
بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ
لَقَدْ خَلَقْنَا الْإِنسَانَ
فِي أَحْسَنِ تَقْوِيمٍ
صدق الله العظيم
(التين: ٤)

Review of Spine Biomechanics

By
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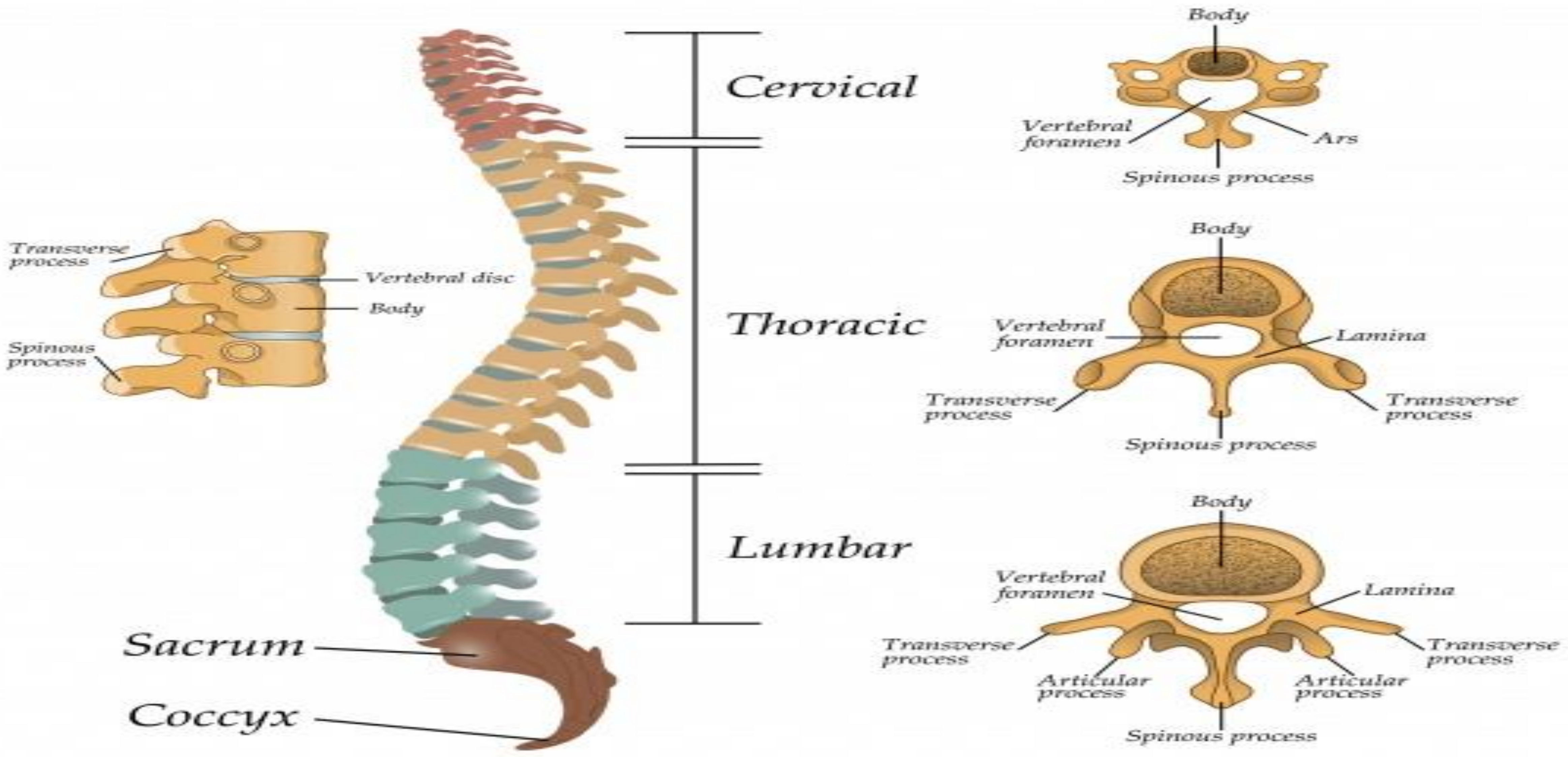
The structure of the segments of the spine



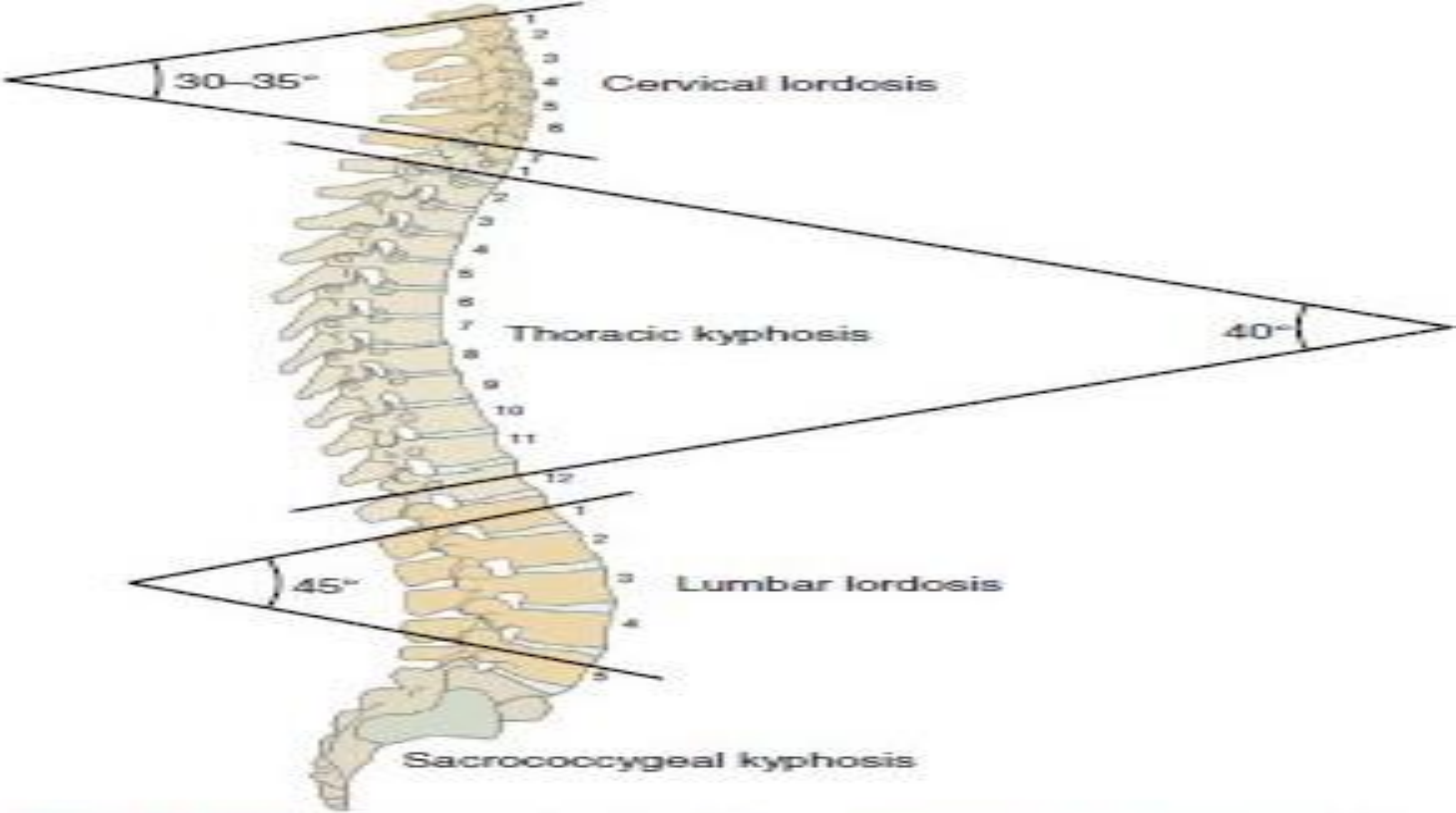


FIGURE 9–39. The normal sagittal plane curvatures across the regions of the vertebral column. The curvatures define the *neutral position* for each region, often referred to as "ideal" posture while standing.

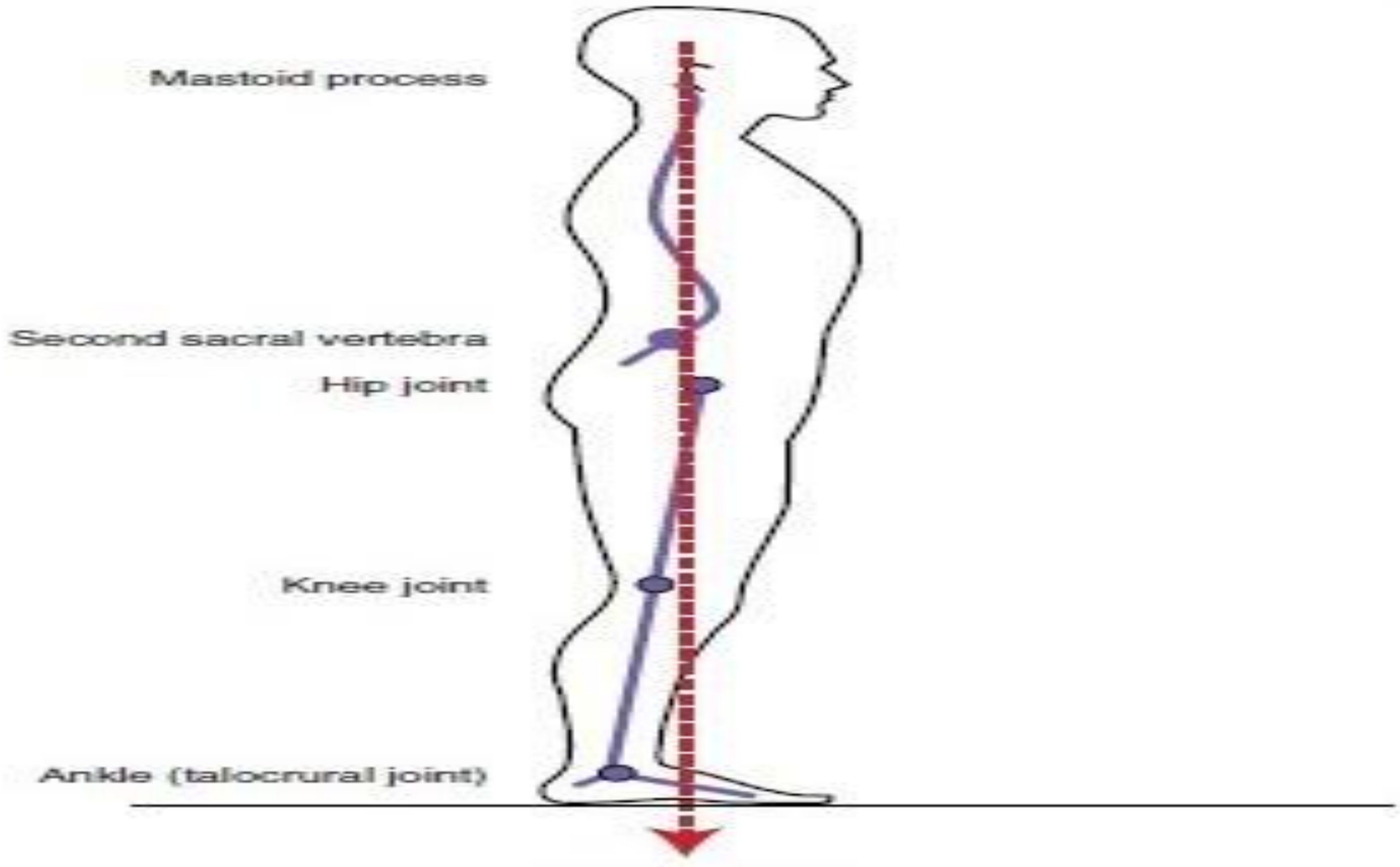
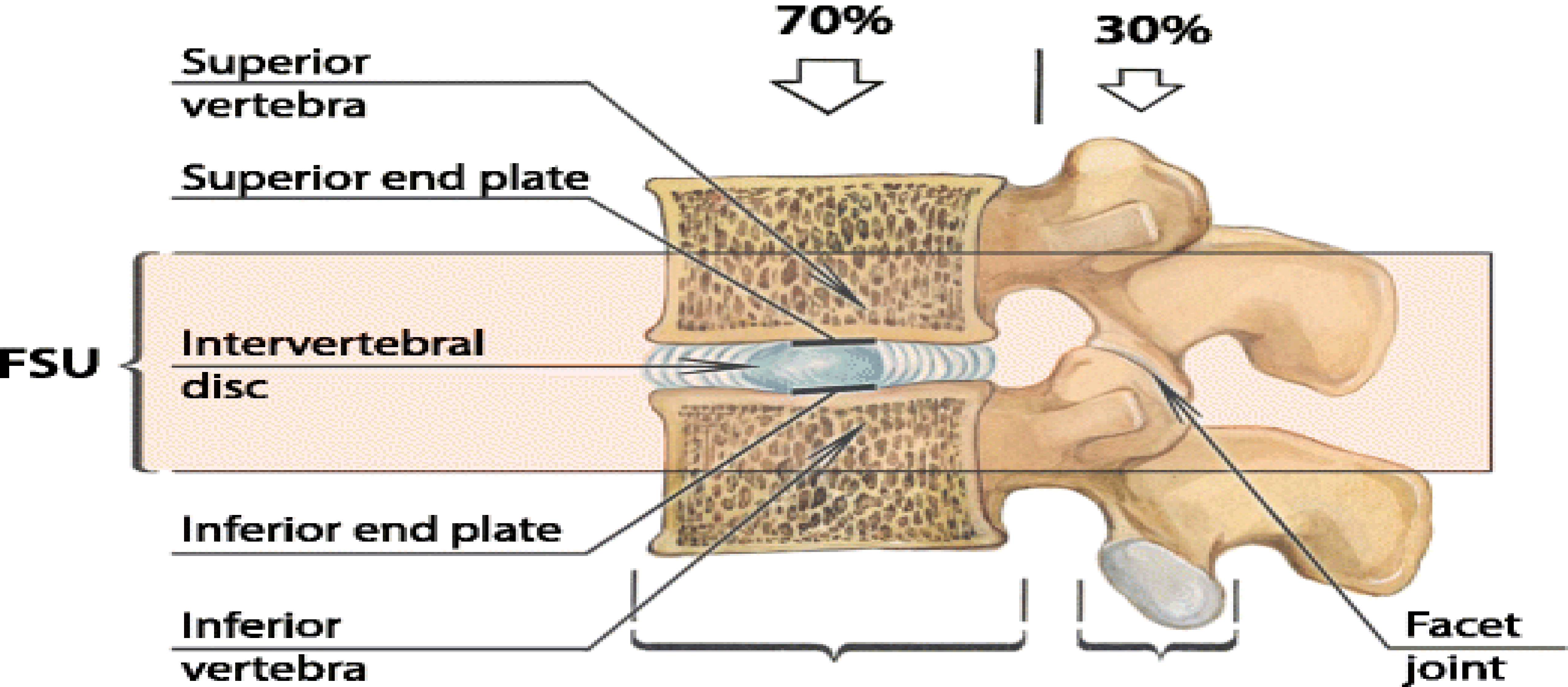
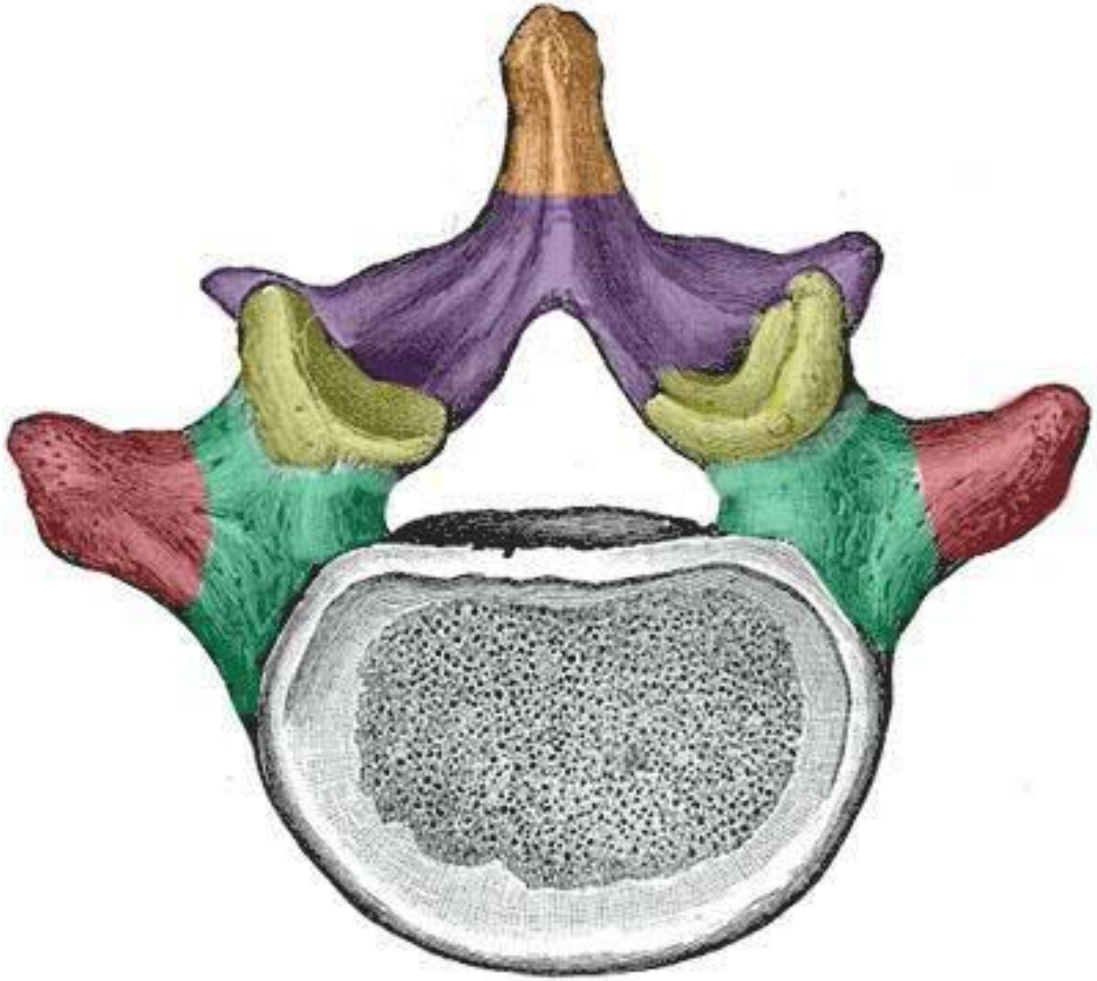


