Biomechanics of the Spine

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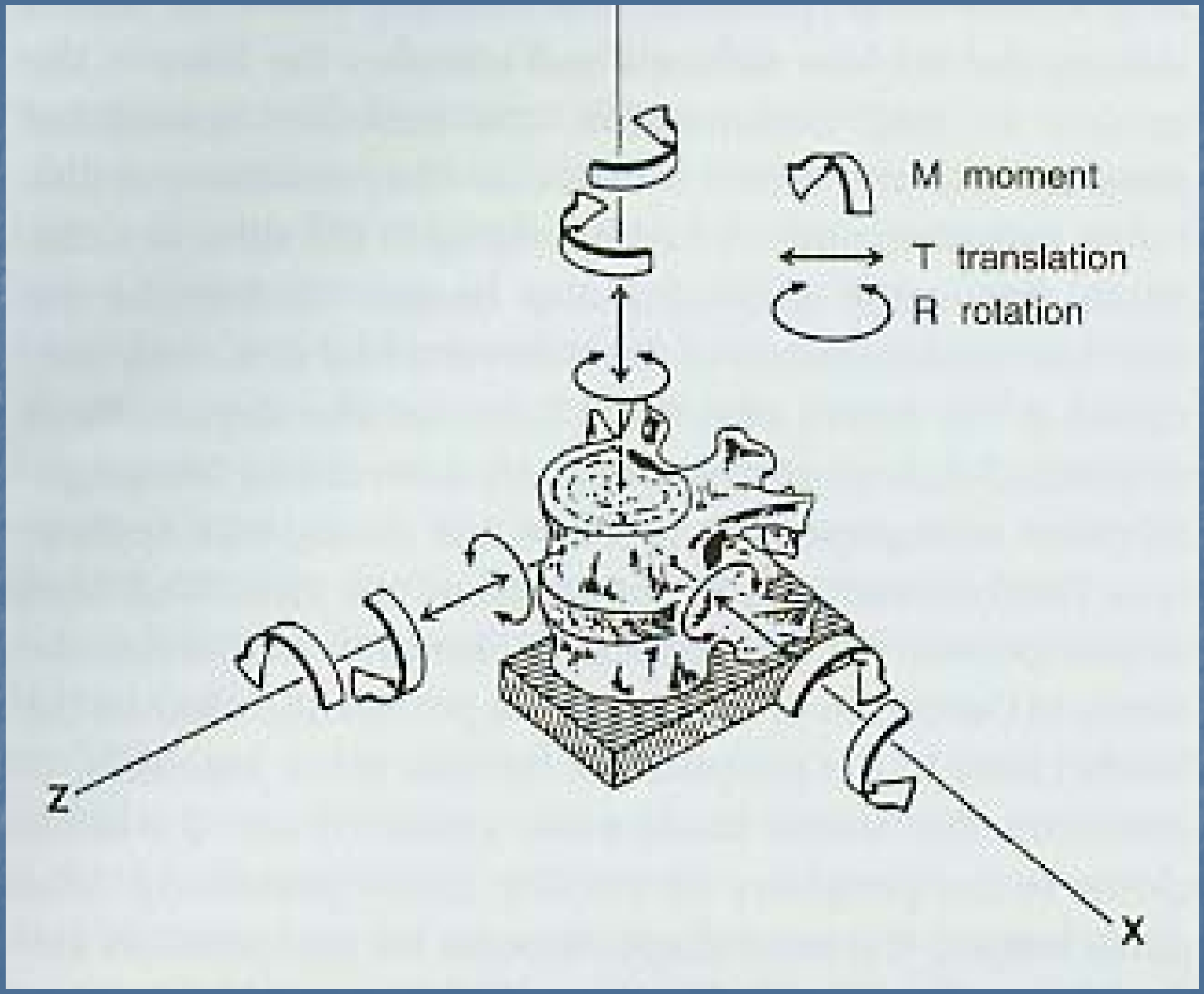
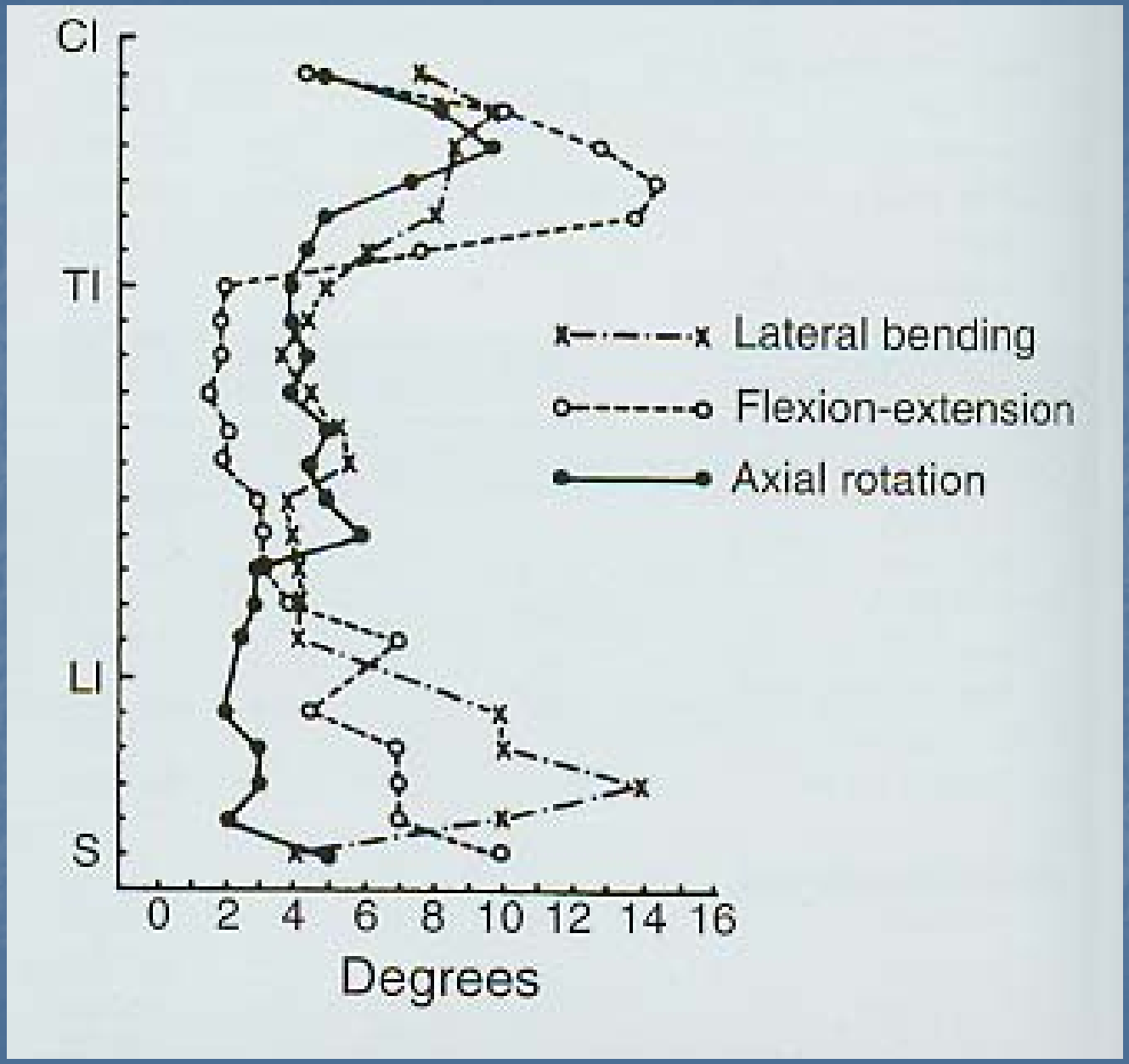
General Kinematics

