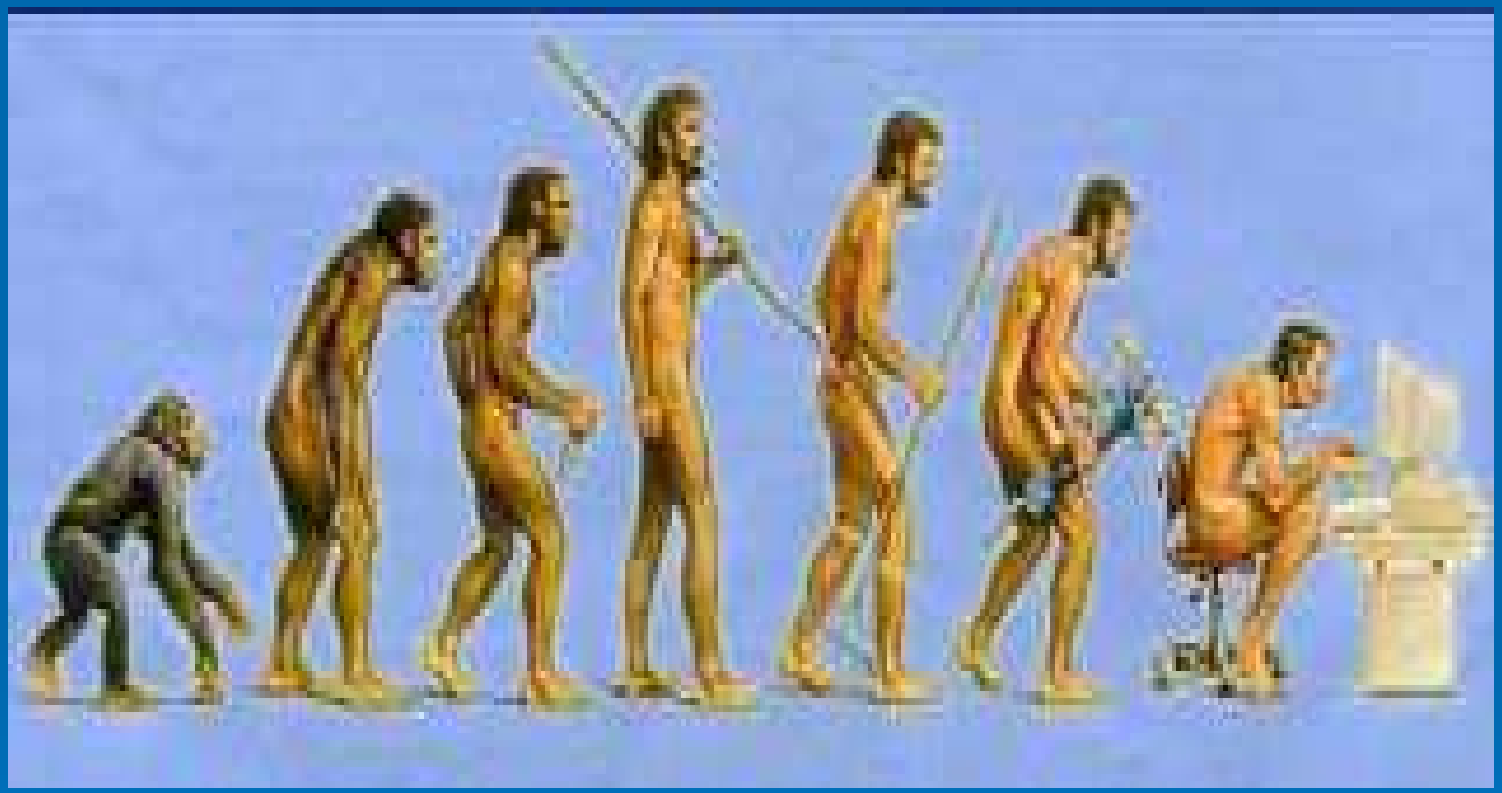
BIOMECHANICS OF SPINE



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What is biomechanics ?

“Biomechanics is the study of the consequences of application of external force on the spine “

Primary Aim

- To understand the underlying mechanical aspects of various spinal disorders and their clinical treatments
- Develop optimal prevention or treatment strategies

Motion segment

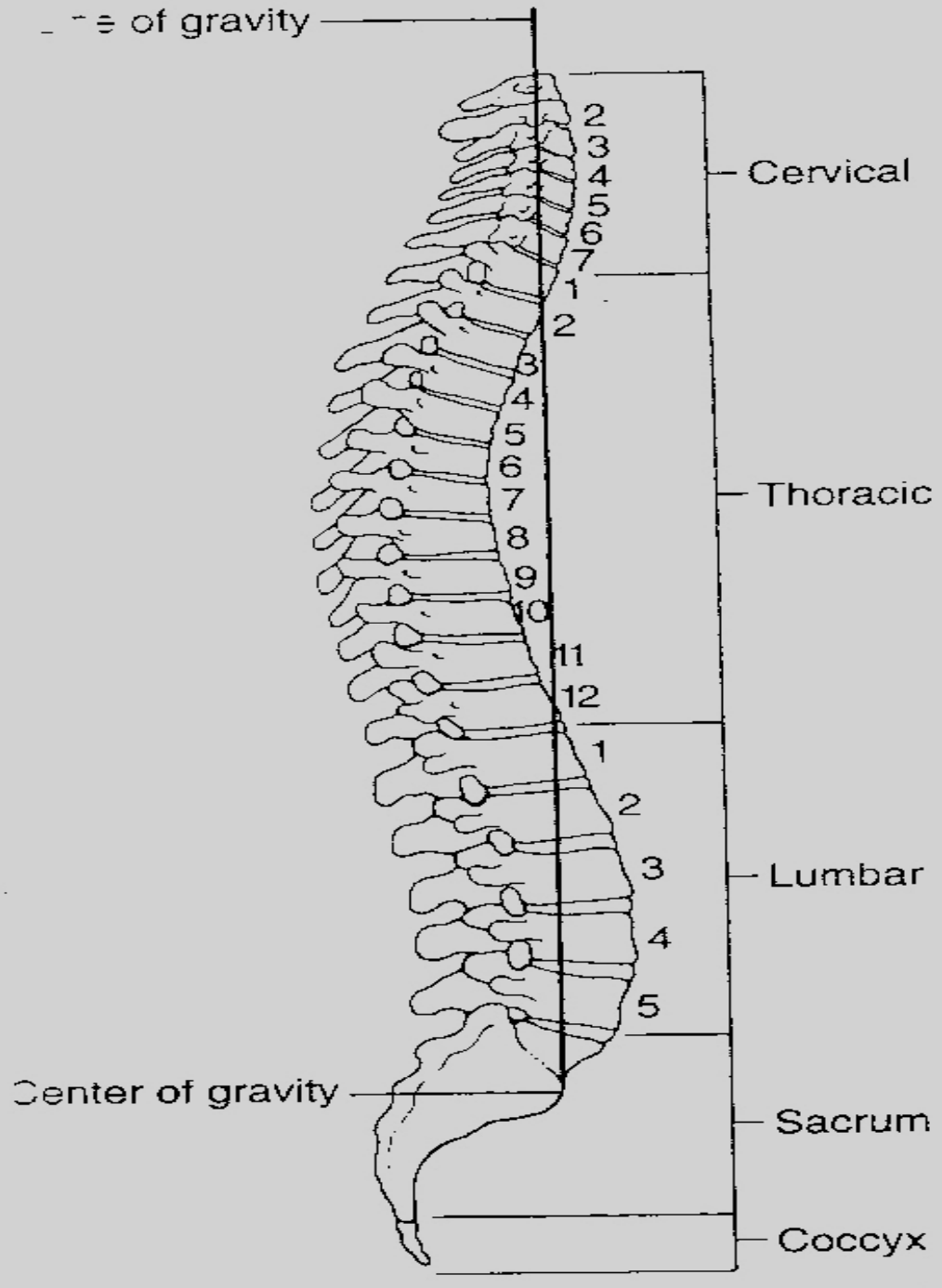
- In the biomechanical context
  the spine is treated as consisting of
  motion segments.
- Concept allows laboratory study of biomechanics of the spine in vitro
- Assuming that behaviour of spinal column can be deduced from summing the behaviour of motion segments is fallacious