FIGURE 9-9. An illustration showing the line of gravity passing through the body of a person standing with ideal posture. (Modified from Neumann DA: Arthrokinesiologic considerations for the aged adult. In Guccione AA, ed: *Geriatric physical therapy*, ed 2, Chicago, 2000, Mosby.)

Functional spinal unit (FSU).





- Spinous process
- Lamina
- Superior articular processes
- Pedicles
- Transverse processes

Functional spinal unit (FSU)

- The FSU represents the smallest motion segment of the spine and exhibits biomechanical characteristics similar to those of the entire spine.
- Approximately 70% of applied axial compression is transmitted by the vertebral body and the intervertebral discs, with the remaining 30% of the load being distributed through the facet joints

Student activities (Project)

- On Functional unit of spine
- Individual or Group of two -Three students (NO more than Three)
- Should be delivered to the assistant lecturers or the coordinator of the course at the Lab sections
- Dead line 15/ 10/2024

Ligament support of vertebral column

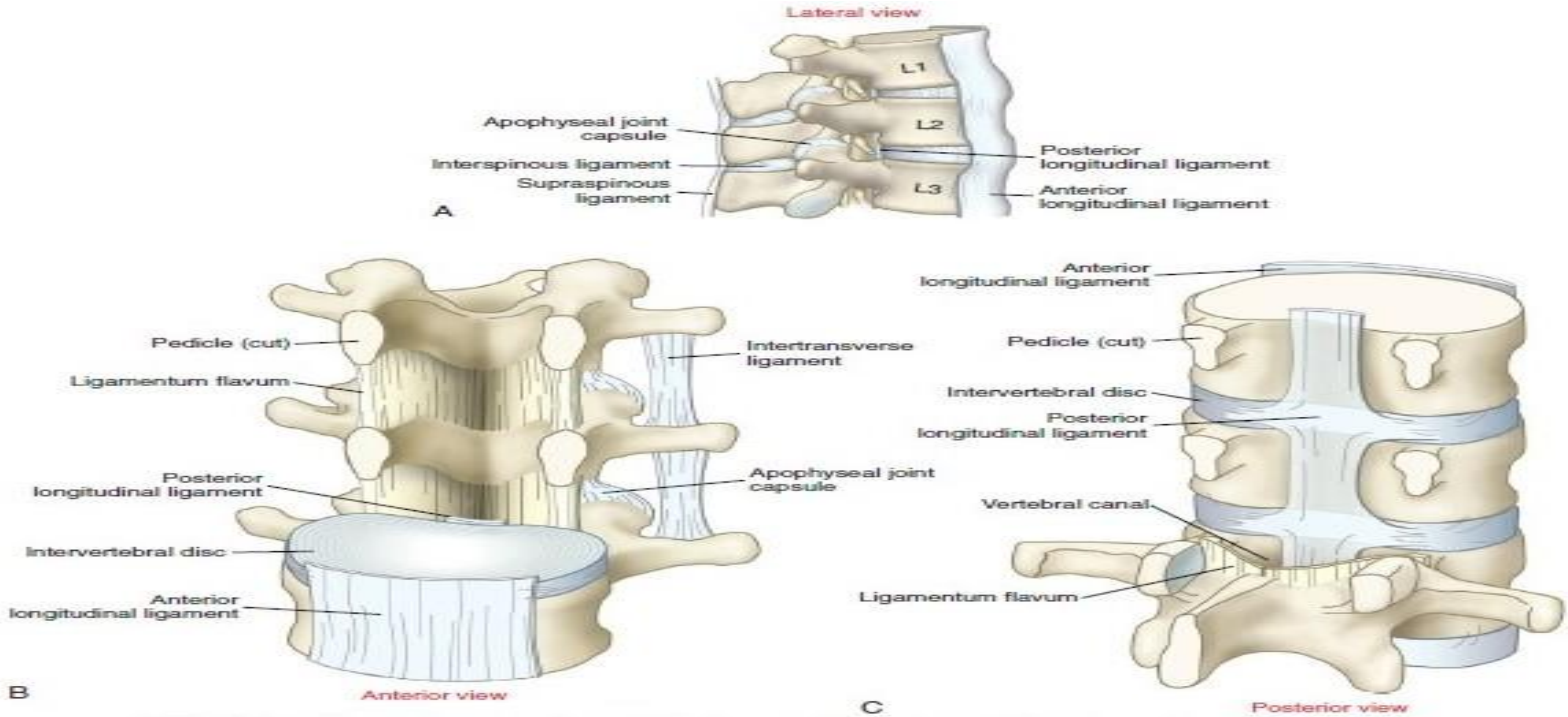


FIGURE 9-11. Primary ligaments that stabilize the vertebral column. **A,** Lateral overview of the first three lumbar vertebrae (L1 to L3). **B,** Anterior view of L1 to L3 vertebrae with the bodies of L1 and L2 removed by cutting through the pedicles. **C,** Posterior view of L1 to L3 vertebrae with the posterior elements of L1 and L2 removed by cutting through the pedicles. In **B** and **C,** the neural tissues have been removed from the vertebral canal.

Intervertebral Disc

- Soft fibro-cartilaginous cushions
  - Between two vertebra
  - Allows some motion
  - Serve as shock absorbers
- Total – 23 discs
- ¼ th of the spinal column's length
- Avascular
  - Nutrients diffuse through end plates

Intervertebral Disc Functions

- Movement of fluid within the nucleus
  - Allows vertebrae to rock back and forth Flexibility
- Act to pad and maintain the space between the twenty-four movable vertebrae
- Act as shock absorbers
- Allow extension and flexion

Thoracic region

- The thorax consists of a relatively rigid rib cage, formed by the ribs, thoracic vertebrae, and sternum.
- The rigidity of the region provides

1. stable base for muscles to control the craniocervical region,
2. protection for the intrathoracic vital organs,
3. a mechanical bellows for breathing

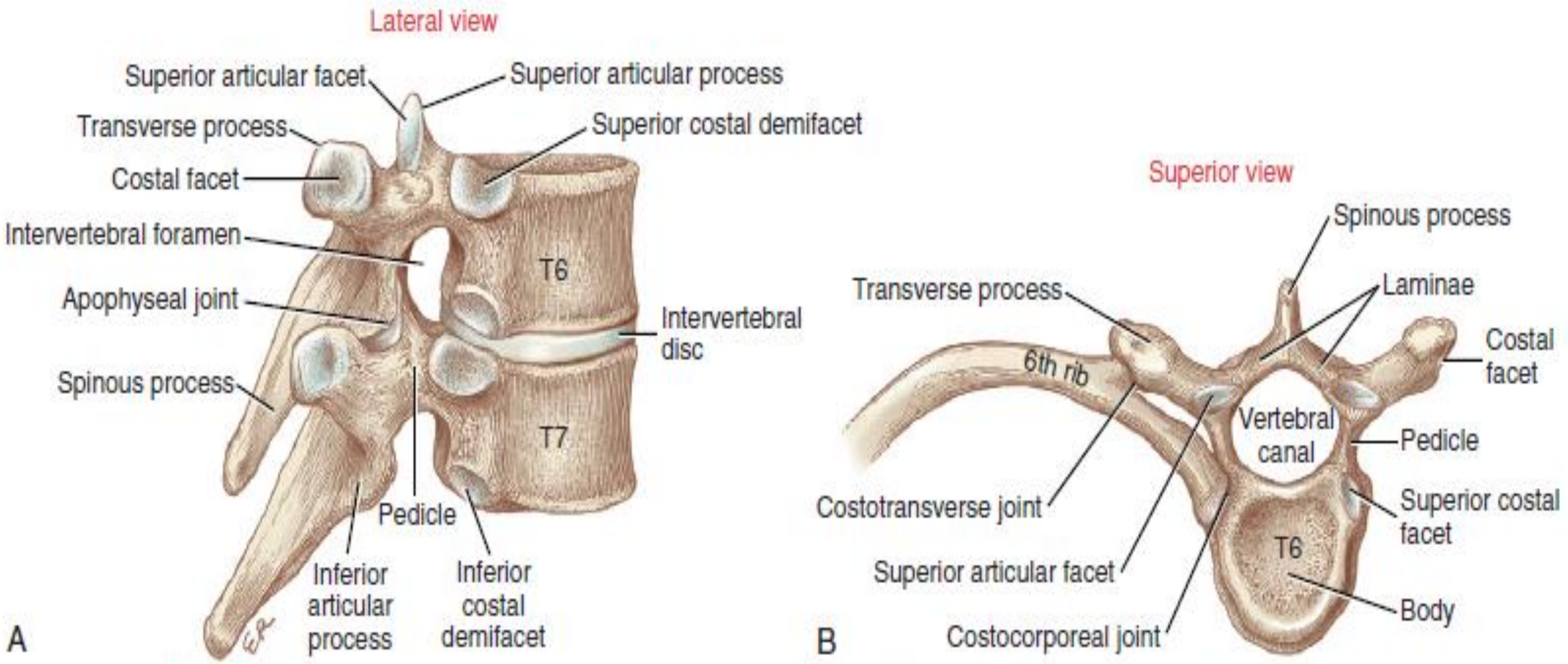
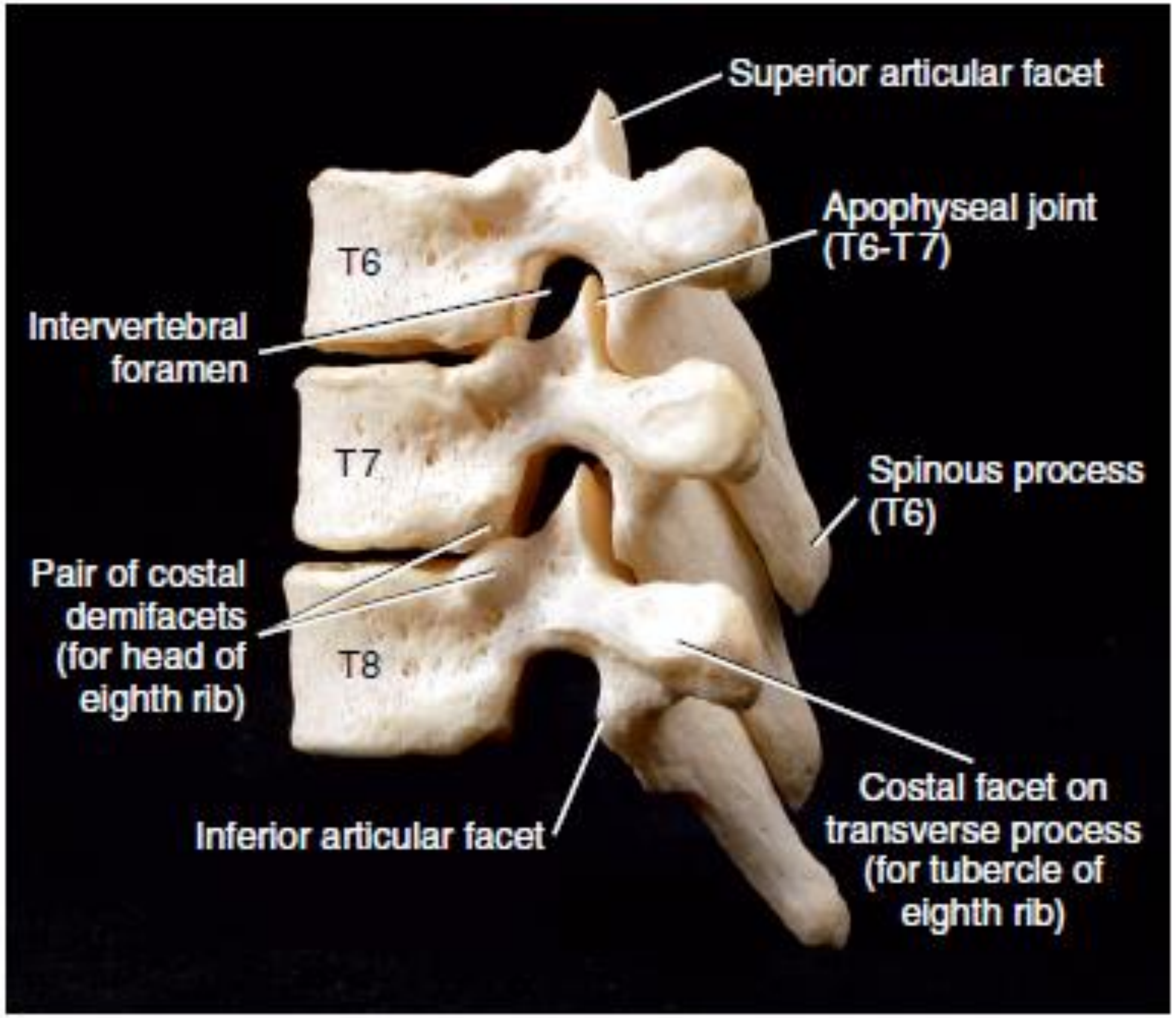
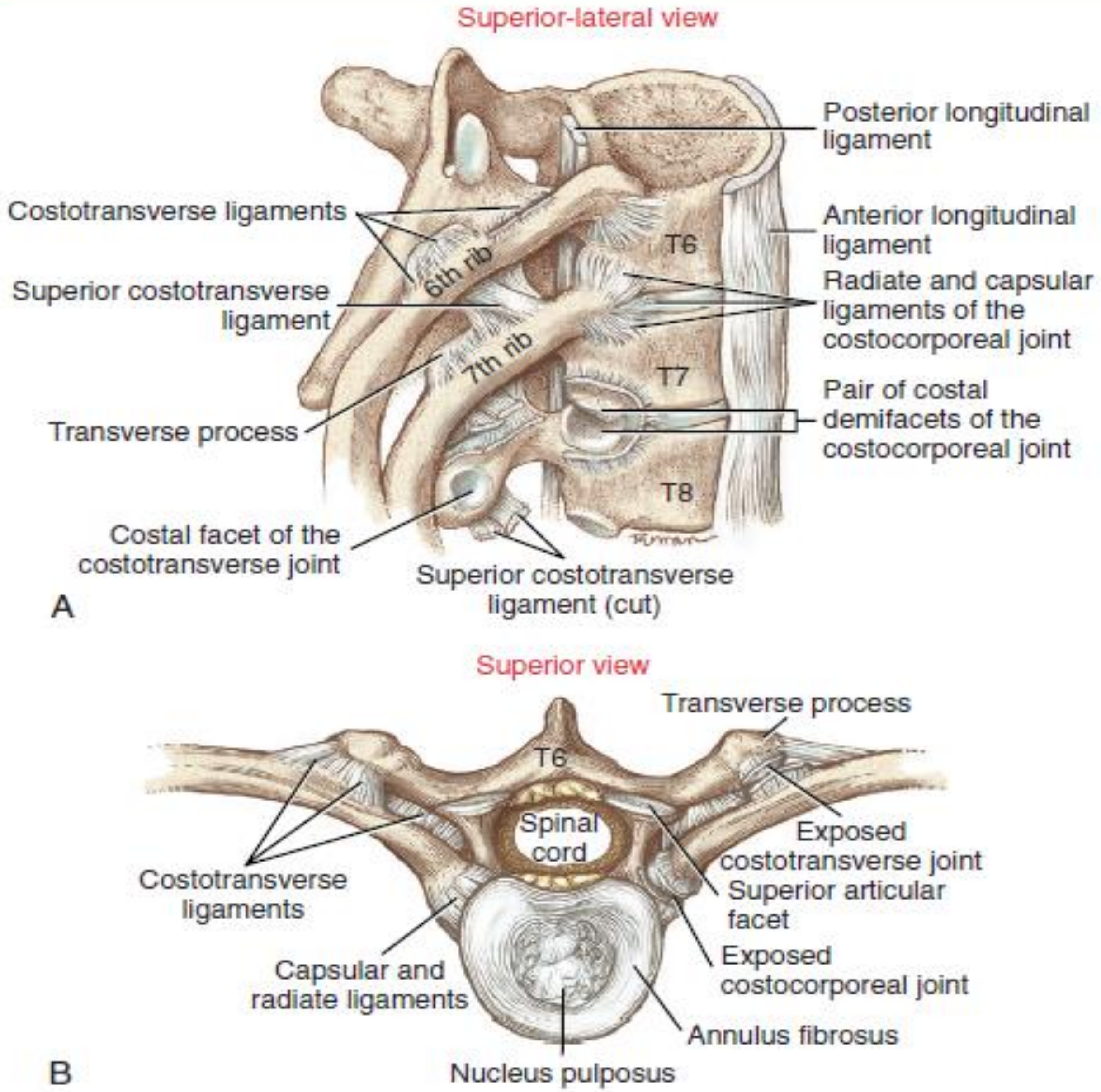