- Curvature
  - Sagittal
  - Shape of vertebrae & disks, rib cage, inclination of sacral end plate
  - Developmental phenomenon, posture, rate of growth
  - Add flexibility & shock absorbing capability
- 6 degrees of freedom
  - Translation & Rotation
  - 3 orthogonal planes
  - Motion usually coupled
- Center of gravity – in front of 2nd sacral segment

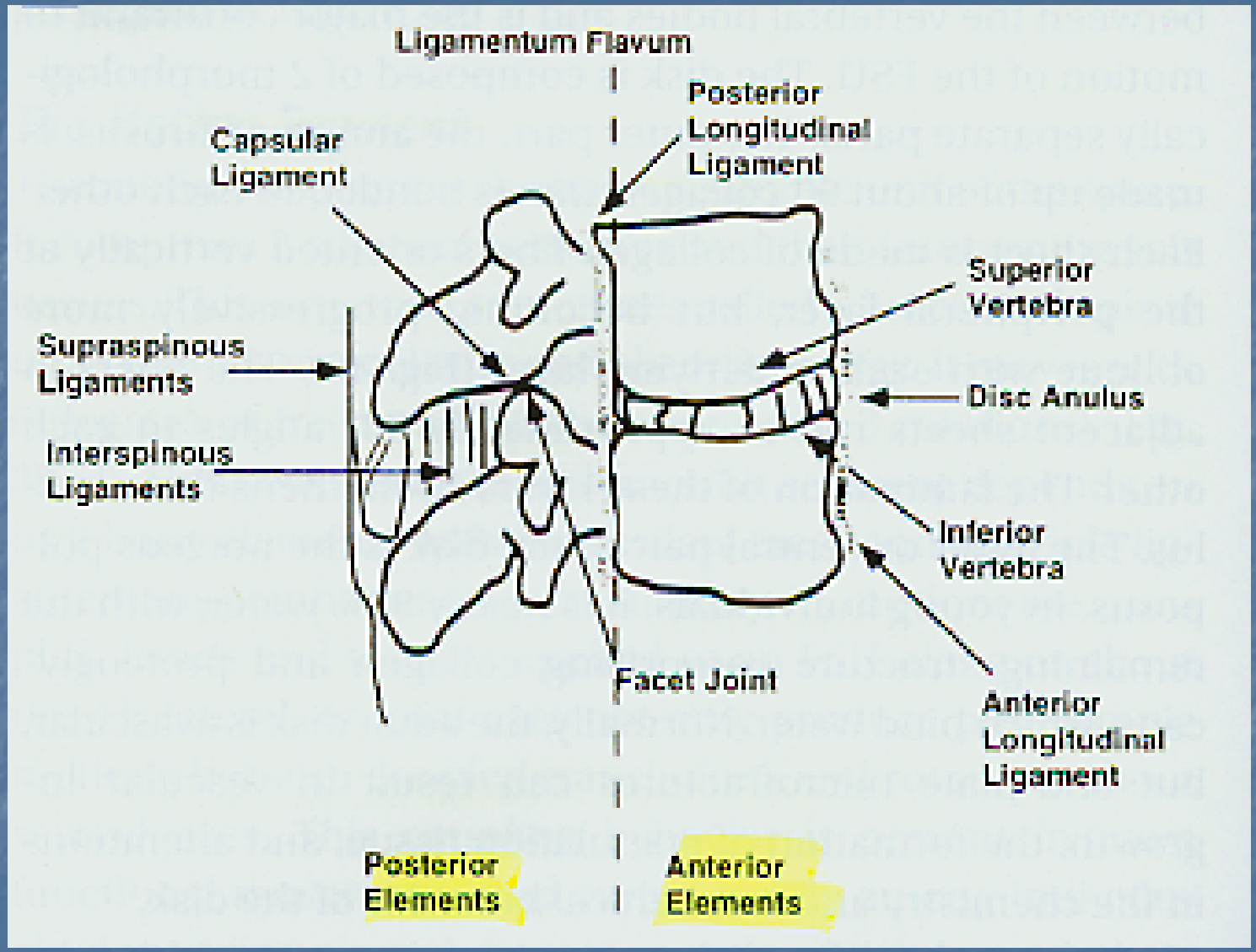

M moment
T translation
R rotation
Z
X

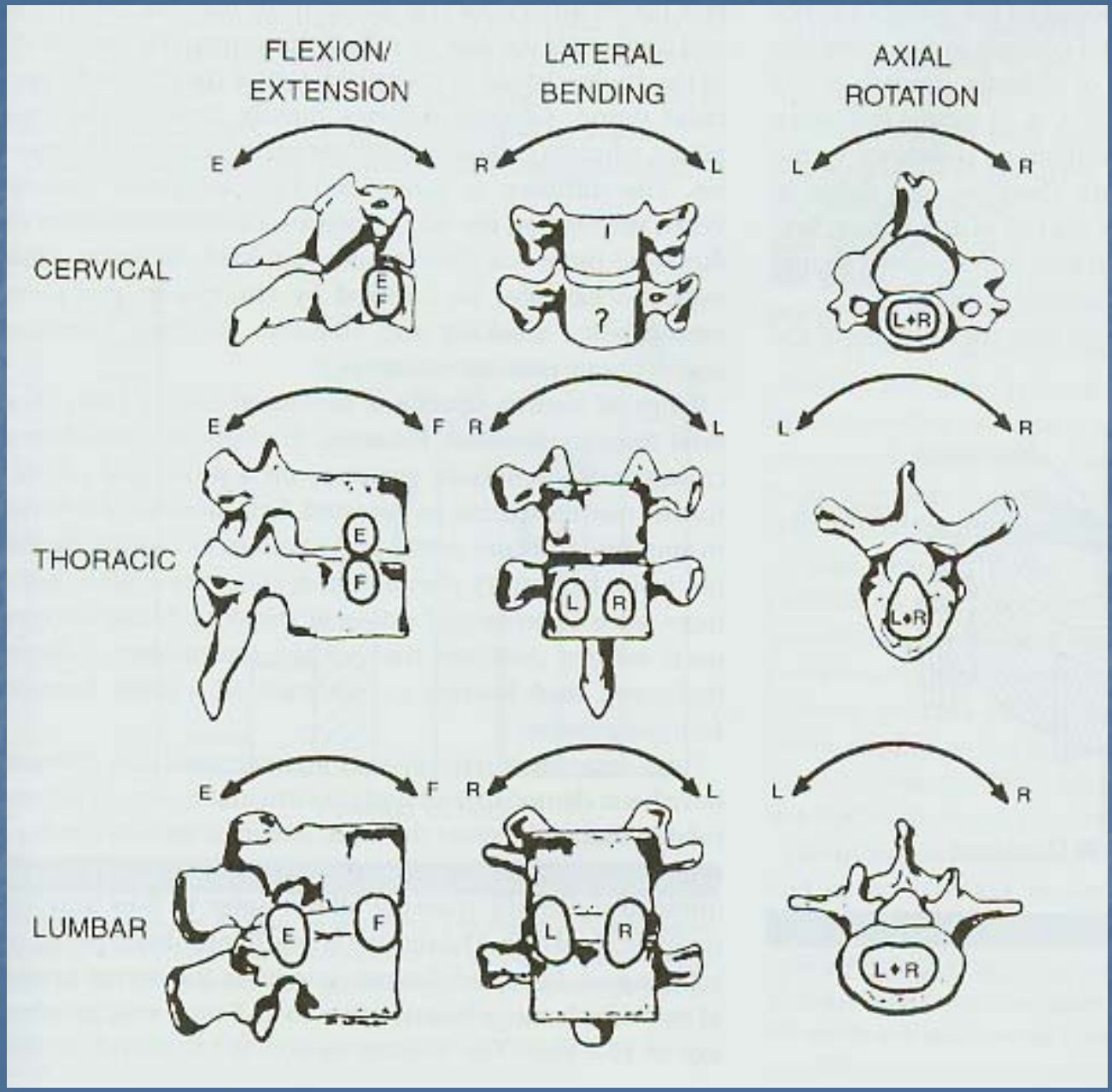
- ROM
  - Facet joints & Intervertebral disks
  - C spine
    - Flexion-extension predominates, midcervical
    - Axial rotation, upper cervical
    - Lateral bending
  - T spine
    - Little motion, rib cage
  - L spine
    - Lateral bending, mid portion
    - Flexion-extension, lumbosacral
    - Rotation, minimal
  - Greater mobility at C & L spine> more stress> more clinical complaints


Cl
TI
LI
S
0 2 4 6 8 10 12 14 16
Degrees
Lateral bending
Flexion-extension
Axial rotation

The Motion Segment

- Functional Spinal Unit
  - 2 adjacent vertebrae & intervening soft tissue
- Anterior
  - Vertebral body
  - Disk
  - ALL, PLL
    - Support, absorb impact, restrict vertical translation
- Posterior
  - Neural arch & its processes
  - Facet joint