The vertebral column: Basic anatomy

- 33 vertebrae:

  7 cervical, 12 thoracic, 5 lumbar, 5 sacral and 4 coccygeal)
- Typical vertebra consists of cylindrical body and a dorsal arch
- Dorsal arch consists of pedicle, lamina, pars interarticularis and spinous process.
- 2 primary curvatures- thoracic and lumbosacral kyphosis
- 2 secondary curvatures- cervical and lumbar lordosis

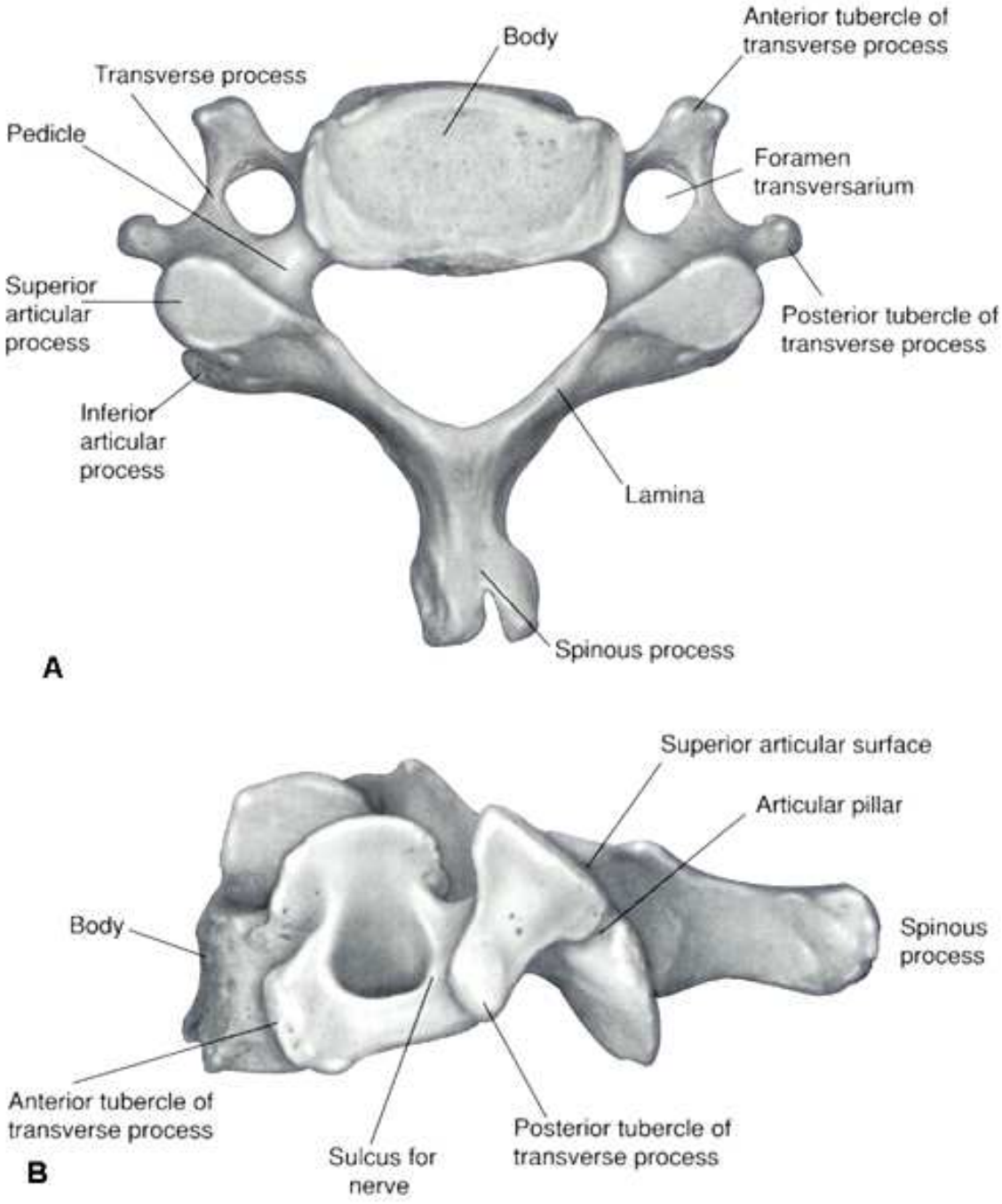
- Curvatures maintained by variation in the intervertebral disc heights and vertebral body dimensions.
- Center of gravity of the spinal column passes from the dens of the axis to the promontory of the sacrum.