FIGURE 9-5. The essential characteristics of a vertebra. **A,** Lateral view of the sixth and seventh vertebrae (T6 and T7). **B,** Superior view of the sixth vertebra with right rib.

Lateral view





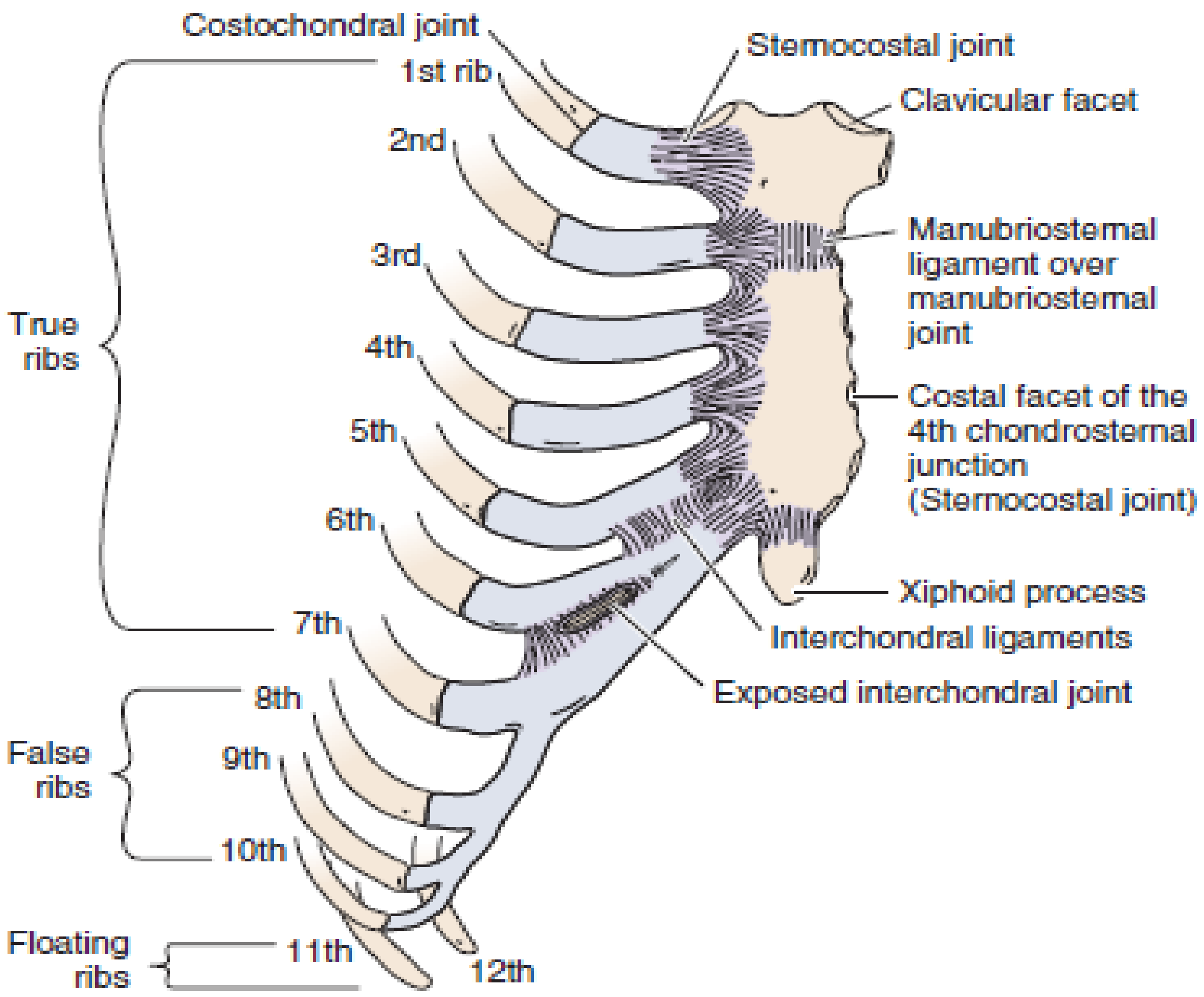
Key Anatomic Aspects of the Costocorporeal and Costotransverse Joints

Each Costocorporeal Joint

- Usually connects the head of rib with a pair of costal demifacets and the adjacent margin of an intervening intervertebral disc
- Is stabilized by radiate and capsular ligaments

Each Costotransverse Joint

- Usually connects the articular tubercle of a rib with the costal facet on the transverse process of a corresponding thoracic vertebra
- Is stabilized by the costotransverse and the superior costotransverse ligaments



Osteologic Features of the Sternum

- Manubrium
- Jugular notch
- Clavicular facets for sternoclavicular joints
- Body
- Costal facets for sternocostal joints
- Xiphoid process

Intrasternal Joints

- Manubriosternal joint
- Xiphisternal joint

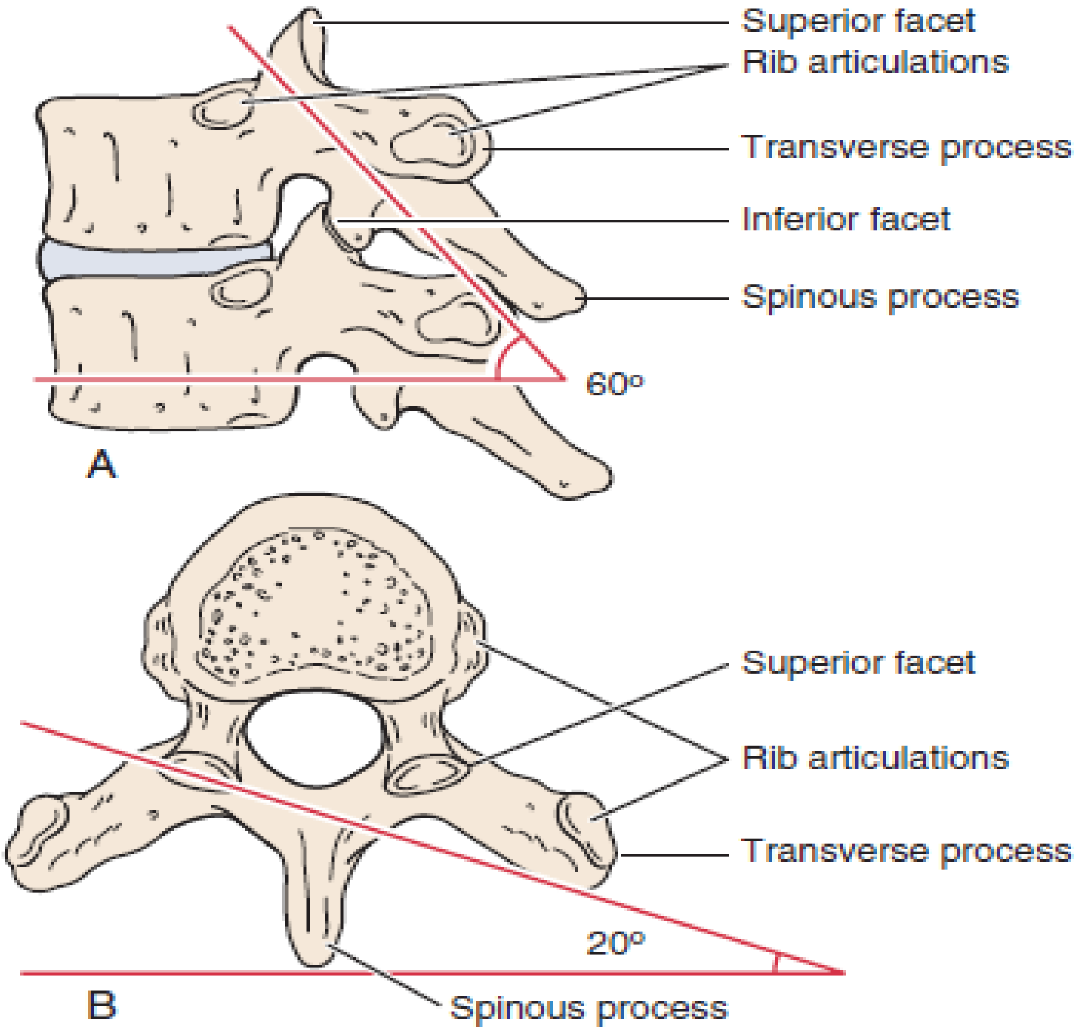


Figure 8-4 Thoracic vertebra. A, Side view. B, Superior view.

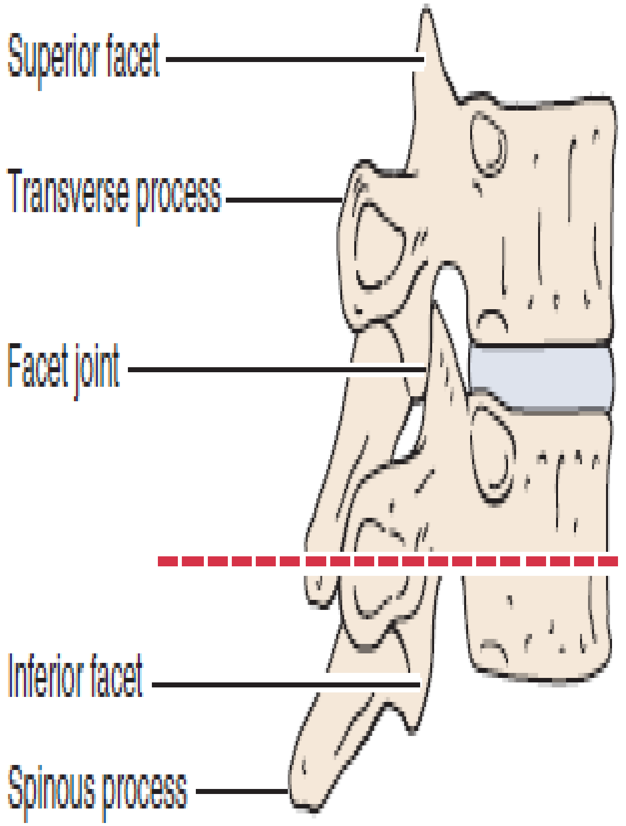


Figure 8-5 Spinous process of one thoracic vertebra at level of body of vertebra below (T7–T9).

Lateral view

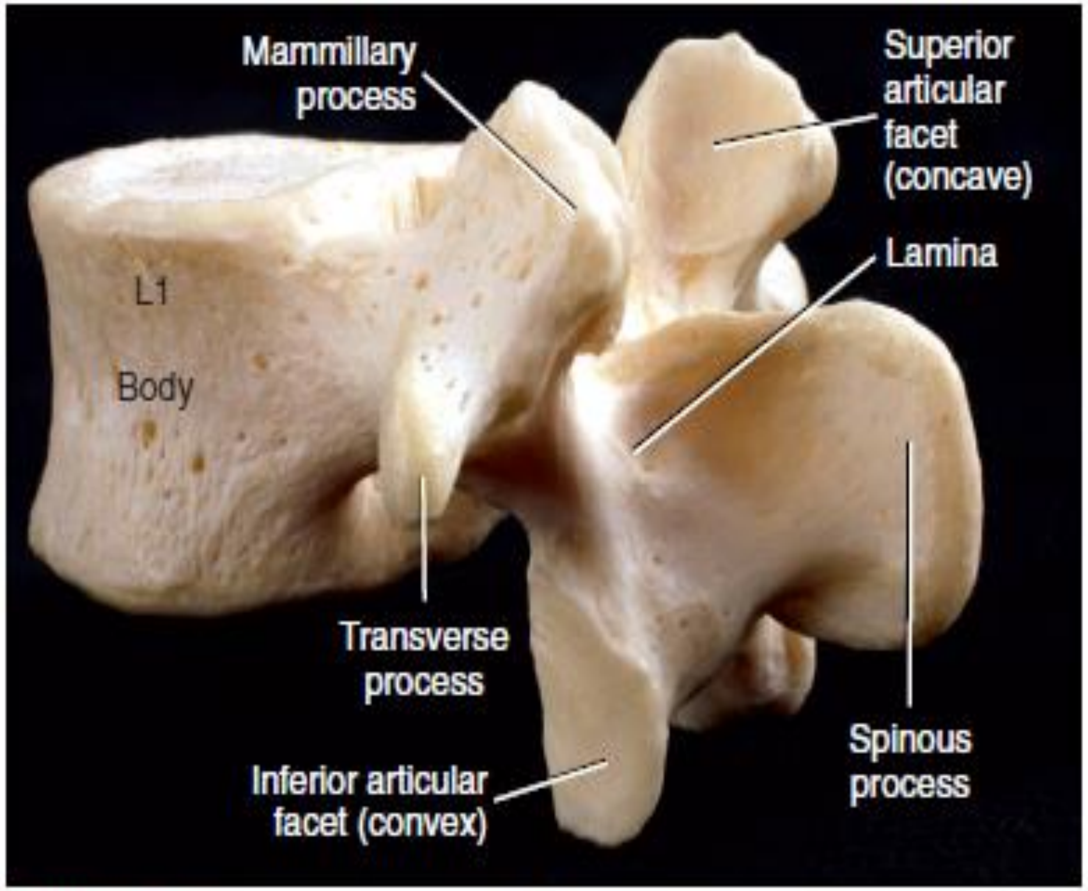


FIGURE 9-24. A lateral and slightly posterior view of the first lumbar vertebra.