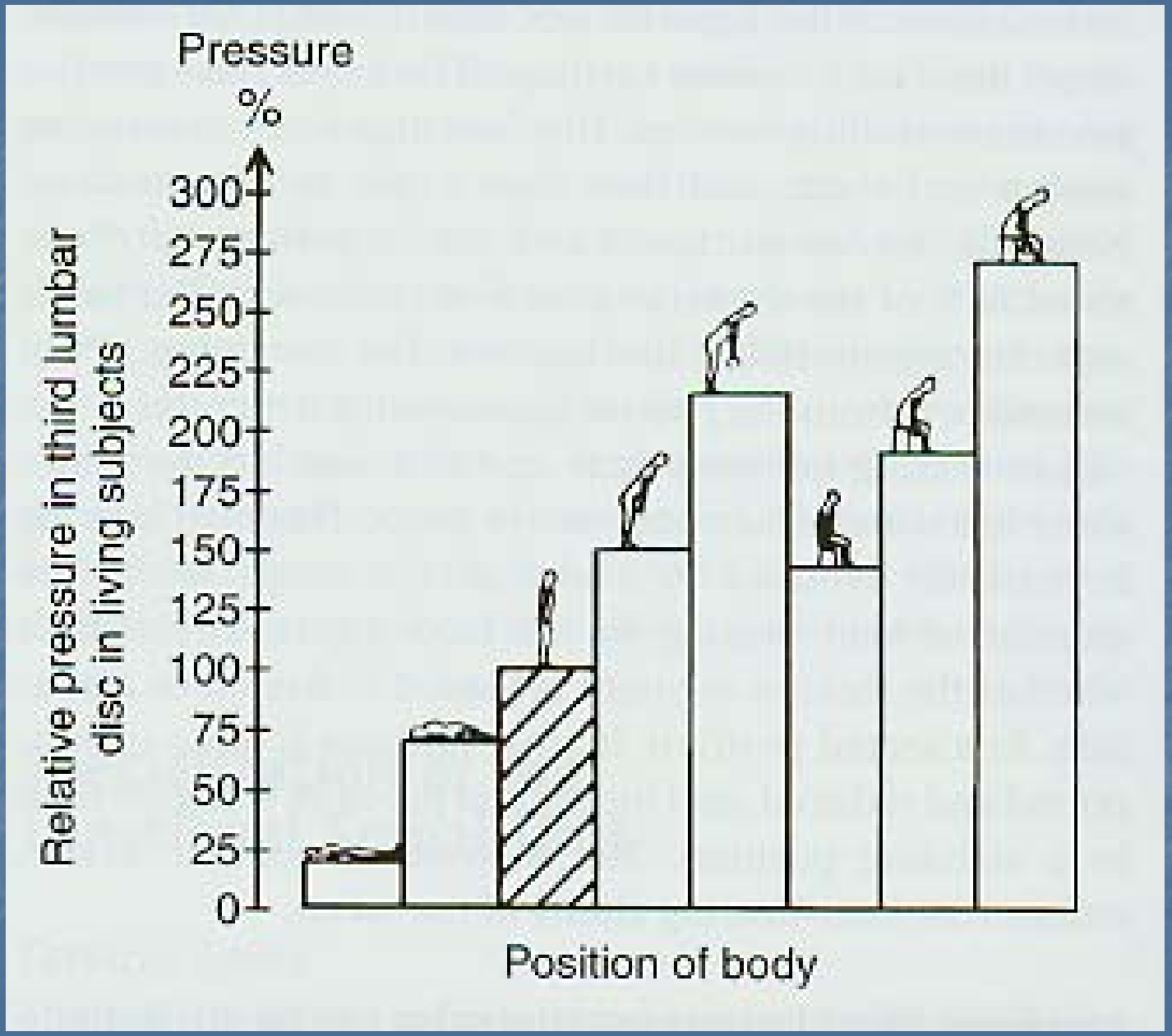

Ligamentum Flavum
Posterior Longitudinal Ligament
Capsular Ligament
Superior Vertebra
Supraspinous Ligaments
Disc Anulus
Interspinous Ligaments
Inferior Vertebra
Facet Joint
Anterior Longitudinal Ligament
Posterior Elements
Anterior Elements


FLEXION/
EXTENSION
LATERAL
BENDING
AXIAL
ROTATION
CERVICAL
THORACIC
LUMBAR
E
F
R
L
L+R

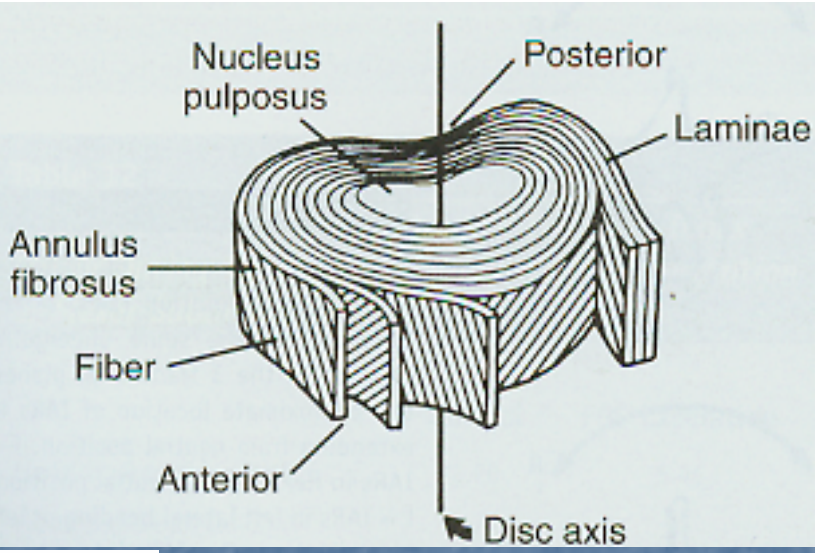
Disk

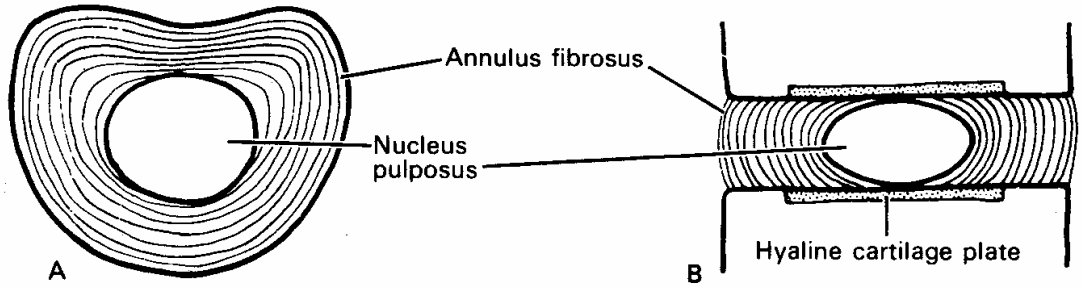
- Major restraint to motion
- Viscoelastic behavior, demonstrates Creep & Hysteresis
- Avascular
  - End-plate microfractures> vascular ingrowth & granulation tissue> altered mechanical behavior
  - End-plates influence the nutrition; diffusion
- Lumbar FSU
  - Disk – 40% of torque resistance
  - Rest by posterior element and ligaments
- Diurnal change in height
  - 1% shorter at night; 2% for children; 0.5% for elderly
  - 50% of height lost during first 2 hours in upright
- Healthy disks creep slower