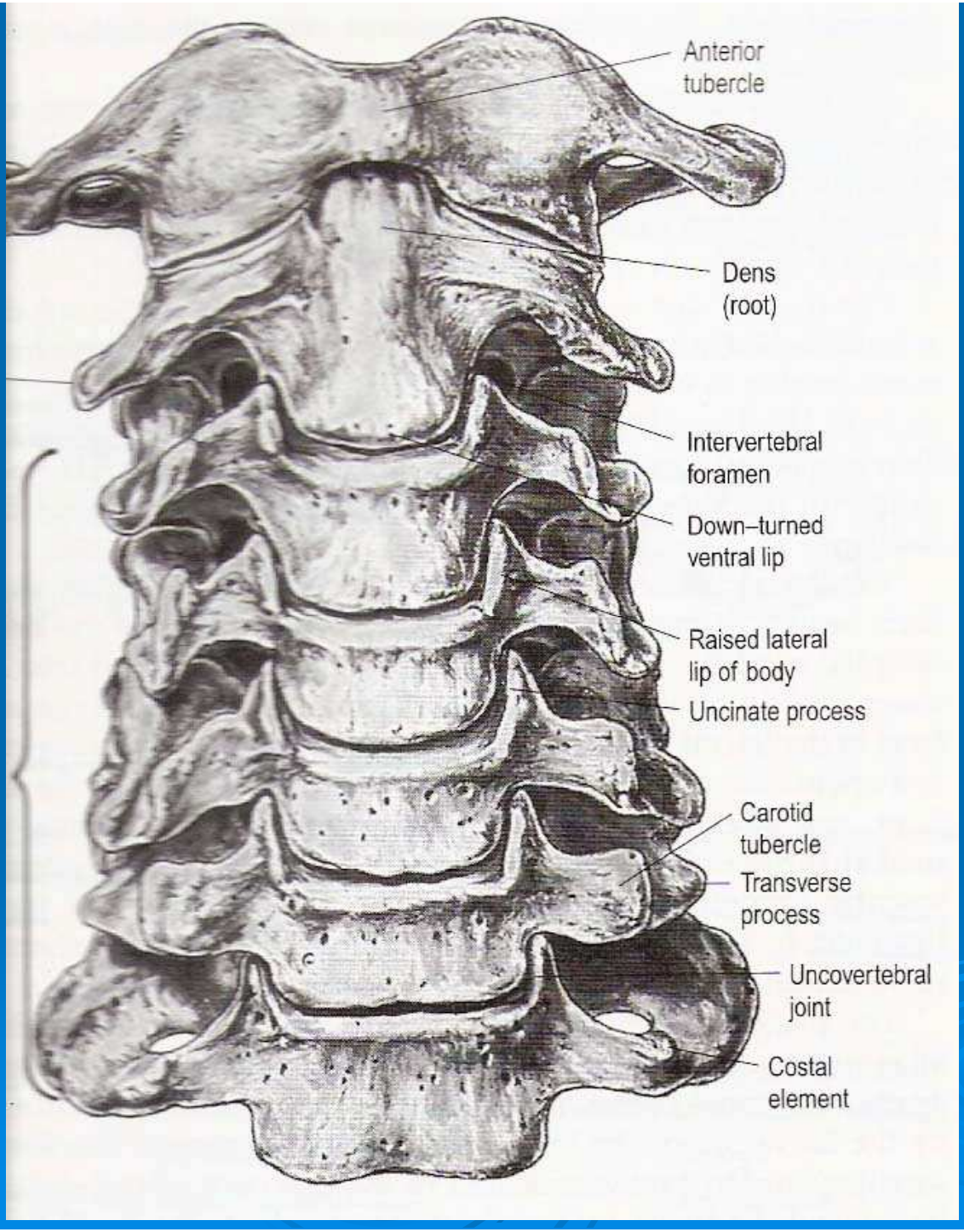

of gravity
2
3
4
5
6
7
Cervical
1
2
3
4
5
6
7
8
9
10
11
12
Thoracic
1
2
3
4
5
Lumbar
Center of gravity
Sacrum
Coccyx

Regional characteristics of the vertebral column

The cervical column

- Vertebrae smaller
- Lamina narrow and overlap
- The pars interarticularis in the cervical spine have been termed the lateral masses
- The superior and inferior facets extend from the pars


Body
Anterior tubercle of transverse process
Transverse process
Pedicle
Foramen transversarium
Superior articular process
Posterior tubercle of transverse process
Inferior articular process
Lamina
Spinous process
A
Superior articular surface
Articular pillar
Body
Spinous process
Anterior tubercle of transverse process
Sulcus for nerve
Posterior tubercle of transverse process
B


Anterior tubercle
Dens (root)
Intervertebral foramen
Down–turned ventral lip
Raised lateral lip of body
Uncinate process
Carotid tubercle
Transverse process
Uncovertebral joint
Costal element

- The cervical facets from C2-3 to C6-7 are oriented approximately at 45 degrees with respect to the horizontal.
- Coronal orientation of the facets.

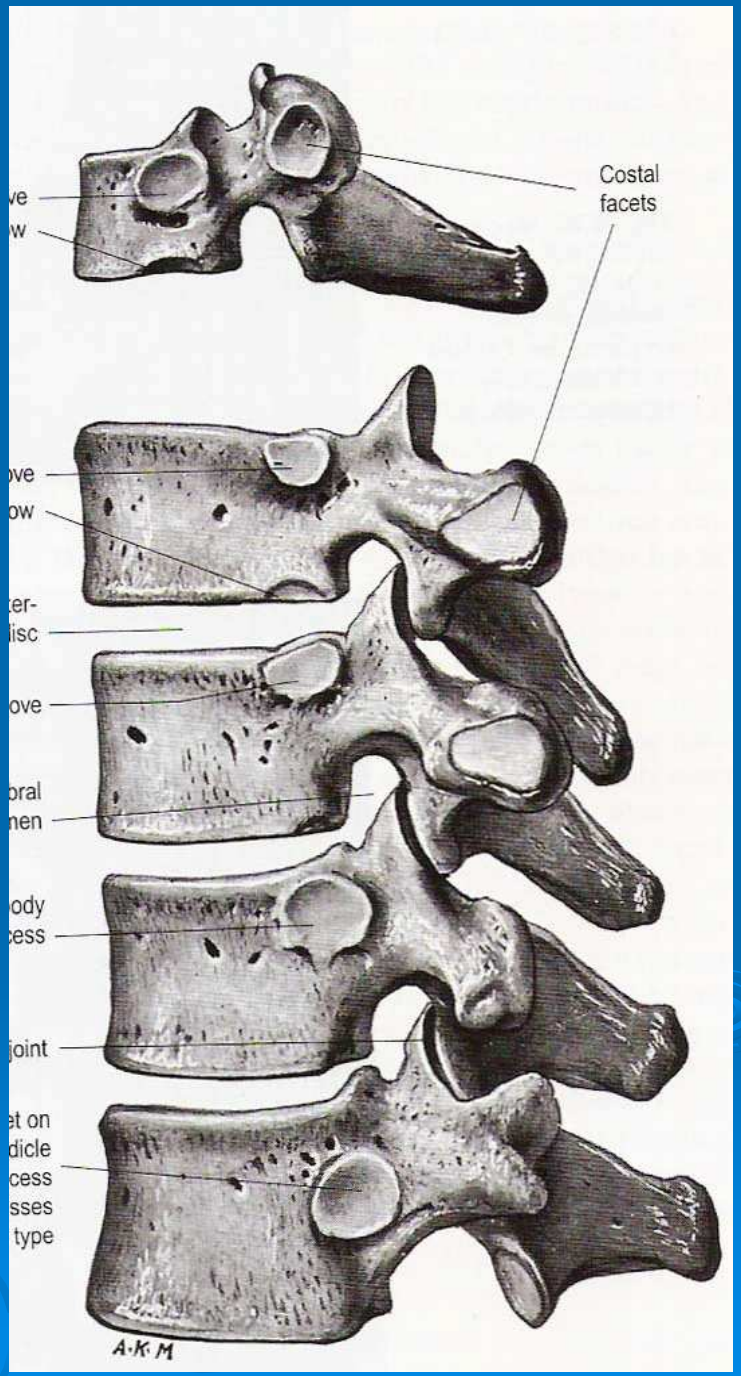

L

Thoracic spine

- Thoracic vertebra are heart shaped
- Uniquely, they possess costal facets at the junction of the body and transverse process for articulation with ribs
- Transitional features :

  Upper thoracic (T1-4) resemble cervical, lower (T9-12) resemble lumbar.