Superior view

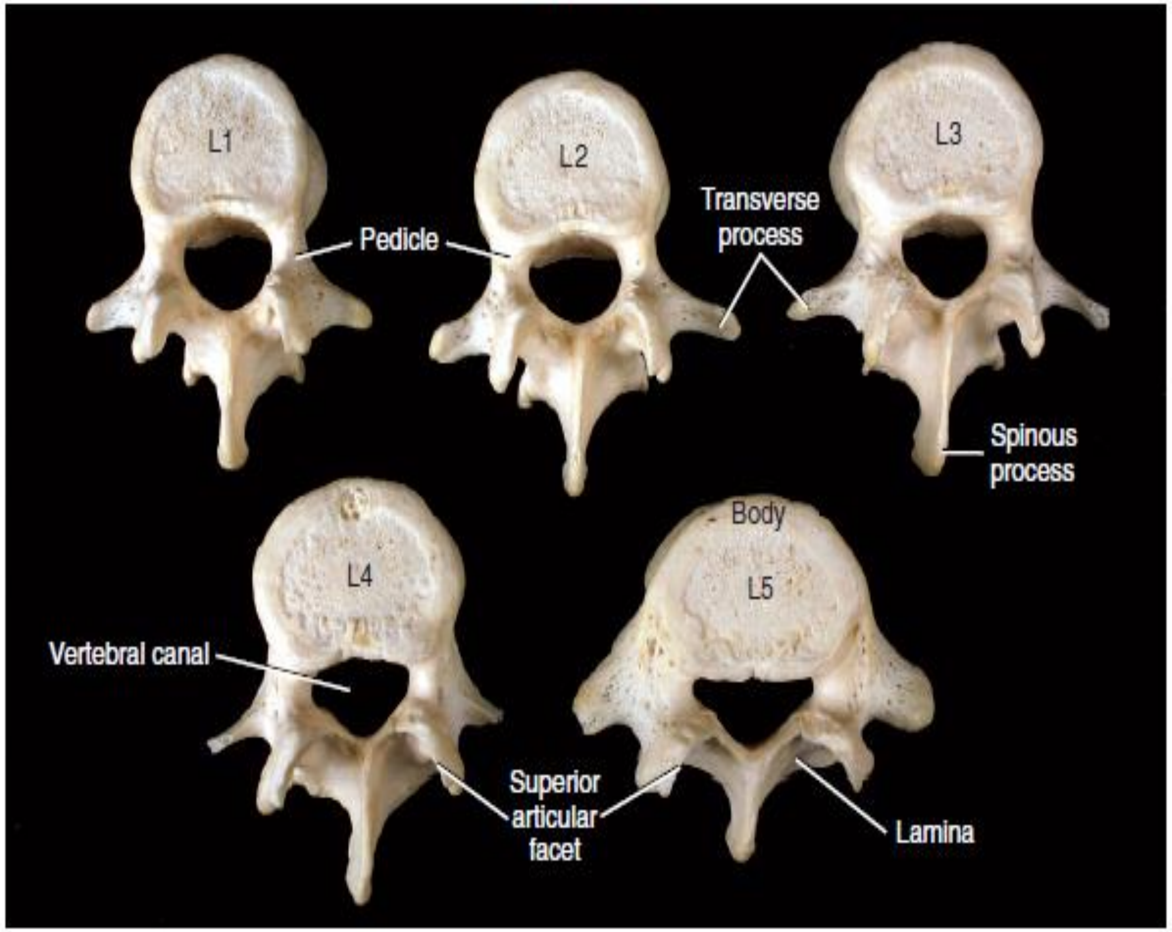
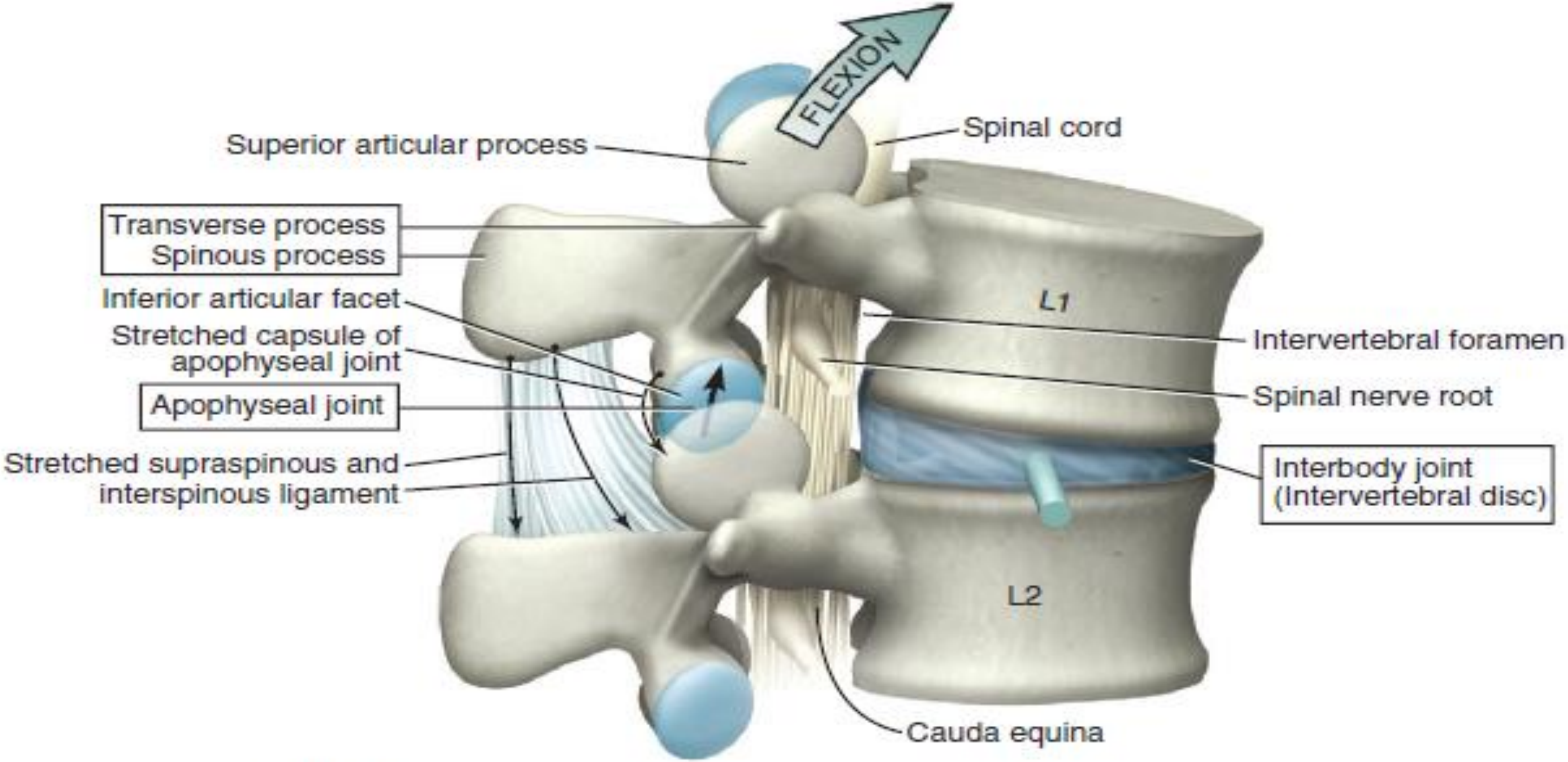
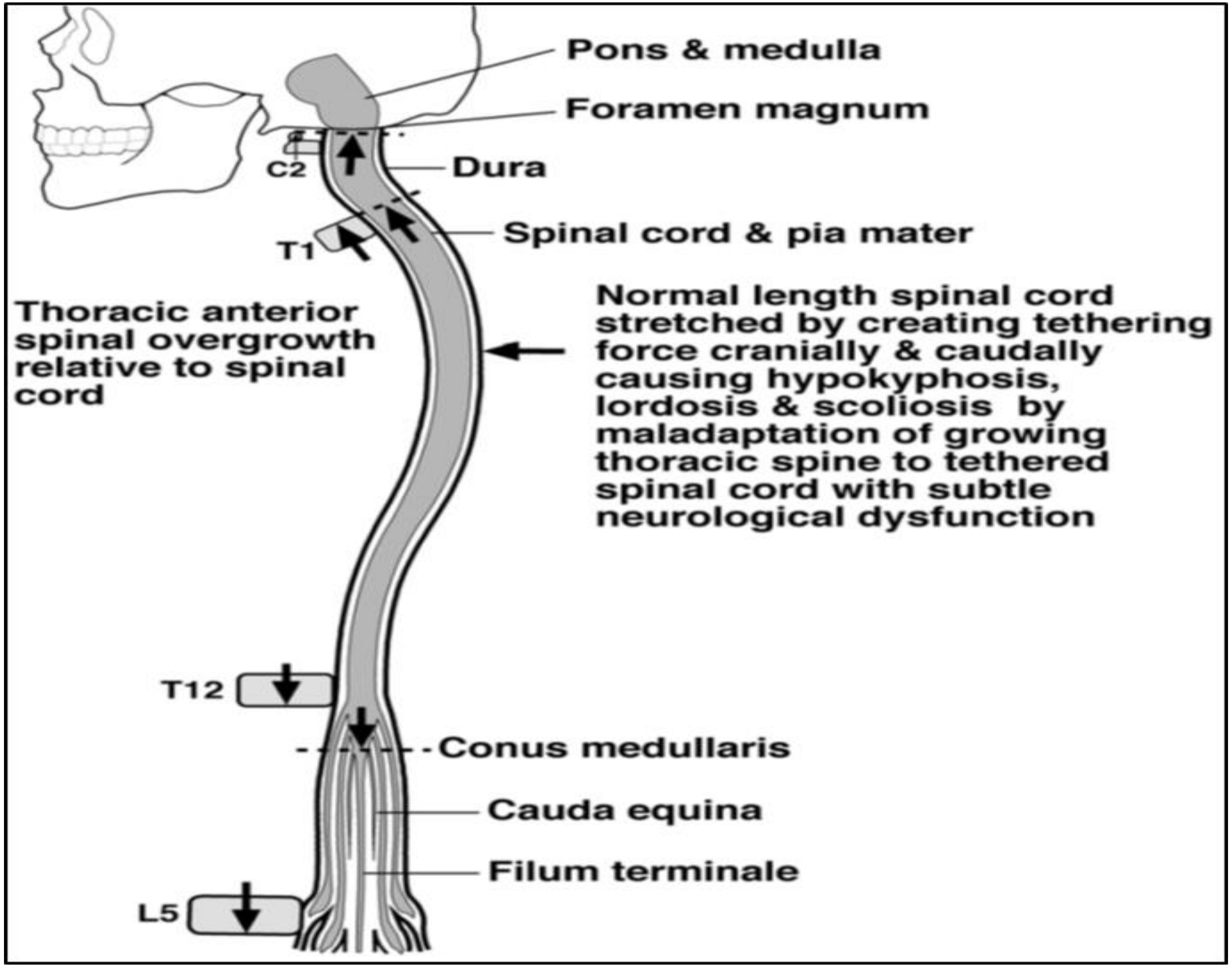


FIGURE 9-23. A superior view of the five lumbar vertebrae.



A model highlights the three functional components of a typical intervertebral junction: transverse and spinous processes, apophyseal joints, and interbody joint, including the intervertebral disc. The L1-L2 junction is shown flexing, guided by the sliding between the articular facet surfaces of the apophyseal joints *(black, thicker arrow).*


Pons & medulla
Foramen magnum
C2
Dura
Spinal cord & pia mater
T1
Thoracic anterior spinal overgrowth relative to spinal cord
Normal length spinal cord stretched by creating tethering force cranially & caudally causing hypokyphosis, lordosis & scoliosis by maladaptation of growing thoracic spine to tethered spinal cord with subtle neurological dysfunction
T12
Conus medullaris
Cauda equina
Filum terminale
L5

Osteokinematics of the axial skeleton

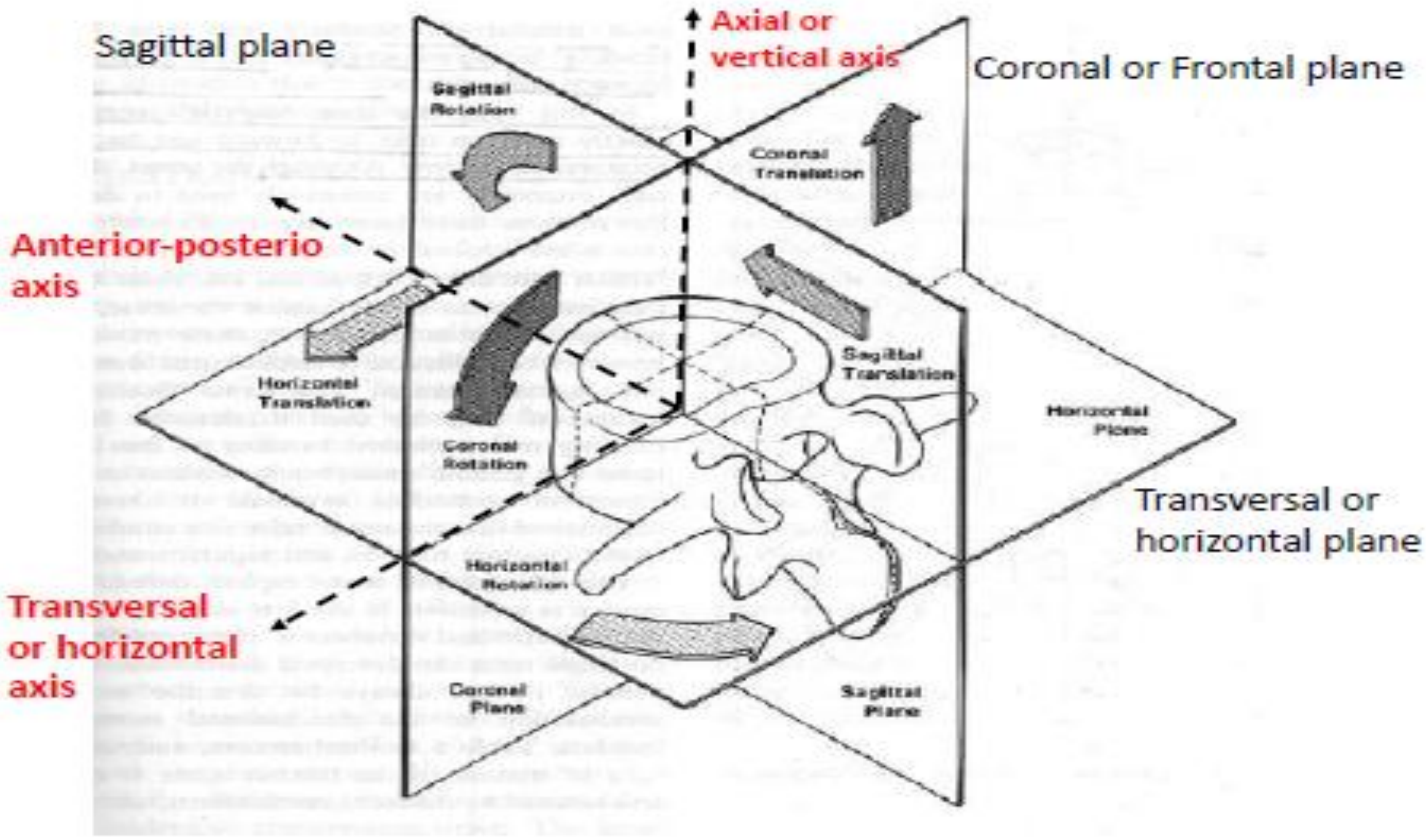
Terminology Describing the Osteokinematics of the Axial Skeleton