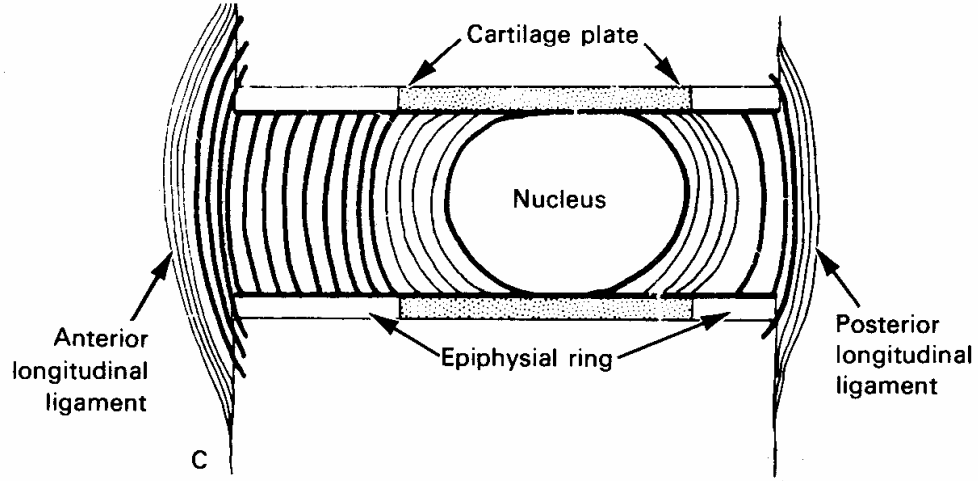
- Intradiscal Pressure
  - Compressive loads in vivo: 500N standing, 700N sitting
  - Increased to 3000 to 6000N during lifting of moderate weights, decreases with load closer to body
  - Estimate of P = 1.5X compressive load divided by the cross sectional area
  - Disk pressure is usually uniform
  - Pressure lowest in supine position
  - Disk usually does not fail, but end plates fracture


Pressure
%
300
275
250
225
200
175
150
125
100
75
50
25
0
Relative pressure in third lumbar disc in living subjects
Position of body

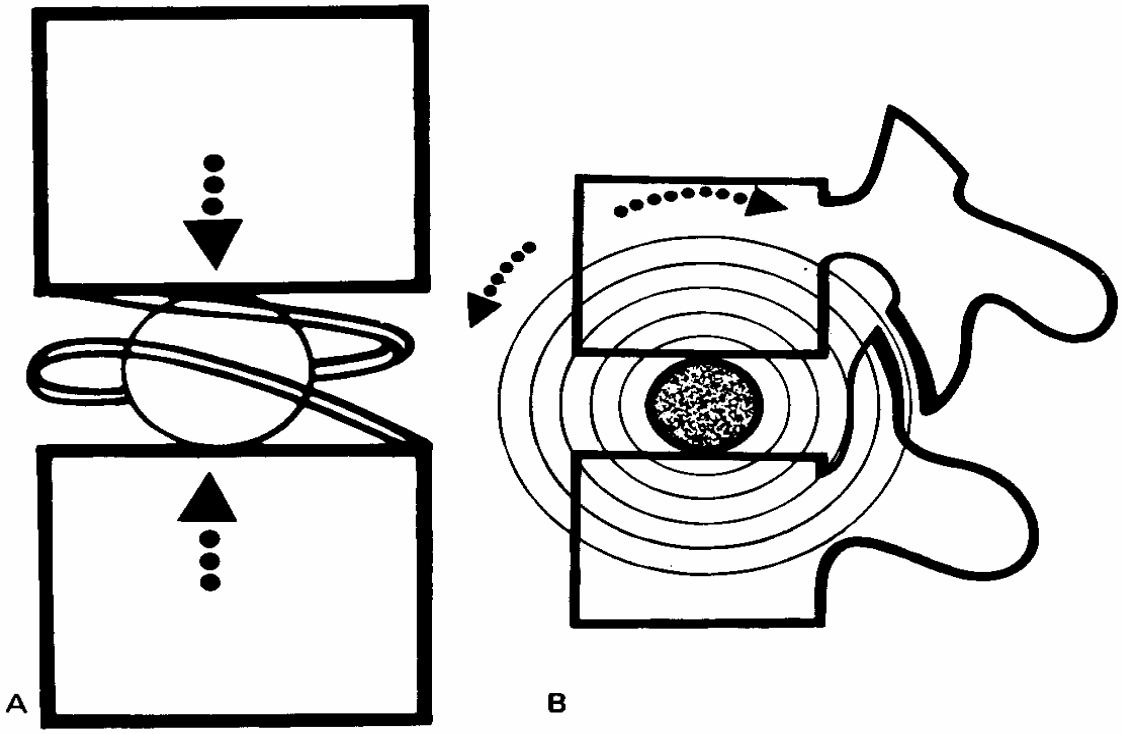
- Annulus Fibrosus
  - 90 collagen sheets
  - Fibers of adjacent sheets 30º to each other
  - Hyaline cartilage plates & bony ring epiphyses of vertebral bodies
  - Vertical component – tension resistor during flex-ex & lateral bending
  - Horizontal component – rotary stress
  - Axial load – tensile stress