- Spinous processes of T1, T2 , T11 and T12 are horizontal
- T3, T4 and T9, T10 are oblique
- T5 –T8 spinous processes overlap considerably and are long and vertical
- Thoracic facets are oriented along coronal plane
- Thoraco-lumbar junction- there is change to assume a more sagittal orientation



Lumbar spine

- Largest and typically increase in diameter as one descends
- Bodies of L1-2 vertebra are deeper dorsally, that of L4 -5 deeper ventrally while L3 is transitional
- 5^{th} vertebra represents the transition from lumbar to sacral spine

- L5 body is taller ventrally contributing to the lumbosacral angle

- Articular facets are oriented obliquely in the sagittal plane limiting axial rotation of the spine.

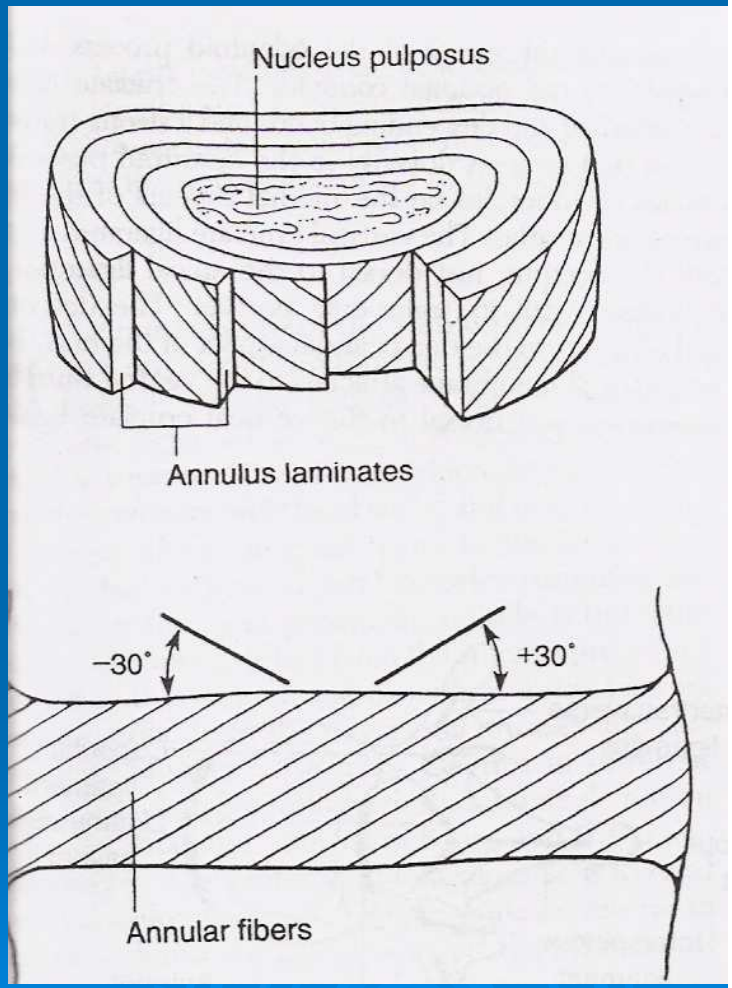
Sacrum and Coccyx

- Sacrum is triangular, concave and having a relatively smooth pelvic surface.
- Dorsal surface formed by the fusion of costal ligaments and transverse processes of sacral vertebral elements.
- The fused bodies are demarcated by transverse lines that end laterally in four pair of ventral sacral foramina.

Intervertebral discs

- 23 Interverbral discs are interposed between the vertebral bodies.
- Most rostral- C2-3 disc and distally L5- S1 disc.
- They account for one third to one fifth of the height of vertbral column.

- Four concentrically arranged components
  - Outer alternating layer of collagen fibres forming the peripheral rim of annulus fibrosus
  - Fibrocartilage component that forms a major portion of the annulus
  - Transitional region: annulus and nucleus merge
  - Central nucleus pulposus (NP) : Mucoprotein gel
- Age related disc changes :
  - loss of water content of NP and height
  - Number and size of collagen fibres decreases



- Structural organisation of the discs permits them to tolerate compression,shear,torsion and bending forces.
- During axial loading stress , the first component to fail is the vertebral end plate, due to herniation of the nucleus pulposus into the end plate.

Ligaments

- The longitudinal ligaments
  - Anterior
  - Posterior
- Ligamentum flavum
- Supraspinous ligament
- Interspinous ligament
- Intertransverse ligament
- Capsular ligaments

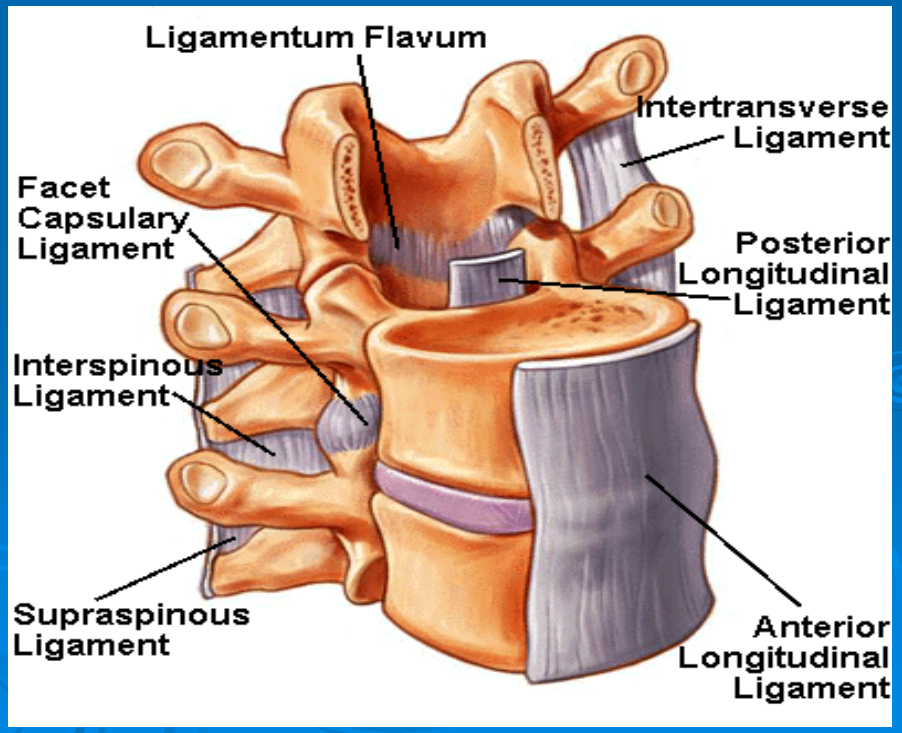
- Anterior longitudinal
  - From occiput to sacrum covering a fourth to third of the ventral circumference of vertebral bodies.
  - Consisting of three layers
    - Deepest layer binds the edges of disc extending between adjacent vertebrae.
    - Middle layer binds vertebral bodies and disc over three levels
    - Superficial layer extends over four or five levels
    - High collagen content preventing hyperextension and over distraction