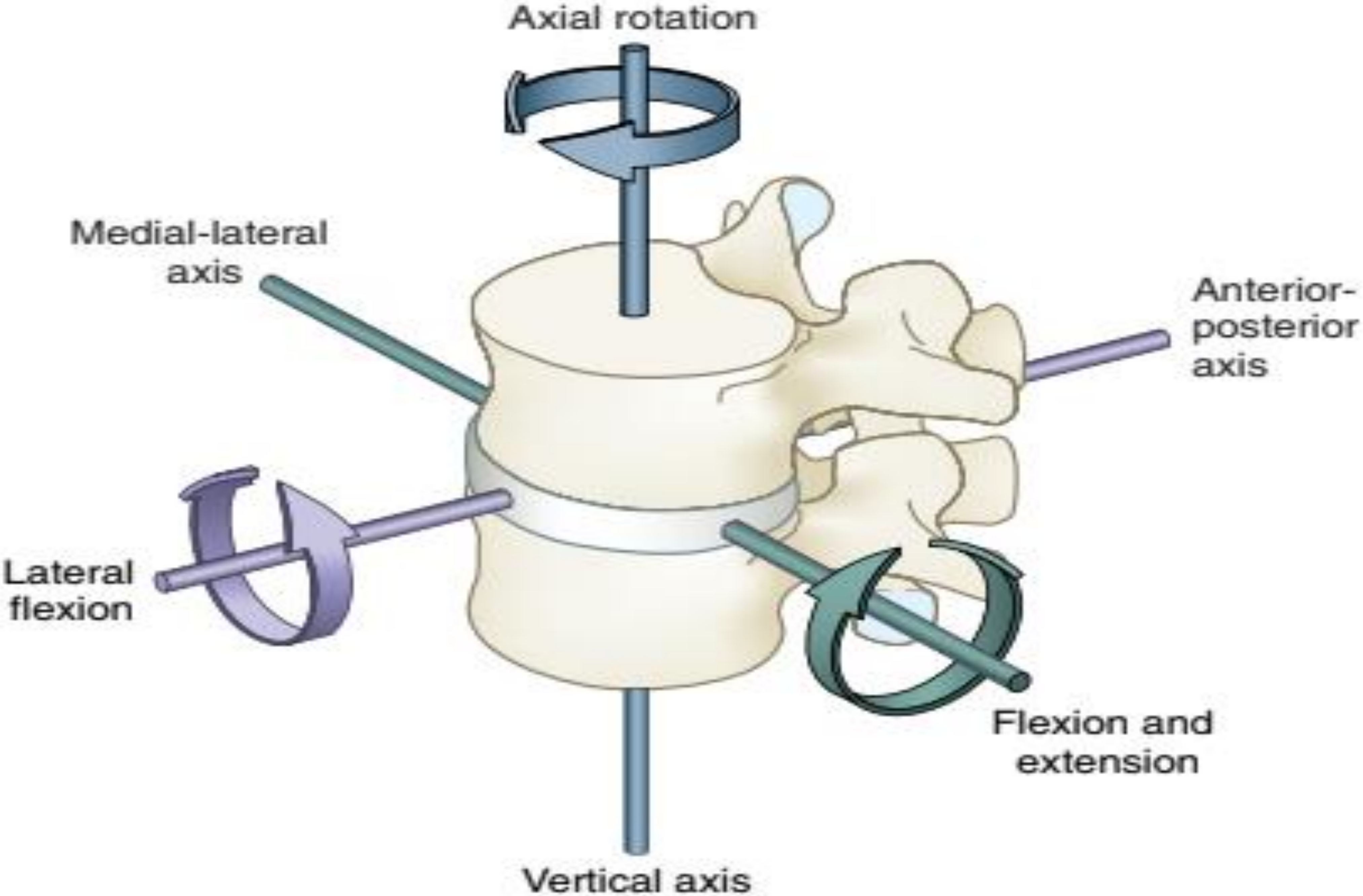
Common Terminology	Plane of Movement	Axis of Rotation	Other Terminology
Flexion and extension	Sagittal	Medial-lateral	Forward and backward bending
Lateral flexion to the right or left	Frontal	Anterior-posterior	Side bending to the right or left
Axial rotation to the right or left*	Horizontal	Vertical	Rotation, torsion

*Axial rotation of the spine is defined by the direction of movement of a point on the *anterior side* of the vertebral body.

FIGURE 9-30. Terminology describing the osteokinematics of the vertebral column; illustrated for a typical lumbar intervertebral junction.

Planes and Axes




Axial rotation
Medial-lateral
axis
Anterior-
posterior
axis
Lateral
flexion
Flexion and
extension
Vertical axis

Spinal Coupling

- Movement performed within any given plane throughout the vertebral column is usually associated with an automatic, and usually imperceptible, movement in another plane. This kinematic phenomenon is called *spinal coupling.*
- *Ipsilateral spinal coupling*
- *Contralateral spinal coupling*
- Causes may include

1. muscle action,
2. Articular facet alignment within apophyseal joints,
3. preexisting posture, attachment of ribs,
4. stiffness of connective tissues, and
5. geometry of the physiologic curve itself.

CLINICAL PEARL

Within the spine, only two articulations permit pure axial rotation:

- The A-A joint
- The thoracolumbar junction

Kinematics

Convex-Concave rule

For spine, convex rule applies at the Atlantoccipital joint, below C2 concave rule applies

Arthrokinematics of the Apophyseal joint

TABLE 9-5. Terminology Describing the Arthrokinematics at the Apophyseal Joints

Terminology	Definition	Functional Example
Approximation of joint surfaces	An articular facet surface tends to move closer to its partner facet. Joint approximation is usually caused by a *compression* force.	Axial rotation between L1 and L2 typically causes an approximation (compression) of the contralateral apophyseal joint
Separation (gapping) between joint surfaces	An articular facet surface tends to move away from its partner facet. Joint separation is usually caused by a *distraction* force.	Therapeutic traction as a way to decompress or separate the apophyseal joints
Sliding (gliding) between joint surfaces	An articular facet translates in a linear or curvilinear direction relative to another articular facet. Sliding between joint surfaces is caused by a force directed tangential to the joint surfaces.	Flexion-extension of the mid to lower cervical spine

TABLE 9-8. Approximate Range of Motion for the Three Planes of Movement for the Thoracic Region

Flexion and Extension (Sagittal Plane, Degrees)	Axial Rotation (Horizontal Plane, Degrees)	Lateral Flexion (Frontal Plane, Degrees)
Flexion: 30-40 Extension: 20-25 Total: 50-65	30-35	25-30

TABLE 9-9. Approximate Range of Motion for the Three Planes of Movement for the Lumbar Region

Flexion and Extension (Sagittal Plane, Degrees)	Axial Rotation (Horizontal Plane, Degrees)	Lateral Flexion (Frontal Plane, Degrees)
Flexion: 40-50 Extension: 15-20 Total: 55-70	5-7	20

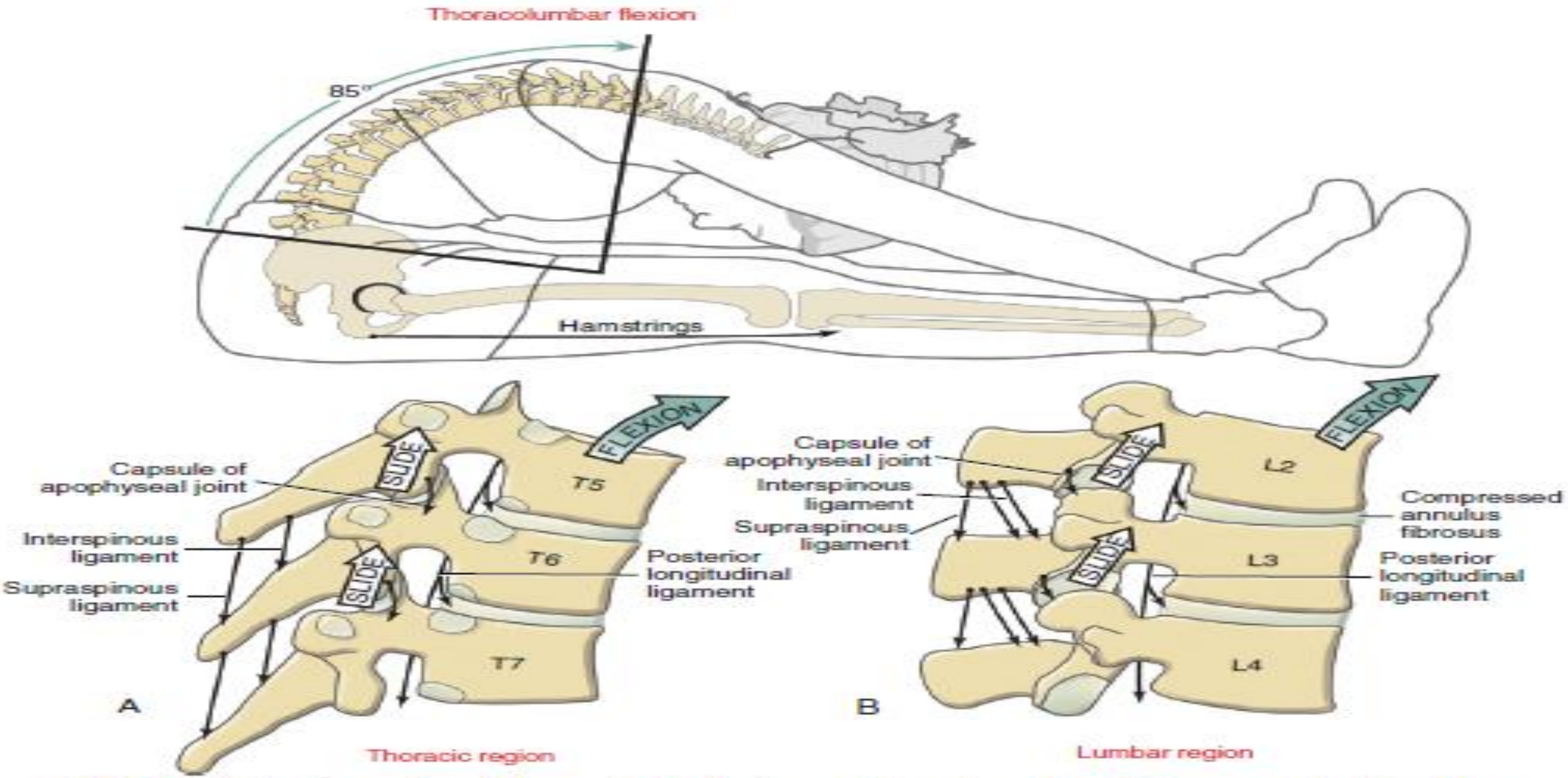


FIGURE 9-52. The kinematics of thoracolumbar flexion are shown through an 85-degree arc: in this subject, the sum of 35 degrees of thoracic flexion and 50 degrees of lumbar flexion. **A,** Kinematics at the thoracic region. **B,** Kinematics at the lumbar region. Elongated and taut tissues are indicated by thin black arrows.

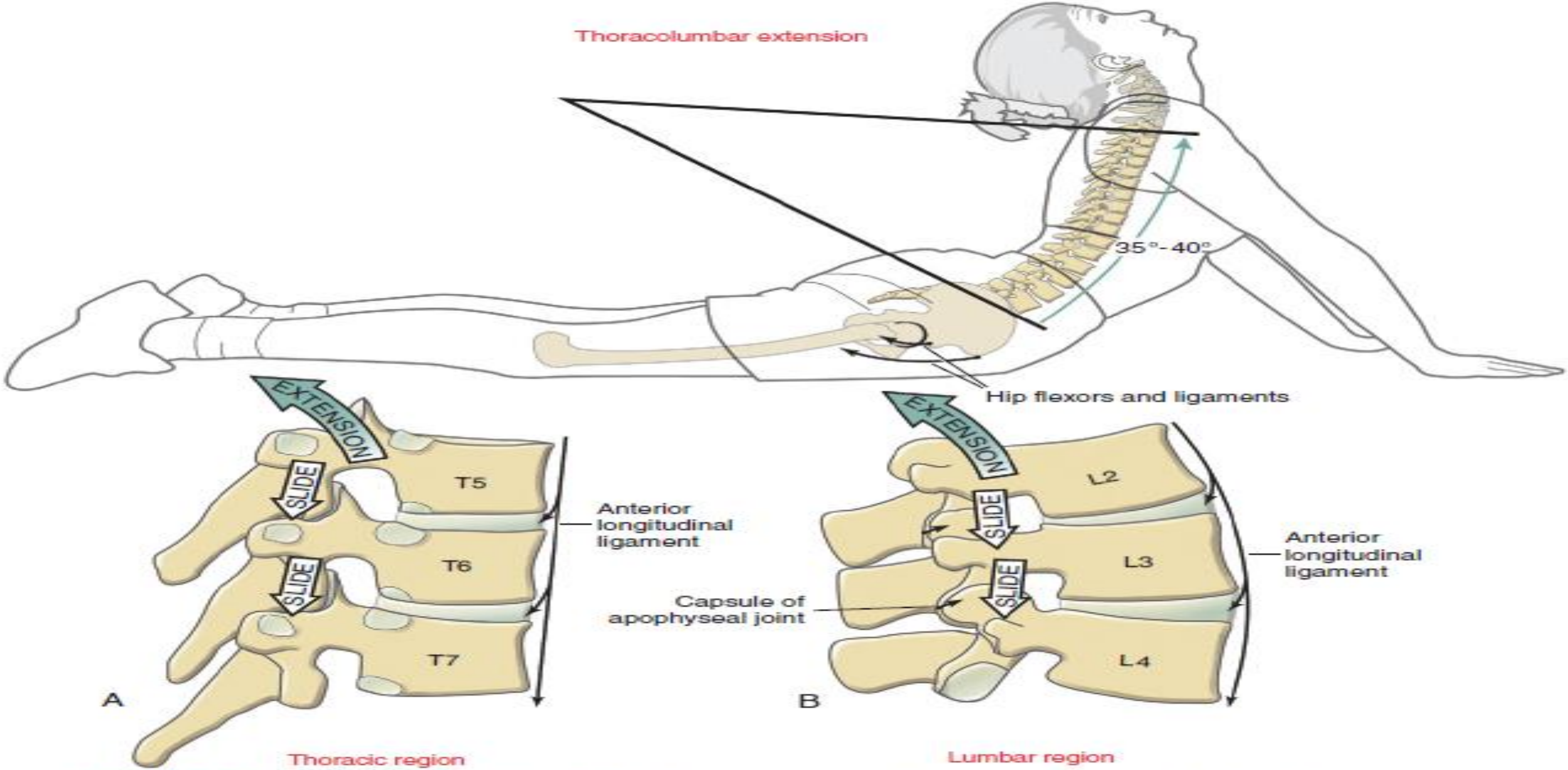


FIGURE 9-53. The kinematics of thoracolumbar extension are shown through an arc of 35 to 40 degrees: the sum of 20 to 25 degrees of thoracic extension and 15 degrees of lumbar extension. **A,** Kinematics at the thoracic region. **B,** Kinematics at the lumbar region. Elongated and taut tissue is indicated by thin black arrows.