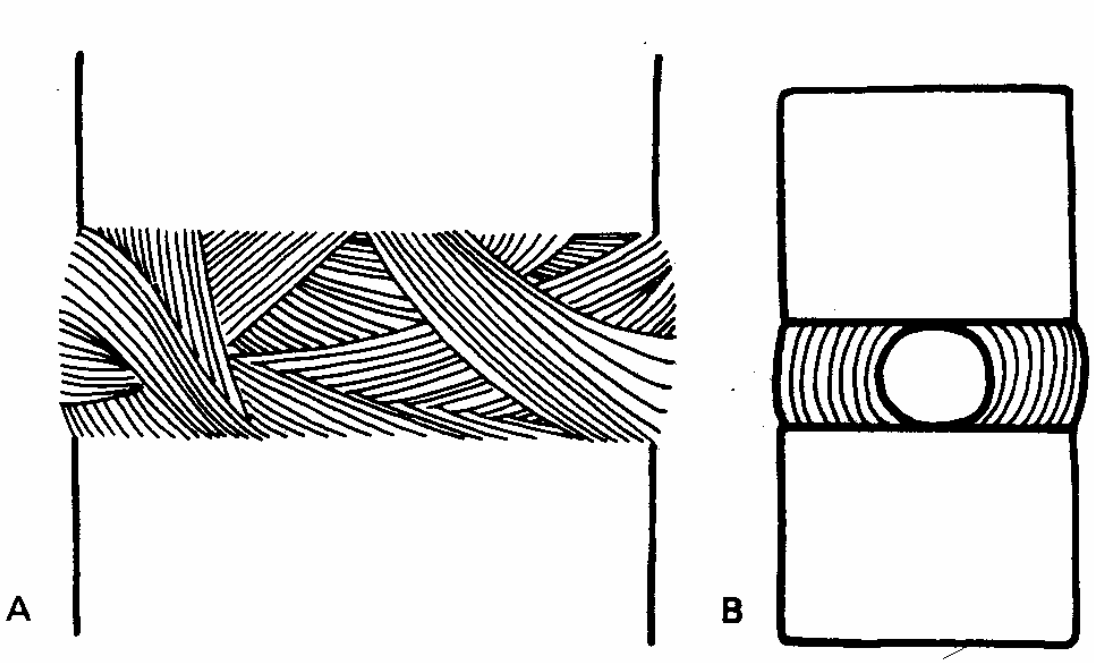

Nucleus pulposus
Posterior
Laminae
Annulus fibrosus
Fiber
Anterior
Disc axis


Annulus fibrosus
Nucleus pulposus
A
B
Hyaline cartilage plate

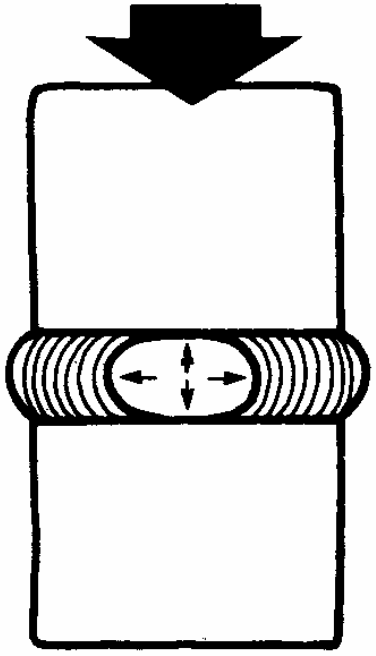

Cartilage plate
Nucleus
Anterior longitudinal ligament
Epiphysial ring
Posterior longitudinal ligament
C

- Nucleus Pulposus
  - Eccentrically positioned posteriorly
  - Young & healthy
    - 50% cross-sectional
    - 90% water, bound to proteoglycans
  - Aging> dessication> increase viscosity> fissuring
  - Pascal's law
    - Fluid mass within closed container> local increase in pressure> transmit around entire side wall (annulus)
    - Young nucleus> even distribution of load
    - Old nucleus> undue concentration on vertebral body edges
  - Small displacement w/ ROM, ball-bearing like
  - Compressive stress predominates


A
B

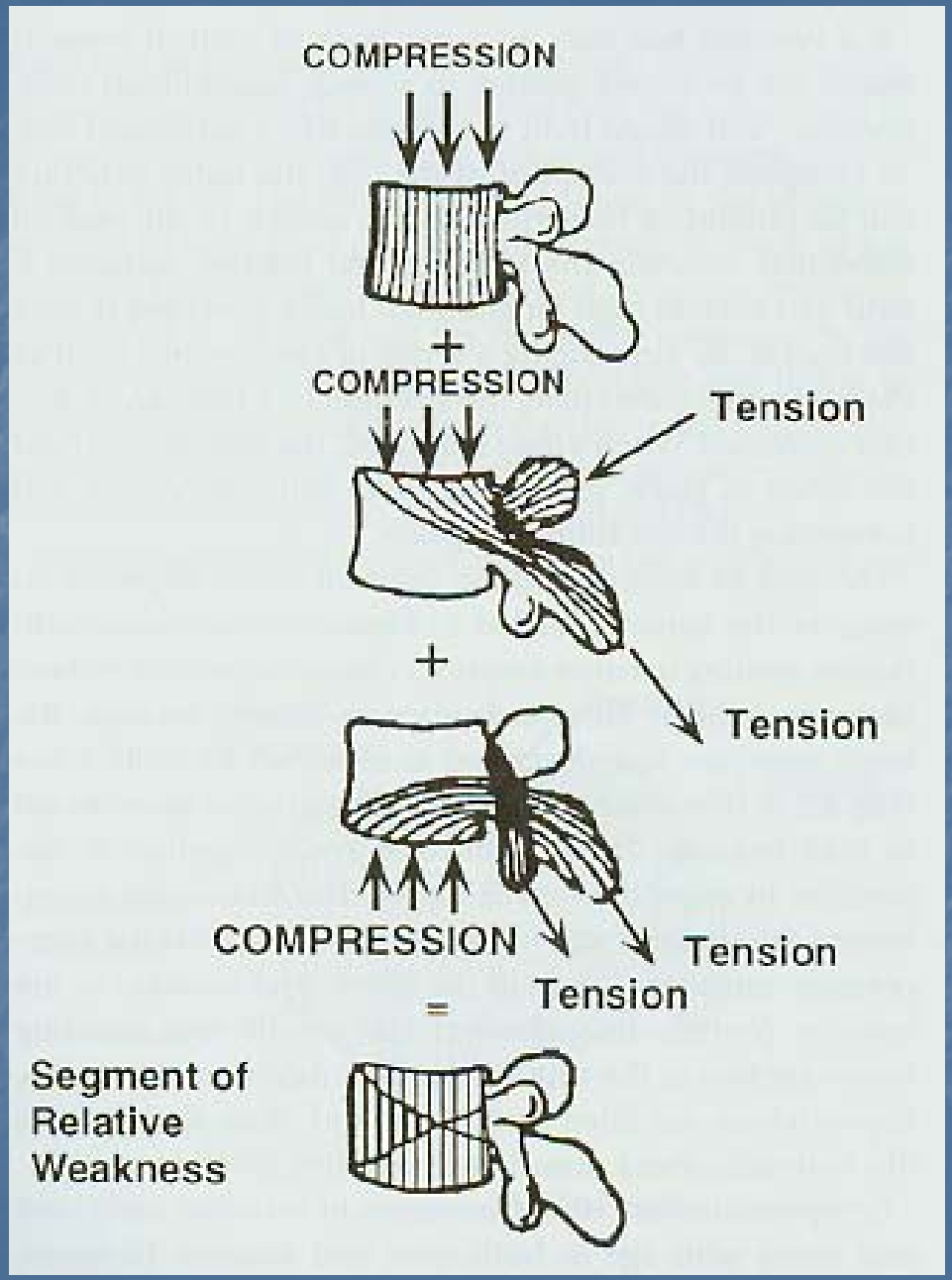

A

B



Vertebral Body

- Primary load-transmitting element, 80-90%
- Bone Mineral Content, Size
  - Osteoporosis> loss of horizontal trabeculae
  - Increasing size from C to L spine
- Compressive load> pressure higher in center of end plates than periphery
- In vivo, filled with blood> greater strength, hydraulic shock absorber
- Weaker anterior trabeculae, Wolff's law