- Posterior longitudinal ligament
  - Begins at C2 as the tectorial membrane and extends upto sacrum
  - Fibres spead out at the disc level and narrow in the middle of vertebral body
  - The ligament is much thinner over the vertebral body than over the disc
  - Multilayered, maximum thickness in thoracic region

- Ligamentum flavum
  - Yellow ligament (flava= yellow)
  - High elastin content
  - Broad paired ligaments- connect the lamina of adjacent vertebrae
  - Extend from C1-2 level to L5-S1

- Arise from ventral surface of caudal lamina and attach to dorsal border of adjacent rostral lamina
- High elasticity, assume their original size once a flexed spine straightens or extends
- Loose their elasticity with age, impinge upon the dura when slack

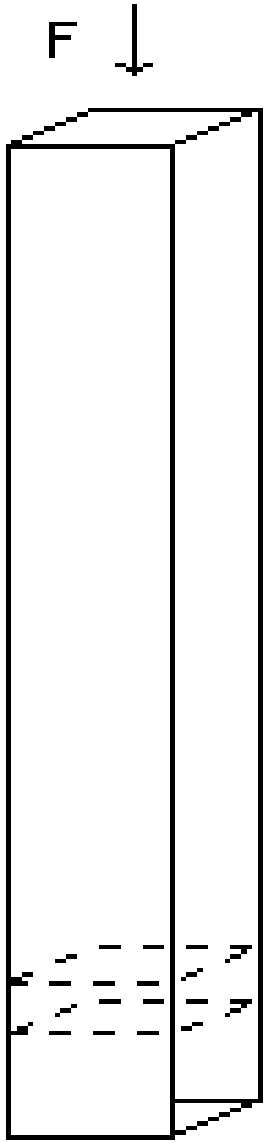
- Capsular ligaments
  - Attach to vertebra adjacent to articular joints.
  - Perpendicular to the plane of facets
  - Primarily prevent distraction of the joint.



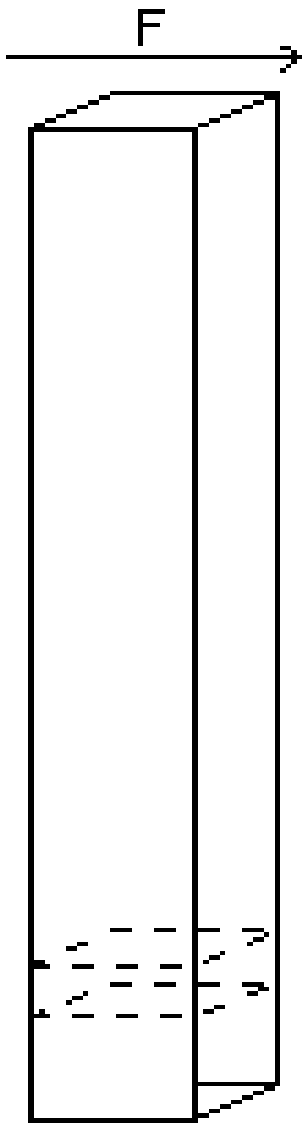
- Intertransverse ligaments
  - Seen only in thoracic and upper lumbar spine.
  - Pass between the transverse processes and attach to the deep muscles of the back.
- Interspinous and supraspinous ligaments
  - Interspinous attach from base to tip of each spinous process
  - Supraspinous attach at the tips of spinous processes
  - Ligament is weakest in cervical region and becomes progressively stronger caudally

Biomechnical concepts

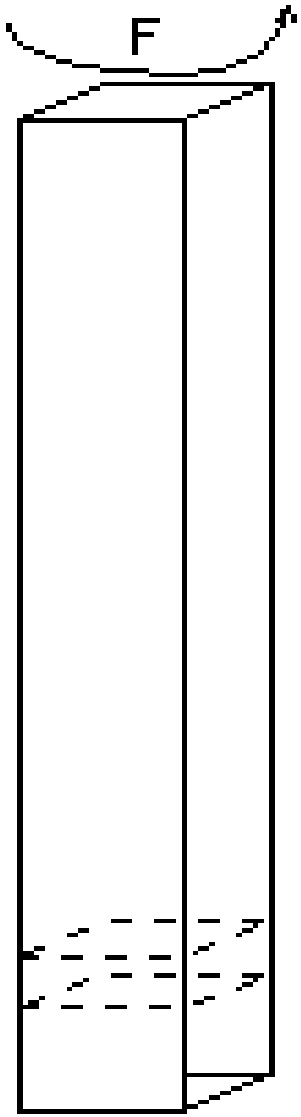
- Deformations
  - Application of force to a rigid body like the spine results in deformation
    - Translational: change in length
    - Rotational : change in the angle
- Strain
  - Change in unit length/angle in body subjected to force