Thoracolumbar axial rotation

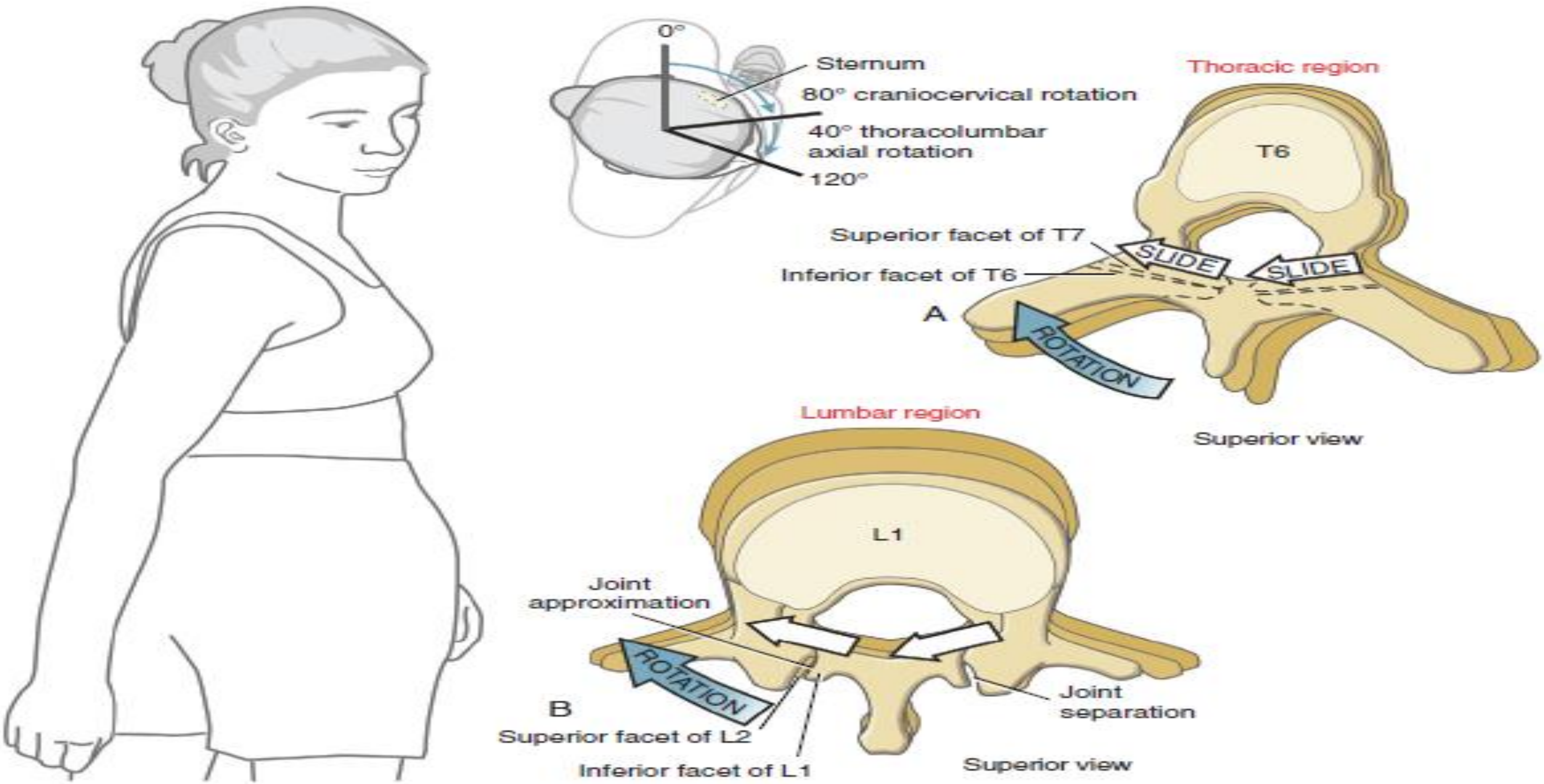


FIGURE 9-54. The kinematics of thoracolumbar axial rotation is depicted as the subject rotates her face 120 degrees to the right. The thoracolumbar axial rotation is shown through an approximate 40-degree arc: the sum of about 35 degrees of thoracic rotation and 5 degrees of lumbar rotation. **A,** Kinematics at the thoracic region. **B,** Kinematics at the lumbar region.

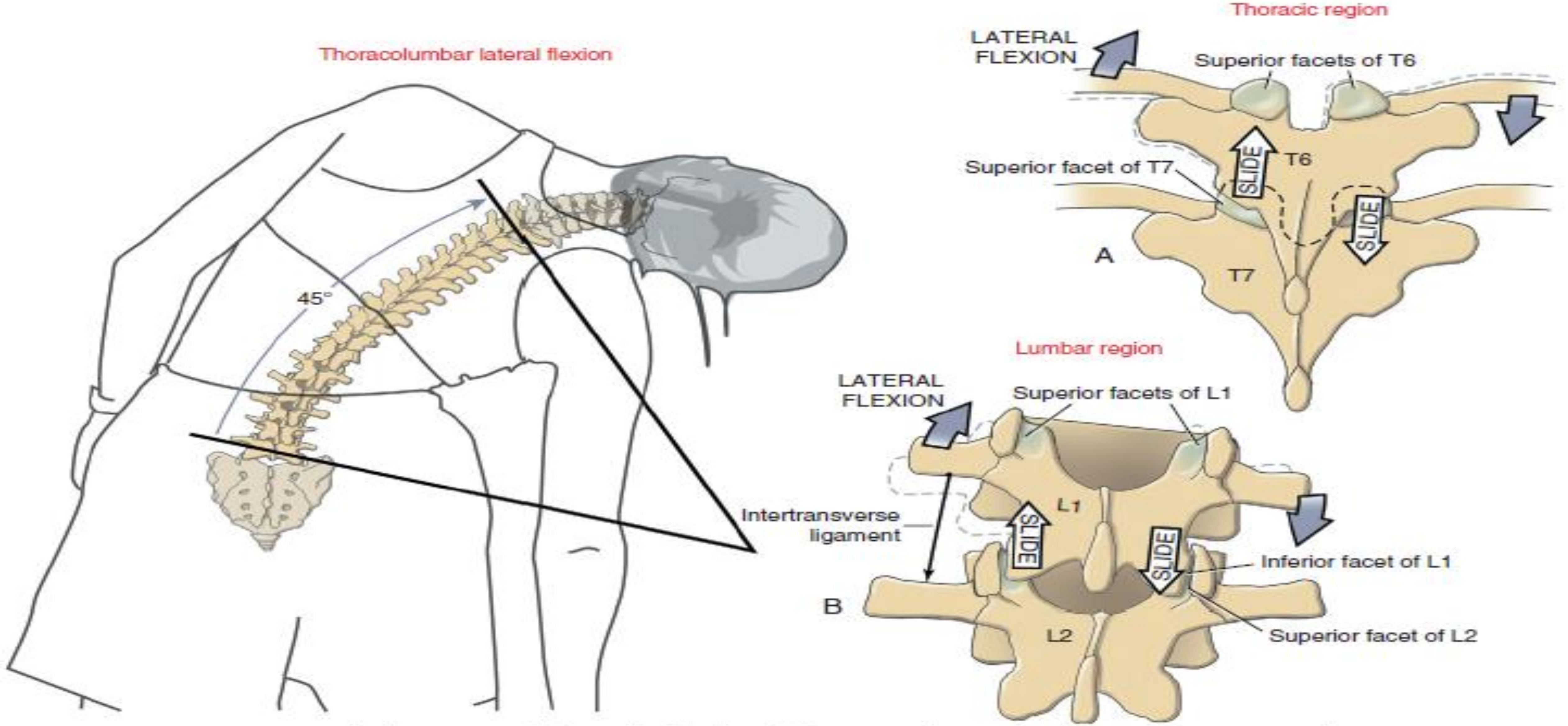
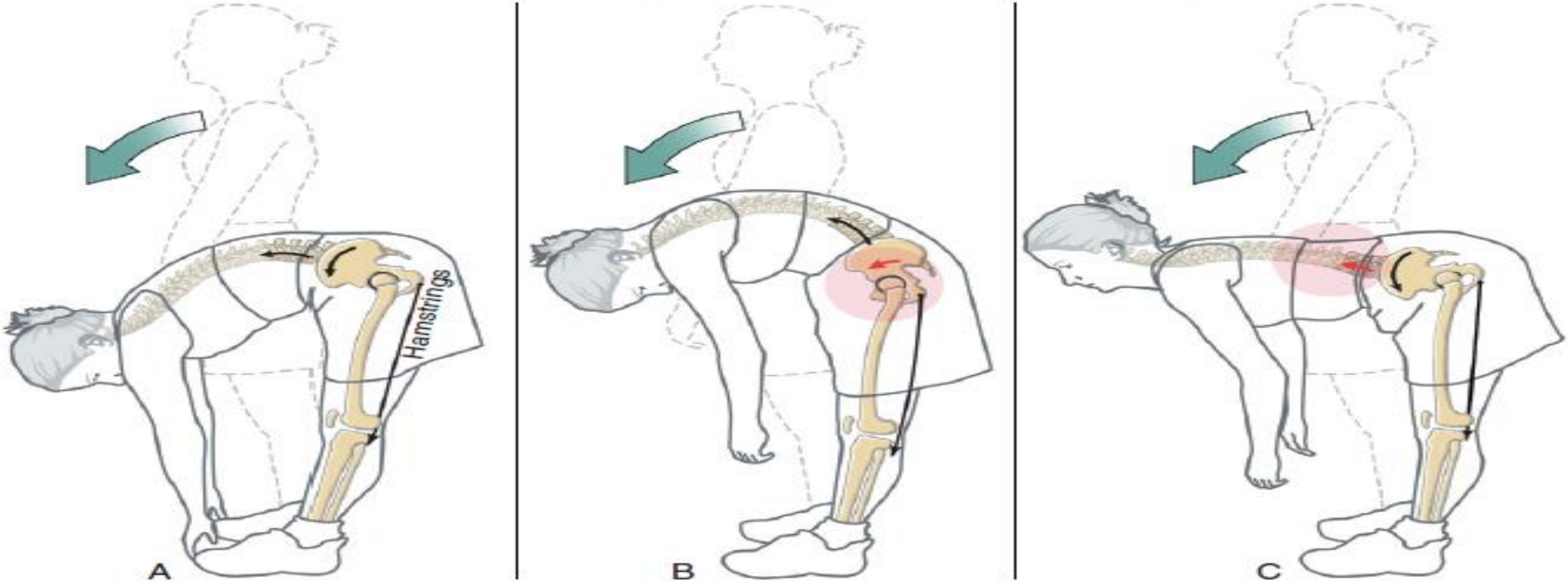


FIGURE 9-55. The kinematics of thoracolumbar lateral flexion are shown through an approximate 45-degree arc: the sum of 25 degrees of thoracic lateral flexion and 20 degrees of lumbar lateral flexion. **A,** Kinematics at the thoracic region. **B,** Kinematics at the lumbar region. Elongated and taut tissue is indicated by a thin black arrow.

Lumbopelvic rhythm

Variations of lumbopelvic rhythms during trunk flexion: A kinematic analysis



Normal lumbar and hip flexion

Limited hip flexion with excessive lumbar flexion

Limited lumbar flexion with excessive hip flexion

FIGURE 9-61. Three different lumbopelvic rhythms used to flex the trunk forward and toward the floor with knees held straight. **A,** A normal kinematic strategy used to flex the trunk from a standing position, incorporating a near simultaneous 40 degrees of flexion of the lumbar spine and 70 degrees of hip (pelvic-on-femoral) flexion. **B,** With limited flexion in the hips (for example, from tight hamstrings), greater flexion is required of the lumbar and lower thoracic spine. **C,** With limited lumbar mobility, greater flexion is required of the hip joints. In **B** and **C,** the red shaded circles and red arrows indicate regions of restricted mobility.

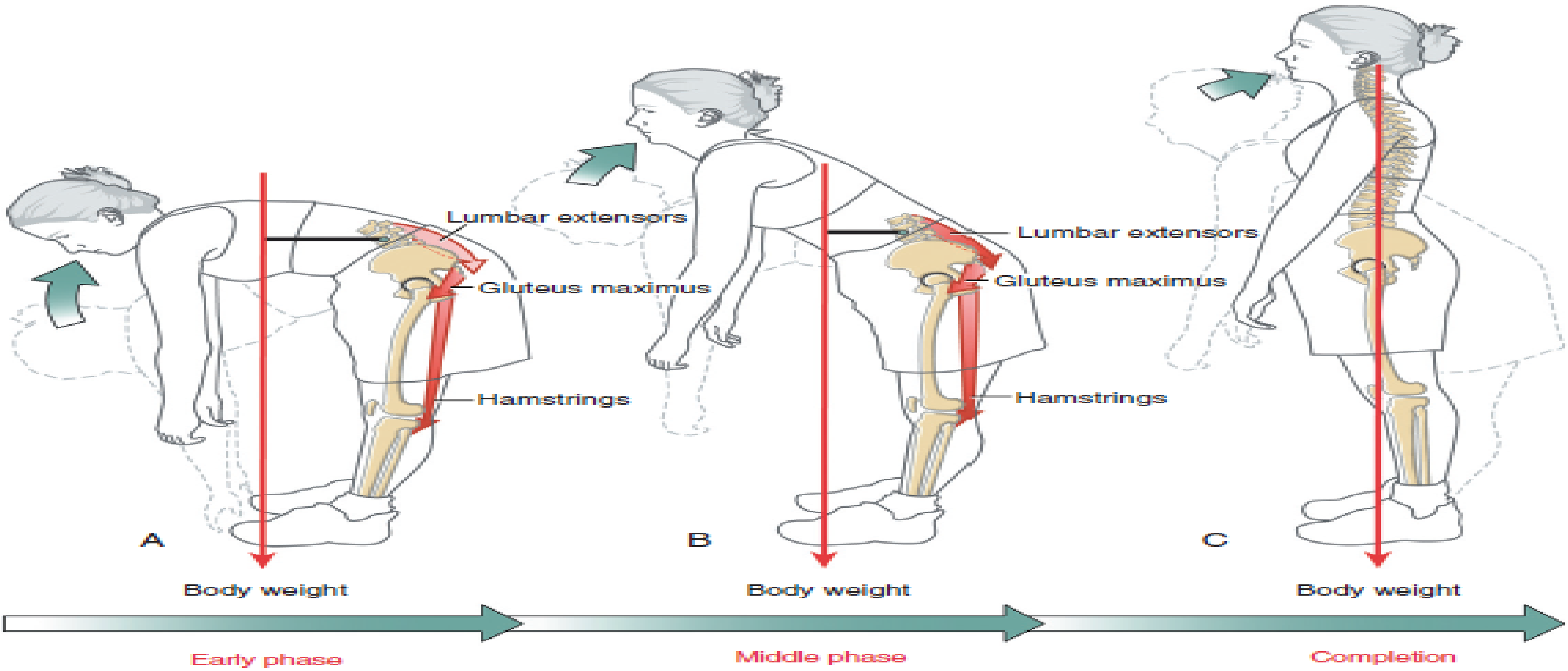


FIGURE 9-62. A typical lumbopelvic rhythm is shown in three phases while the trunk is extended from a forward bent position. The motion is conveniently divided into three chronologic phases (**A** to **C**). In each phase the axis of rotation for the trunk extension is arbitrarily placed through the body of L3. **A**, In the *early phase*, trunk extension occurs to a greater extent through extension of the hips (pelvis on femurs), under strong activation of hip extensor muscles (gluteus maximus and hamstrings). **B**, In the *middle phase*, trunk extension occurs to a greater degree by extension of the lumbar spine, requiring increased activation from lumbar extensor muscles. **C**, At the *completion* of the event, muscle activity typically ceases once the line of force from body weight falls posterior to the hips. The external moment arm used by body weight is depicted as a solid black line. The greater intensity of red indicates relatively greater intensity of muscle activation.