COMPRESSION
+
COMPRESSION
Tension
+
Tension
COMPRESSION
Tension
Tension
=
Segment of
Relative
Weakness

Posterior Elements

- pedicles, lamina, facet joints, spinous & transverse processes
- Bony processes> lengthen moment arms of muscles
- Forces on processes> transmitted to Lamina
- Forces on posterior elements> transmitted to vertebral bodies from Pedicles
- Pars Interarticularis
  - Large bending forces; excessive extension
  - Thicker than rest of lamina
  - Common site of stress/fatigue fractures> weakens motion segment> spondylolithesis

- Facet Joints
  - Major role in controlling motion
  - Resist torsion & shear, role in compression
  - Lumbar FSU – facets 40% torque resistence, 40% disk, 20% ligaments
  - Load sharing varies with flexion & extension
    - Seated position> decreased lumbar lordosis> increased intradiscal pressure & decreased load-bearing of the facets
  - Orientation of facets
    - C spine - 45º transverse, parallel frontal
    - T spine - 60º transverse, 20º frontal
    - L spine - 90º transverse, 45º frontal
  - Capsules lax> allow gliding

Ligaments

- Nonsegmental longitudinal (ALL, PLL, supraspinous)
- Segmental longitudinal (interspinous, intertransverse, ligamenta flava)
- Capsular ligaments
- Limit motion, provide stability/equilibrium
- ALL
  - Interlinked to disks
  - Resists extension
  - 2X tensile strength of PLL

- PLL
  - Narrow over vertebral bodies, flare out over disks; thin lateral extension
  - Resists flexion
  - Ossification> spinal stenosis
- Ligamentum Flavum
  - Elastic & strong
  - “shingled” configuration with laminae
  - Lengthen w/ flexion, shorten w/ extension
  - Loss of disk height or hyperextension> buckle into spinal canal
- Interspinous & Supraspinous
  - Resist flexion
  - Long moment arms

Cervical Spine

- Almost infinite number of head positions
- Spinous processes increase in length distally
- C 1-2 almost transverse, C 2- T 1 45º to transverse
- Occipitoatlantoaxial complex – specialized articulation, large ROM, no disk
  - 60% axial rotation – C 1-2, difficult for occipital condyles to slide on C 1, no loss w/ aging
  - Lateral bending – small, alar ligament
  - IAR – close to cord, rotate without impingement

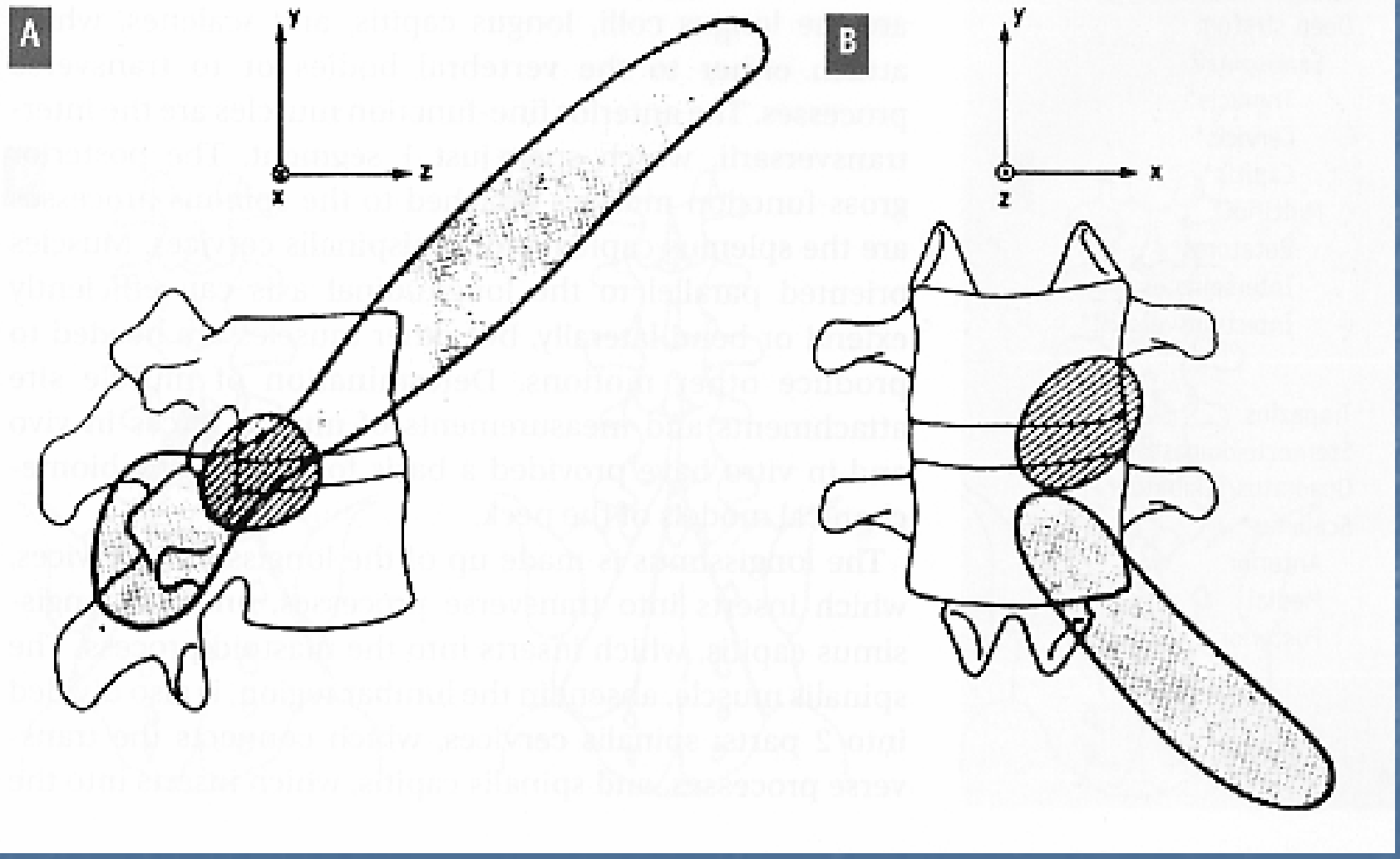
- C 3-7 - flex-ex predominates, lateral bending
  - IAR – lower vertebra (flex-ex); upper vertebra (lateral bending)
  - Distinct coupling pattern – lateral bending & axial rotation, spinous process point opposite to lateral bend
  - Axial rotation – limited by uncinate processes & facets
- Intradural sagittal diameter
  - 2-3mm lower in extension
  - Posteroinferior margin of upper vertebra & ligamentum flavum
  - Cord thicker in extension> less play in ext
  - Canal widest at C 1-2, narrows at C 5

