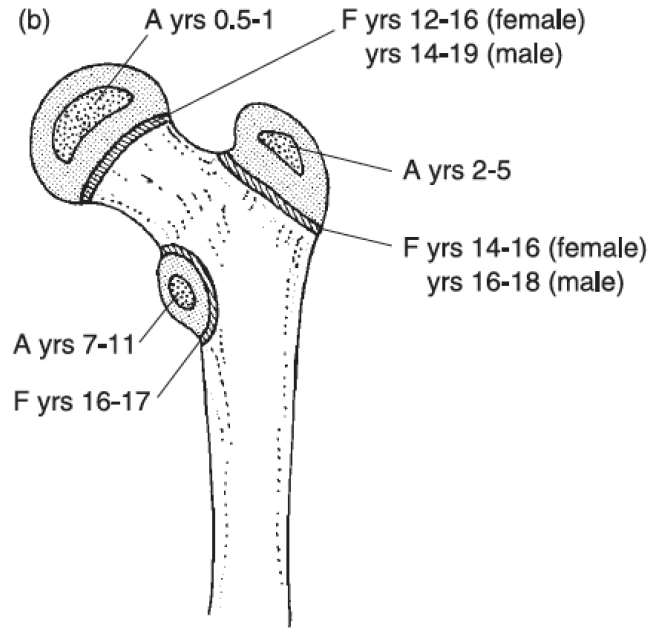
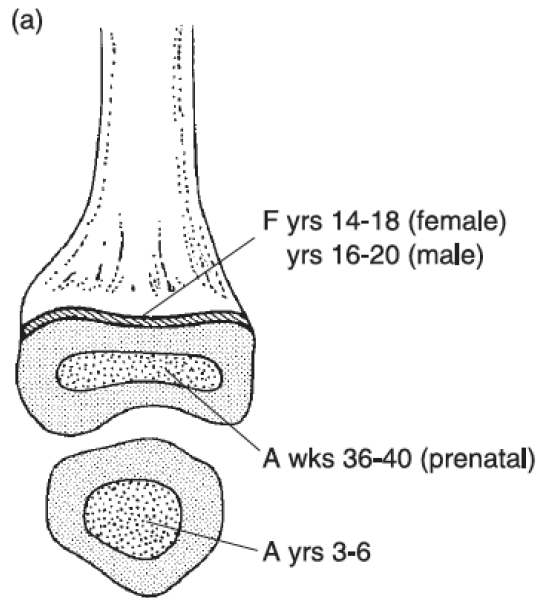


Lower Extremity Anatomy

- Os coxa(e)
- Femur
- Patella
- Tibia
- Fibula
- Tarsals
- Metatarsals
- Phalanges



Lower Extremity Morphological Summary



ATD Improvement Wish List

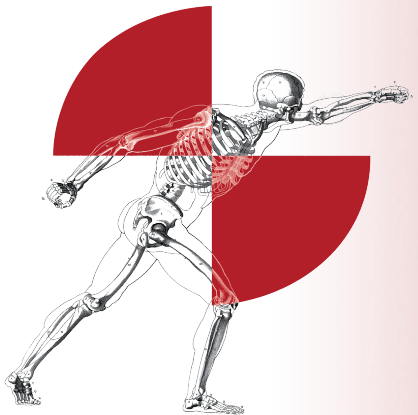
- **Cervical Spine**
 - An accurate representation of the cervical spine that allows for the majority of flexion and extension to occur between C1 – C3
- **Shoulder**
 - Better understanding of the range of motion of the pectoral girdle to ensure realistic belt fit
- **Thorax**
 - Sternum – less rigid sternum
 - Rib cage – more accurate shape to better predict loading to the thorax from the belt
 - Chest deflection sensing – capability to detect max rib deflection
- **Pelvis/Abdomen**
 - Updated geometry to ensure realistic belt fit and proper submarining behavior
- **Lower Extremity**
 - Further development of geometry and accurate range of motion at the hip, knee and ankle to ensure proper kinematics to better evaluate injury risk



Pediatric Anatomy & Biomechanics

John H Bolte IV

*SAFER - Child occupant protection:
Latest knowledge and future opportunities
May 31, 2024*



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