Tensile or compressive stress



Shear stress

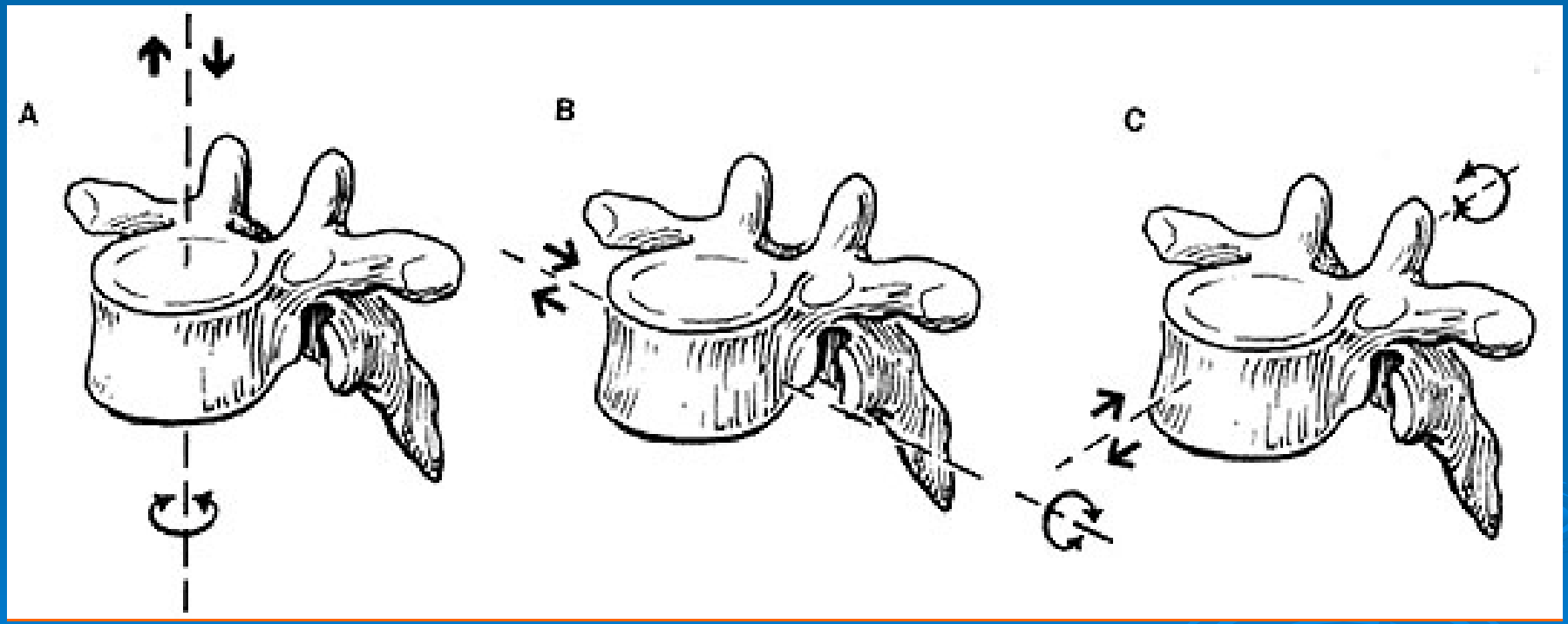


Torsion

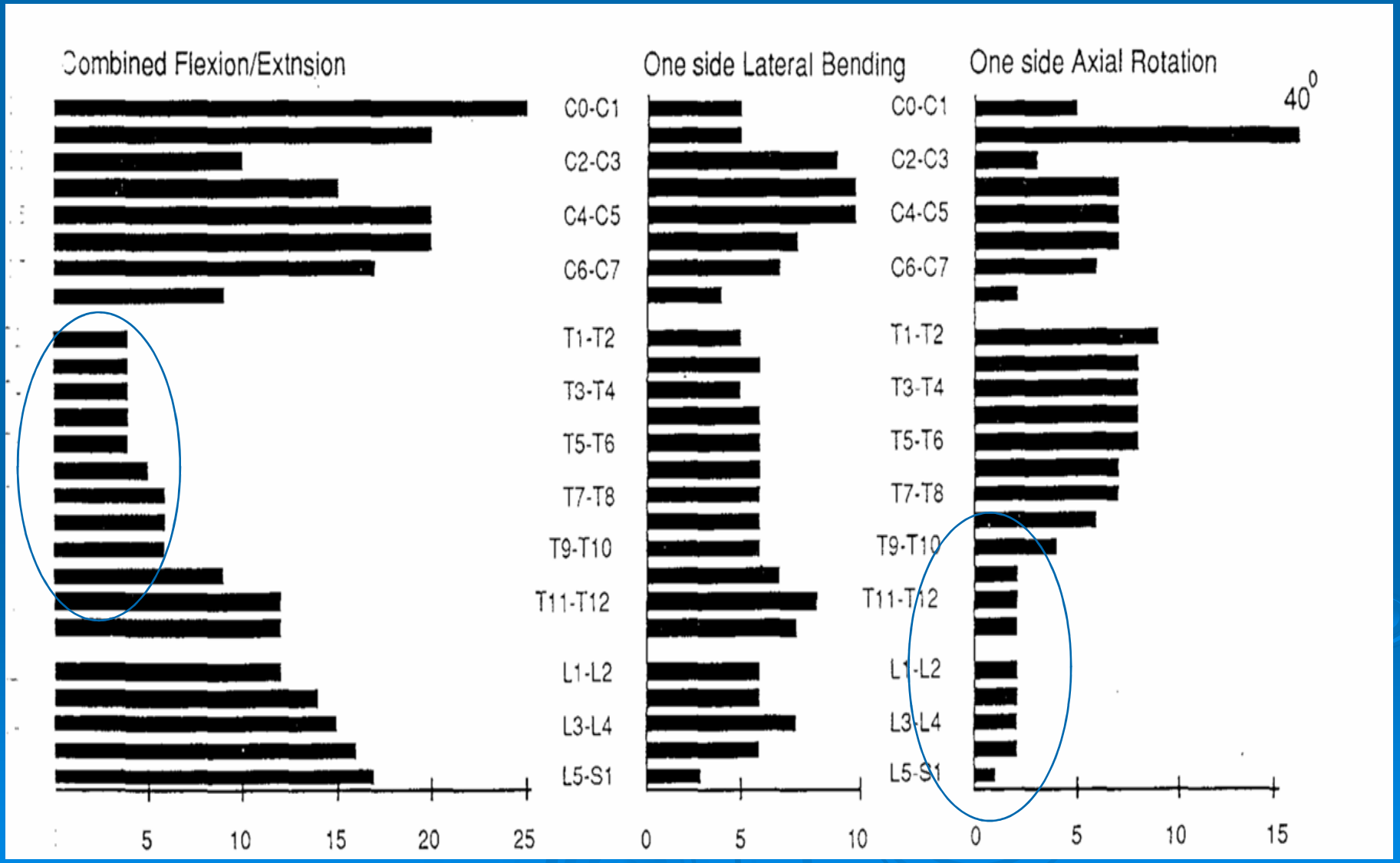
Spinal motion

- Degrees of freedom is a useful concept in the description
- No of unique independent motion one vertebra can have with respect to another.
- Six degrees of freedom
  - Three translational
  - Three rotational, along three axes

Movements of the spine



Mobility of the normal spine



Facets

- 18% of compressive load, 45% of torsion strength and variable amount of stability contributed by facet joints
- Do not substantially support axial compressive load unless spine is in extension
- Also changes with orientation of facets

- Coupling
  - Defined as obligatory movements of the spine (translations and rotations) that accompany a primary motion
  - Principal motion is defined as the motion produced in the plane of the force
  - Any associated out of phase motion is coupled

- Instantaneous axis of rotation
  - Defined as the axis perpendicular to the plane of motion and passing through the points within or outside the body which is static during the motion
  - Example, when opening a door, the axis of rotation passes through the hinges

Functional biomechanics of the spine

Spinal stability

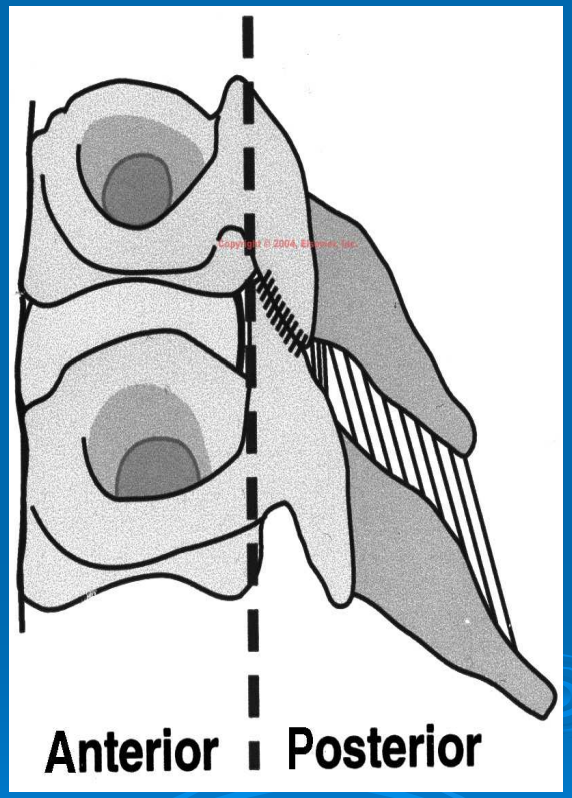
- Paramount concept

  Ability of spine to maintain its pattern of displacement under physiologic loads without producing-

  - Incapacitating pain
  - Deformity
  - Neurological deficit

Theories of spine stability

- The two column concept:
  - Advanced by Holdworth
  - Stressed upon the integrity of posterior ligamentous complex in maintaining stability.
  - Unstable fractures involved disrupted PLC and one component of anterior Column.