Thoracic Spine

- Rigid, transition between C & L regions
- Facet orientation changes, may be abrupt T 9-12
- Flex-ex – upper: 4º, middle: 6º, lower: 12º
- Lateral bending – upper: 6º, lower 2/3: 9º
- Axial rotation – upper 1/2: 8º, lower 3 segments: 2º each
- Upper & lower region – lateral bending & axial rotation strongly coupled
- Middle – variable coupled motion

Lumbar Spine

- Flexion-Extension
  - large, due to sizable disks & lack of facet restraint
  - IAR – posterior half of disk, moves w/ flex-ext
    - Centrode – path of moving IAR
- Lateral bending – IAR on left side of disk w/ right bend
- Axial rotation – IAR in posterior nucleus
- Disk degeneration – IAR spread out


A
Y
Z
X
B
Y
X
Z

- Sagittal plane translation
  - 2-3 mm, normal in symptom free pts
  - Up to 5 mm in L 3-4 & L4-5, 4 mm in L5-S1
- Lateral bending & axial rotation coupling
  - Spinous processes point in same direction as lateral bending
  - Opposite of cervical, upper thoracic, lumbosacral

Sacroiliac Region

- Poorly understood
- Partly synovial, partly syndesmotic
- Stiff, coarse interdigitating articular surfaces
- IAR scattered
- Complete ankylosis in up to 76% over age of 50
- Joint motion – overcome ligamentous resistance, 1 leg stance

Vertebral Muscles

- Spine buckles w/ small compressive forces without muscles
- Anterior, posterior, lateral
- Gross-function – span several motion segs
- Fine-function – span 1 or 2 segs
- Deep back muscles are major spine movers; many other groups

Function	Muscles
Anterior	
Muscles in front flex the spine.	Longus collis*
If the muscle runs a little obliquely and contracts independently of the corresponding muscle on the opposite side, it rotates and bends the spine laterally, as well as flexes it.	Longus capitis Rectus capitis anterior Rectus capitis lateralis* Obliquus externus abdominis* Obliquus internus abdominis* Psoas major* Psoas minor* Iliacus Quadratus lumborum

Posterior

Muscles in back extend the spine.

If the muscle runs a little obliquely and contracts independently of the corresponding muscle on the opposite side, it rotates and bends the spine laterally, as well as extends it.

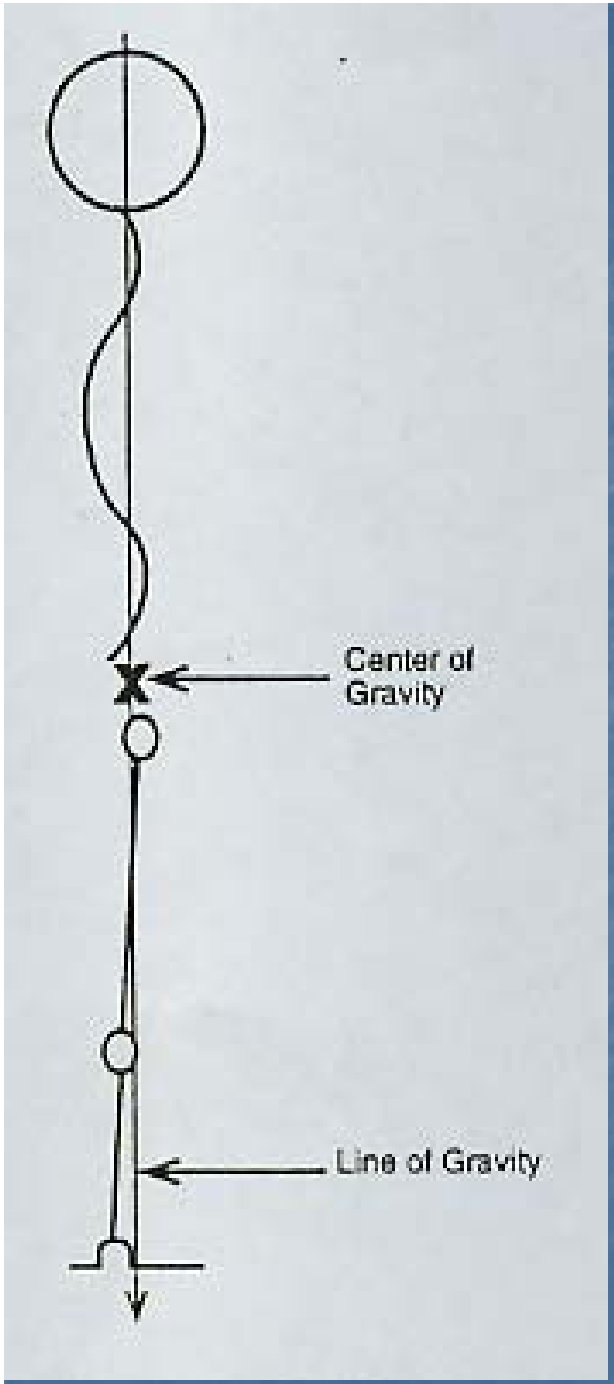
Superficial stratum

Splenius capitis**
Splenius cervicis*
Erector spinae (sacrospinalis)
Iliocostalis**
Longissimus*
Spinalis**
Deep stratum
- Semispinali
  - Thoracis*
  - Cervicis*
  - Capitis*
- Multifidi*
  - Rotatores*
  - Interspinales
  - Intertransversarii*

Lateral

Muscles on the side bend the spine laterally

- Trapezius
- Sternocleidomastoid*
- Quadratus lumborum
- Scalenus*
  - Anterior
  - Medial
  - Posterior



- Little muscular activity to maintain upright position
  - Spine in near equilibrium
  - Cervical & lumbar curvatures
  - Trunk relatively even in front & behind line of gravity
- Flexion
  - Anterior muscles initiate (isotonic)> anterior dysequilibrium> gravity takes over, controlled by extensors (eccentric)