SUMMARY OF THE KINEMATICS WITHIN THE VERTEBRAL COLUMN

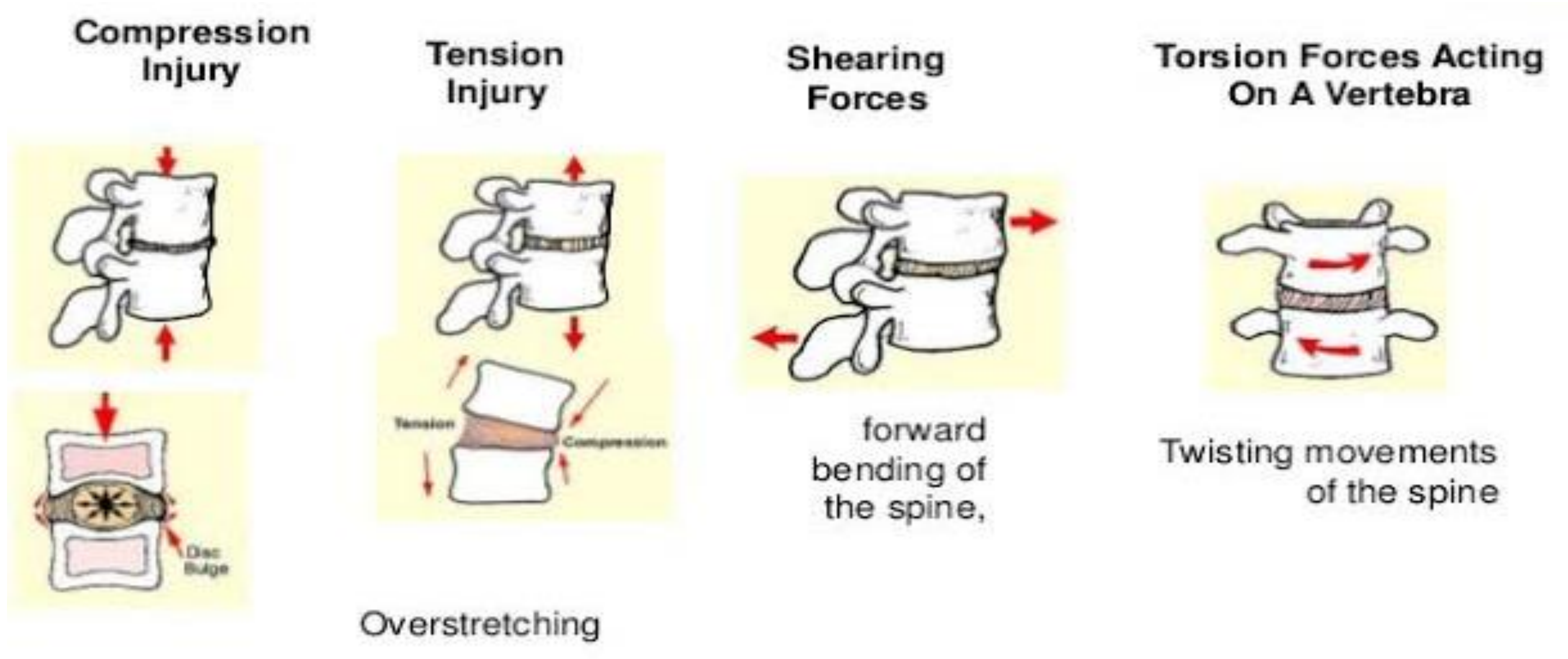
Types of Segmental Loading

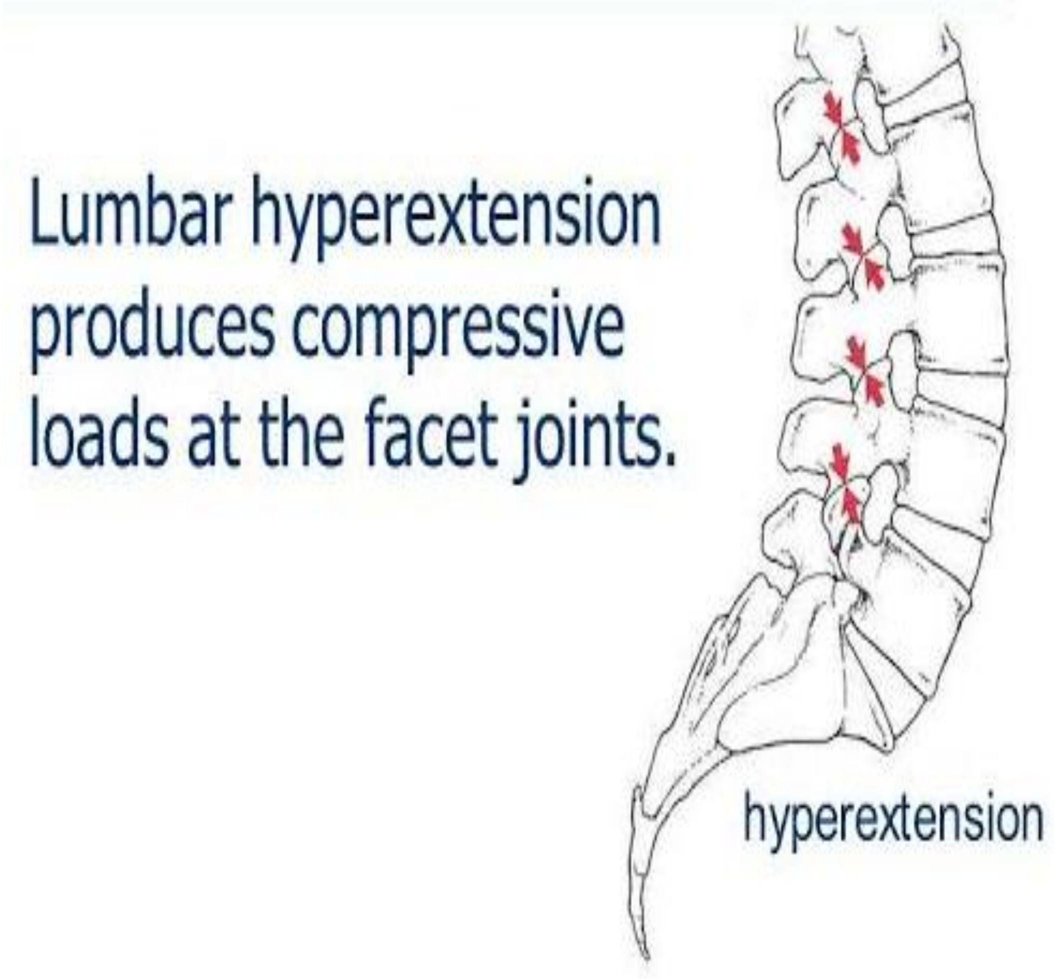
Axial Compression

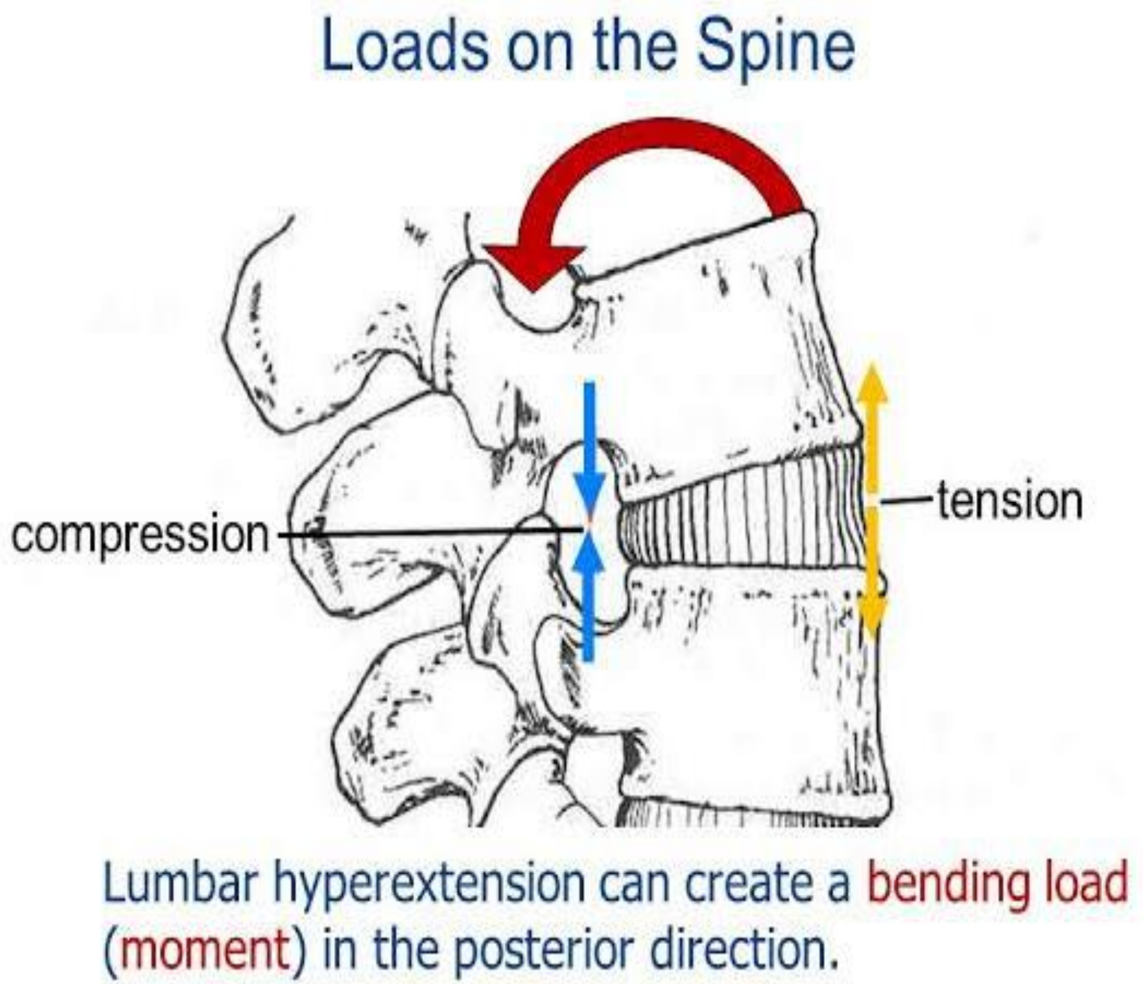
Bending

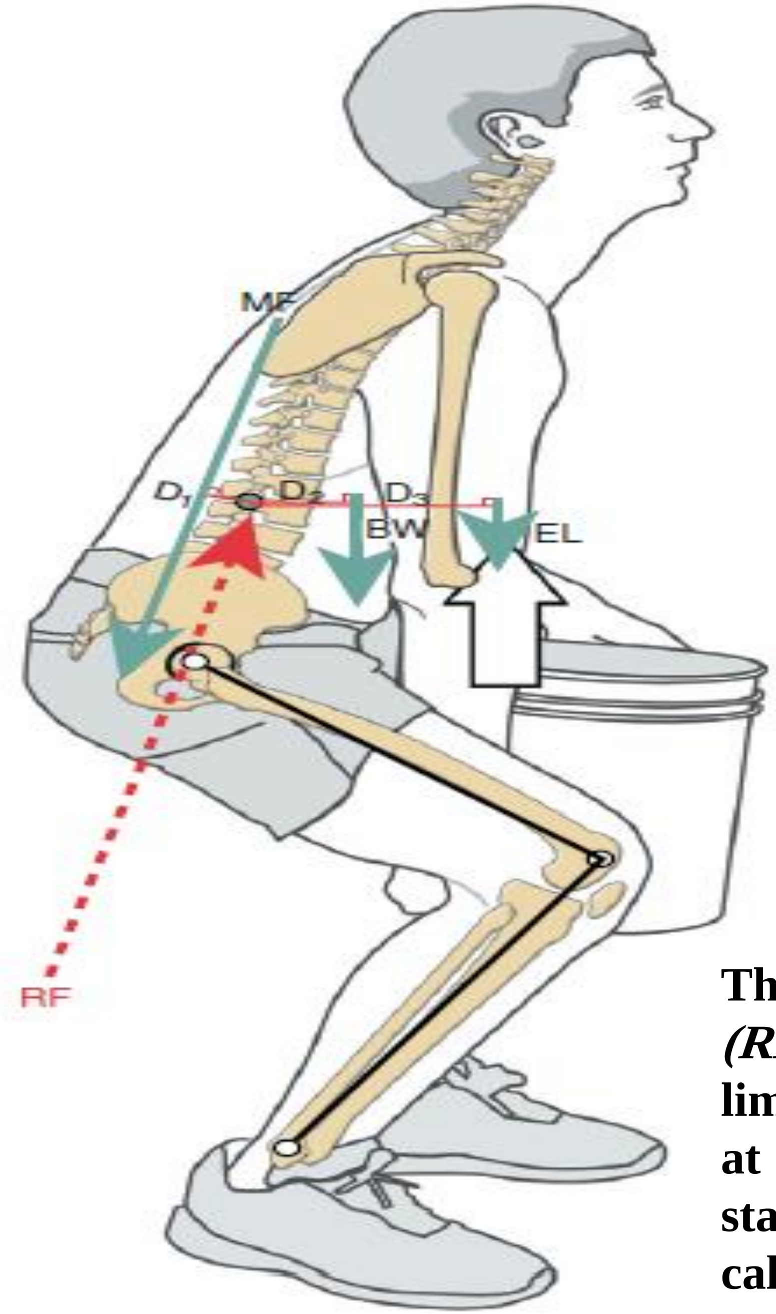
Torsion

Shear


Compression
Injury
Disc
Bulge
Tension
Injury
Tension
Compression
Overstretching
Shearing
Forces
forward
bending of
the spine,
Torsion Forces Acting
On A Vertebra
Twisting movements
of the spine


Lumbar hyperextension produces compressive loads at the facet joints.
hyperextension


Loads on the Spine
compression
tension
Lumbar hyperextension can create a bending load (moment) in the posterior direction.



Data for Calculations:

- Internal moment arm (D_1) = **5 cm**
- Total body weight = **800 N** (about 180 lbs)
- Body weight (BW) above L2 = 65% of total body weight, or about **520 N**
- External moment arm used by BW (D_2) = **13 cm**
- External load (EL) = 25% of total body weight = **200 N** (about 45 lbs)
- External moment arm used by EL (D_3) = **29 cm**

Step 1: Estimate Muscle Force (MF)
By Assuming Σ Torques = 0
Internal torque = External torque
$(MF \times D_1) = (BW \times D_2 + EL \times D_3)$
$(MF \times 0.05\ m) = (520\ N \times 0.13\ m) + (200\ N \times 0.29\ m)$
$MF = \frac{125.6\ Nm}{0.05\ m}$
MF = 2512 N (about **565.1 lbs**)

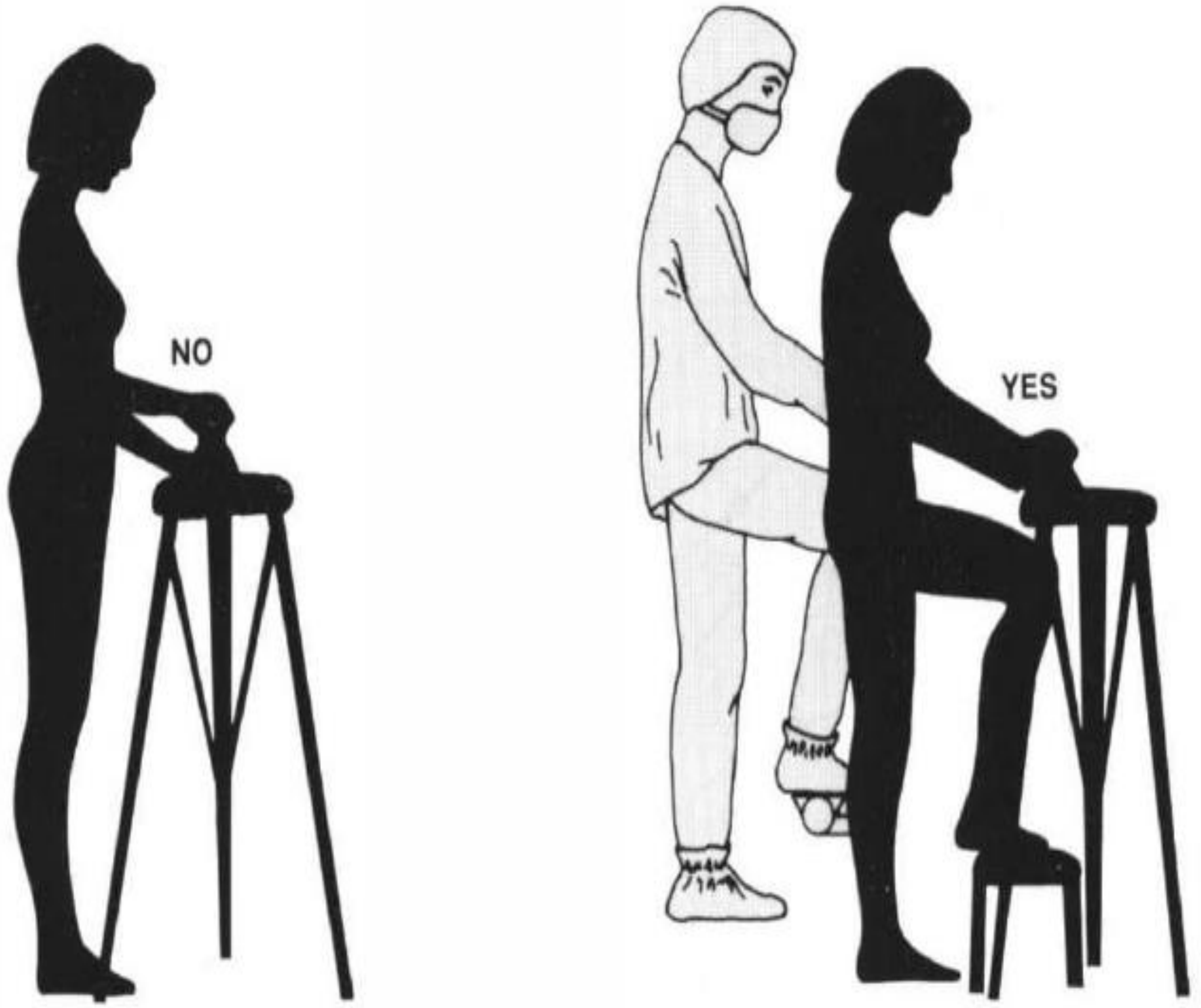
Step 2: Estimate Compression Reaction Force (RF) on L2
By Assuming Σ Forces = 0
Upward directed forces = Downward directed forces
RF = MF + BW + EL
RF = (2512 N) + (520 N) + (200 N)
RF = 3232 N (726. 6 lbs); directed upward