- Three column concept:
  - Better agreement with clinical observations regarding spine stability
  - For instability 2 out of the 3 columns must be damaged.

Advantages of three column concept

- Assesses bony collapse associated with axial load bearing
- Also details assessment of distraction, flexion and extension components of injury (injury to dorsal elements)
- Middle column comprises of region of neutral axis
- Spine considered to be unstable when any of the two columns are involved
- Thus, in three column concept a burst fracture is considered to be unstable

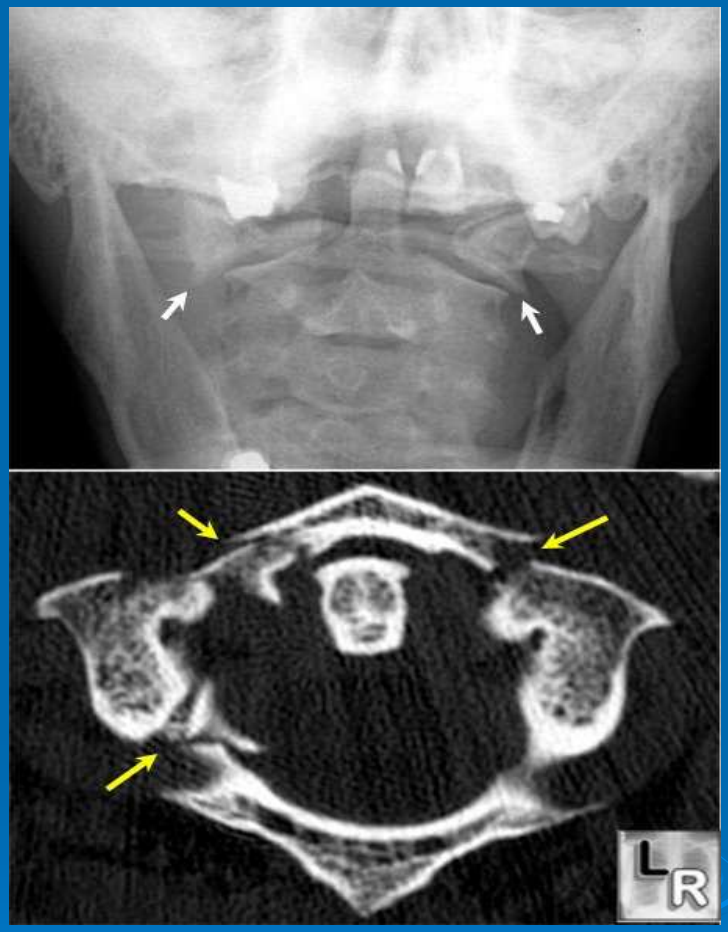
Biomechanics of CVJ

- Cervical spine most mobile part of axial skeleton
- Average range of flexion –extension at occipitoatlantal joint 13-15 degree
- Additional 10 degree occurs at atlantoaxial joint
- Flexion extension evenly distributed over entire cervical spine
- Maximally at C5 –C6
- Anterior-posterior translation between dens and anterior atlantal arch 3mm
- In TAL rupture 5mm displacement occurs
- When alar ligaments also rupture, >5 mm separation occurs

Biomechanics of CVJ

- Axial rotation occurs only at atlantoaxial joint
- Maximum limit of rotation is 40-45 degrees
- Beyond 45 degree facets get locked
- Rotation >32 degrees leads to angulation of contralateral vertebral artery

- Jefferson fracture
  - Diffuse axial loading of cervical spine
  - Bilateral anterior and posterior arch fractures
  - Biomechanically, stable till the lateral mass displacement more than 5 mm, implying transverse ligament disruption.



Fracture of the dens

Type1- avulsion injury of the dens. Stable

Type 2- dens fractured along the base due to flexion/ extension injury. Unstable , because dislocation may increase

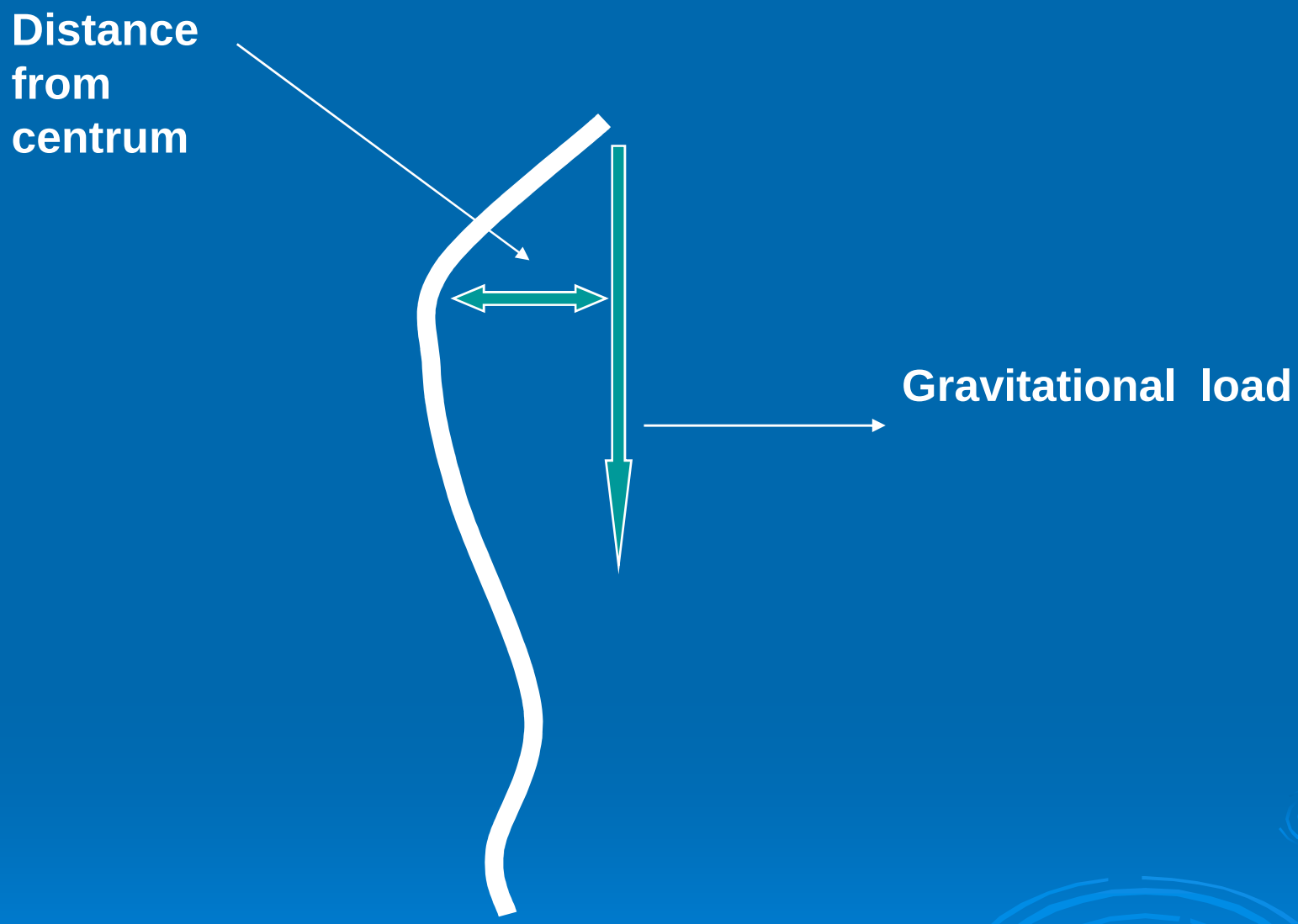
Type 3 : produced by flexion or compression forces or both.

Lower cervical spine

- Burst fractures
  - Disruption of the body and intervertebral discs
  - Direct axial loading of the spine
  - Theoretically should be stable as the PLC is intact
  - But, mostly associated with PLL damage and disc injury making it unstable
  - Biomechanically, only anterior decompression and fusion is not appropriate as it disrupts viable ALL and PLL
  - Circumferential stabilization may be indicated

Thoracic spine injuries

- Mostly caused by flexion compression forces
- The bending moment developed at the vertebra in question is dependent on the length of the column and distance between the line of gravity and the centrum



Bending moment = Load x distance

- In flexion compression injury,
  - Distraction and damage of posterior ligament complex may be more pronounced
  - Thus these injuries are more unstable than burst fractures.
  - The flexion bending moment produced naturally in the lower thoracic spine (T10-12) by anatomic factors
    - Termination of rib cage
    - Normal thoracic kyphosis
    - Orientation of the facets

AO CLASSIFICATION

Arbeitsgemeinschaft fÜr**O**steosythesefragen

- 3 TYPES

TYPE A COMPRESSION FRACTURE

A1 impaction fracture

A2 split fracture

A3 burst fracture

TYPE B FLEXION/DISTRACTION

B1 POSTERIOR DISRUPTION (LIGAMENTOUS)

B2 POSTERIOR DISRUPTION (OSSEOUS)

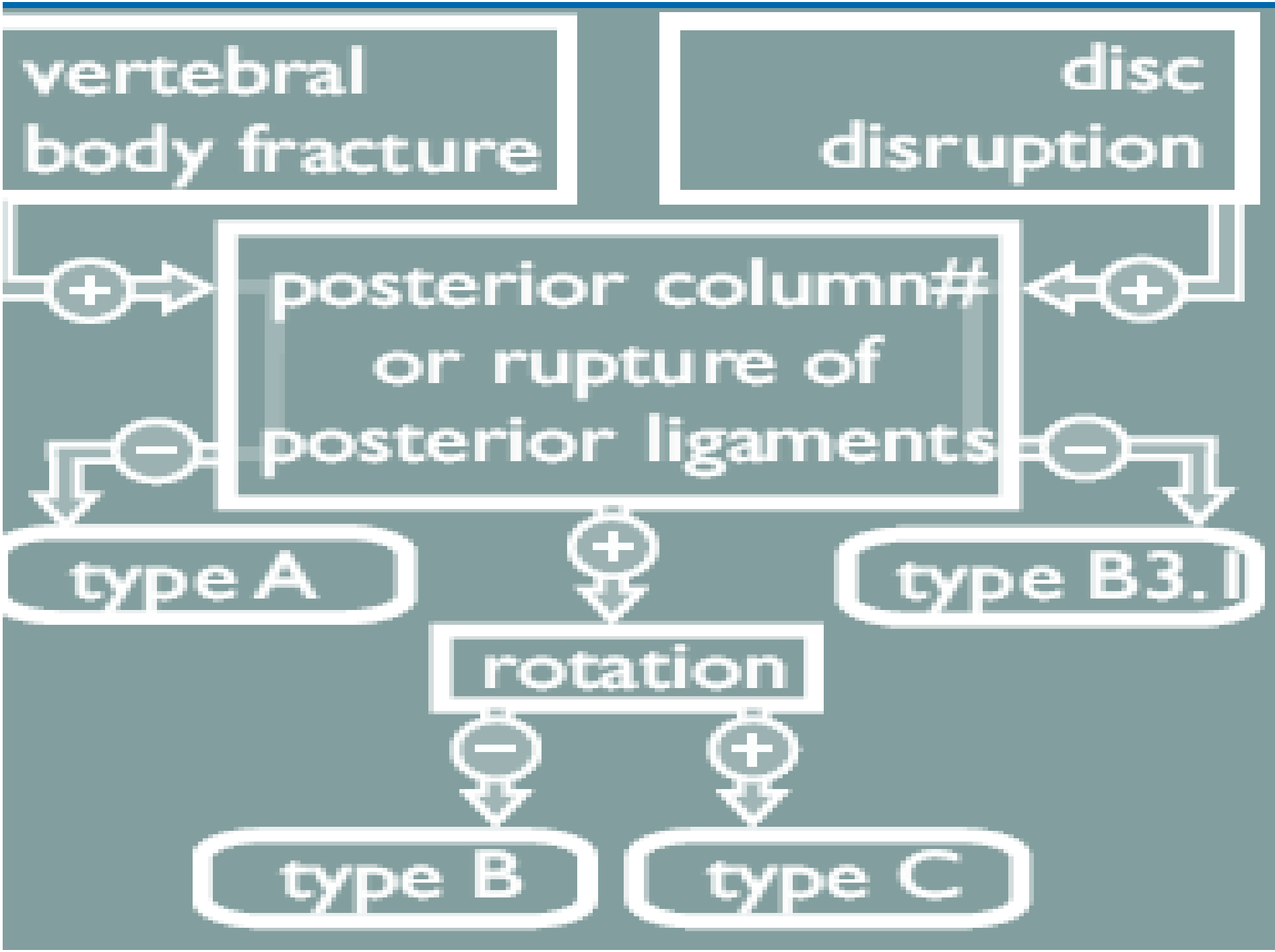
B3 ANTERIOR DISRUPTION THROUGH THE DISC

TYPE C ROTATION INJURY

C1 TYPE A +ROTATION

C2TYPE B +ROTATION

C3 ROTATIONAL SHEAR INJURY


vertebral body fracture
disc disruption
posterior column# or rupture of posterior ligaments
type A
type B3.1
rotation
type B
type C

Thresholds of clinical stability of functional spinal unit

	cervical	thoracic	lumbar
Relative sagittal plane translation	>3.5 mm	>2.5 mm	>4.5 mm
same	>20%	>10%	>15%
Relative sagittal plane rotation	>11	>5	>5

Thank you