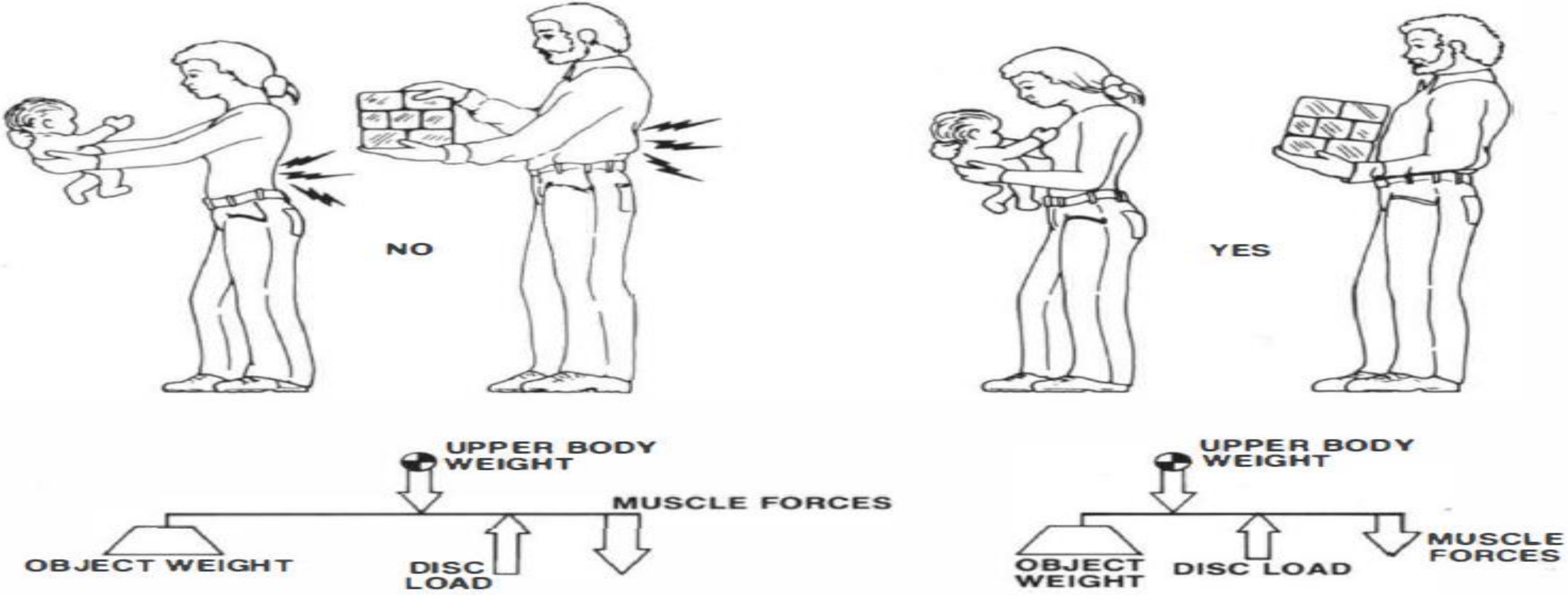
The steps used to estimate the approximate compressive reaction force *(RF)* on the L2 vertebra while a load is lifted. The biomechanics are limited to the sagittal plane, around an axis of rotation arbitrarily set at L2 *(green circle).* The mathematic solutions assume a condition of static equilibrium. All abbreviations are defined in the boxes. (the calculations assume that all forces are acting in a vertical direction.

Four Ways to Reduce the Amount of Force Required of the Back Extensor Muscles during Lifting

- Reduce the speed of lifting.
- Reduce the magnitude of the external load.
- Reduce the length of the external moment arm.
- Increase the length of the internal moment arm.

Flexion of the hip reduces the tension of the psoas muscle and the lordosis of the lumbar spine. resulting in reduced loads on the lumbar spine_ This bit of ergonomic advice is particularly important to the surgeon who may stand for several hours on occasion at the operating table. For housework. the work position shown is advised. This is a valid ergonomic principle.

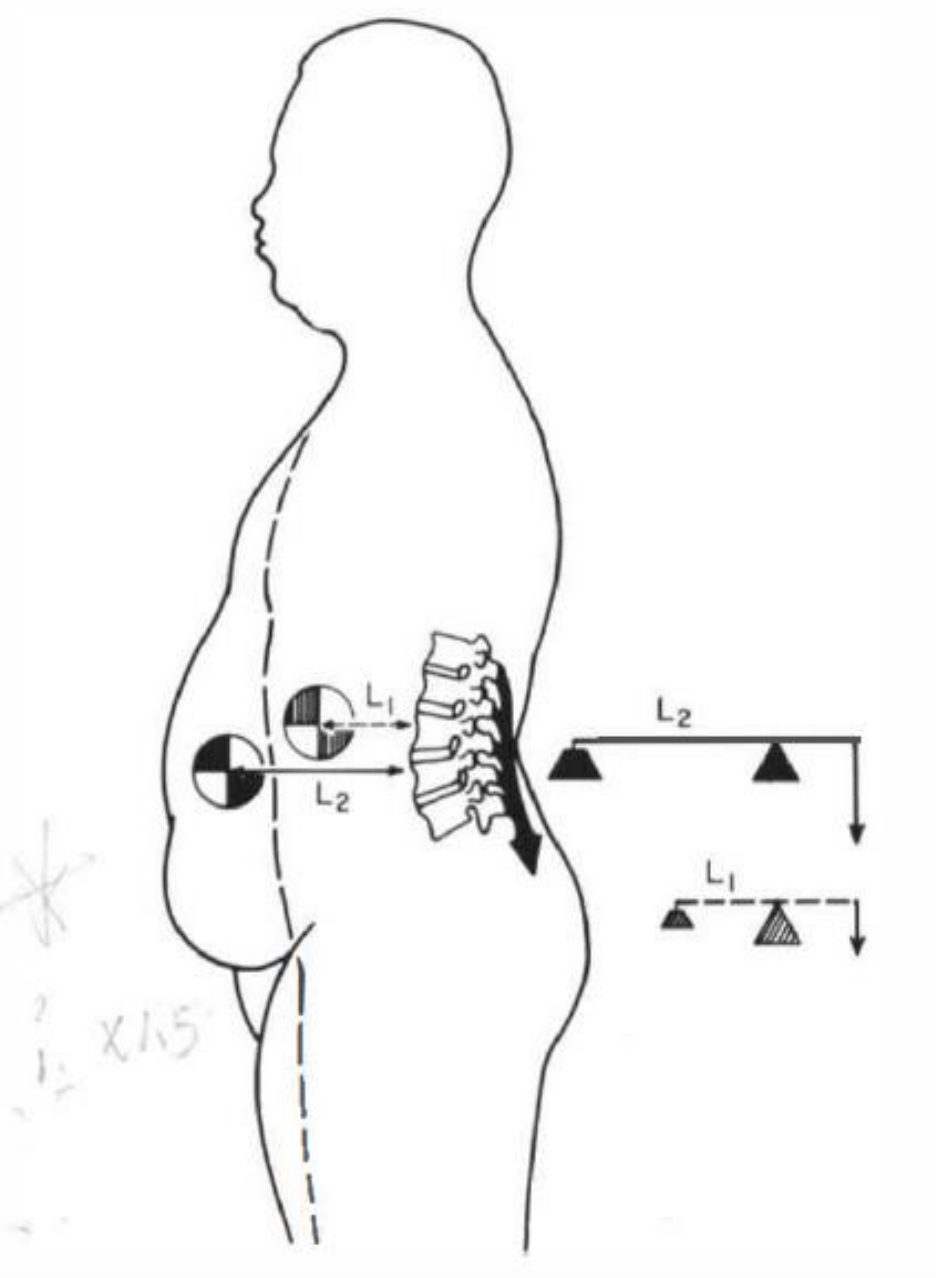


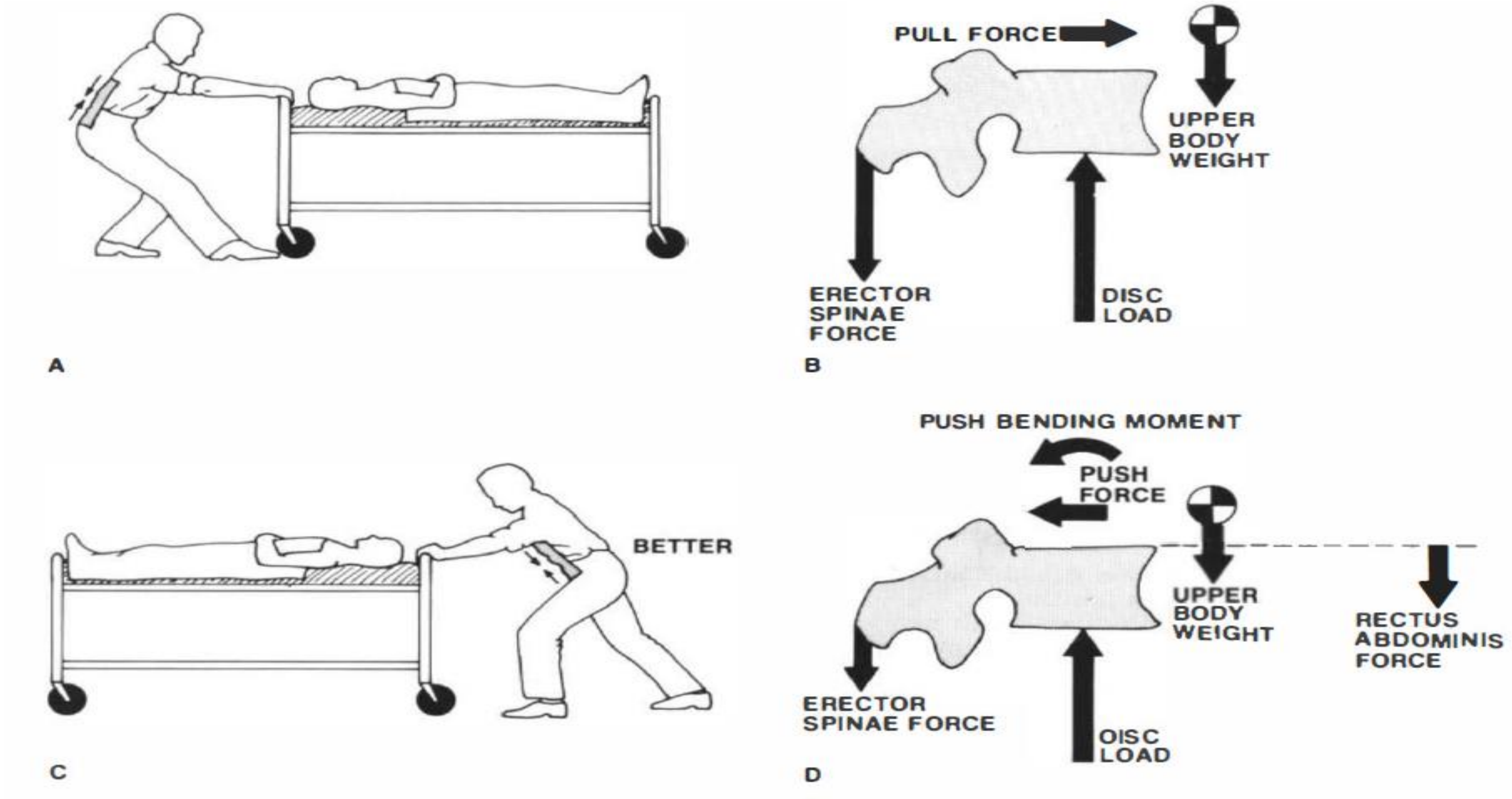


The ergonomics of proper lifting. The load on the discs is a combined result of the object weight. the upper body weight. the back muscle forces. and their respective lever arms to the disc center. On the left, the object is farther away from the disc center compared with the situation on the right. The lever-balances at the bottom show that smaller muscle forces and disc loads are obtained when the object is carried nearer to the disc.

The mechanics here are the same as in carrying object anteriorly, except that the weight here is adipose tissue rather than an external object. in the latter case. it is much easier to correct the lever arm.

However. this diagram does emphasize yet another prophylactic and therapeutic value in avoiding or eliminating obesity.




PULL FORCE
UPPER BODY WEIGHT
ERECTOR SPINAE FORCE
DISC LOAD
A
B
BETTER
PUSH BENDING MOMENT
PUSH FORCE
UPPER BODY WEIGHT
RECTUS ABDOMINIS FORCE
ERECTOR SPINAE FORCE
OISC LOAD
C
D

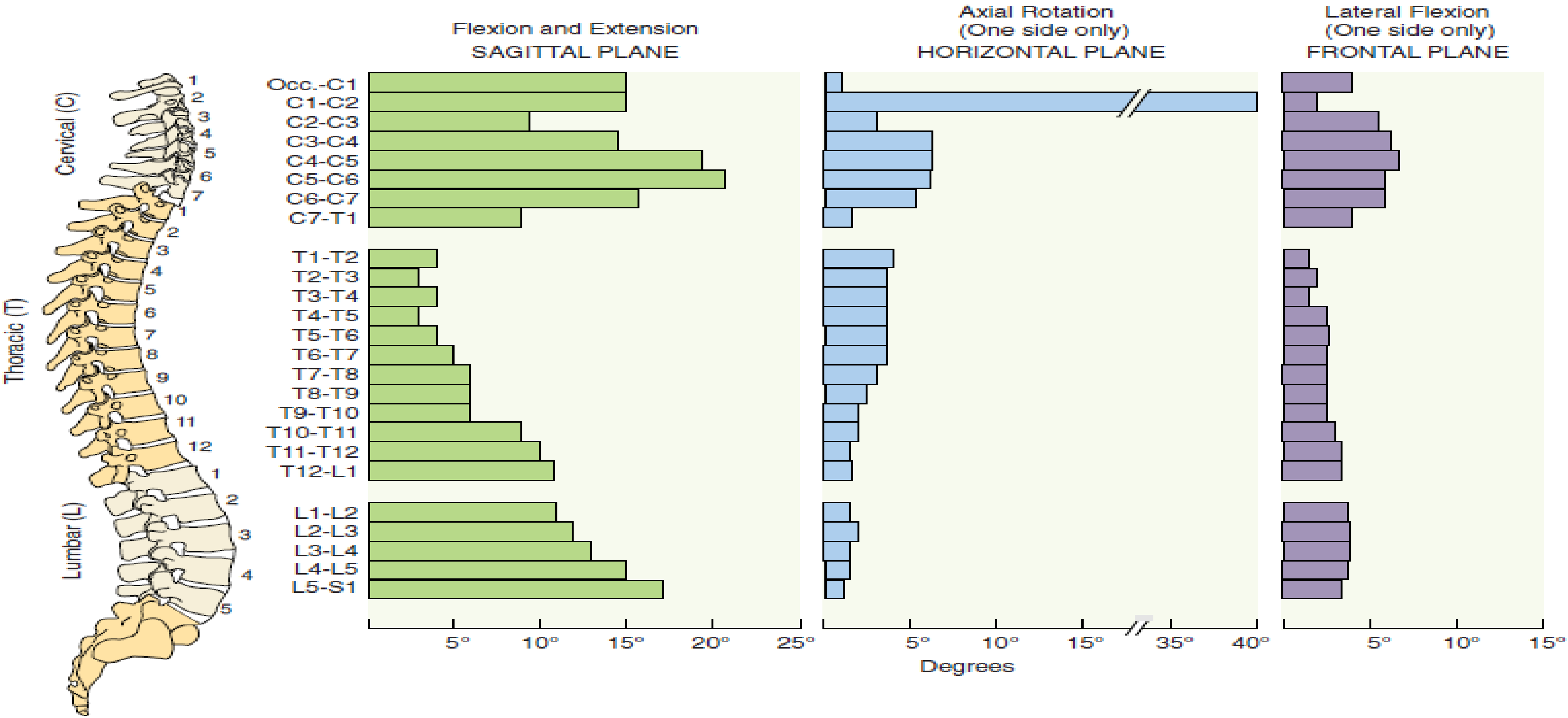
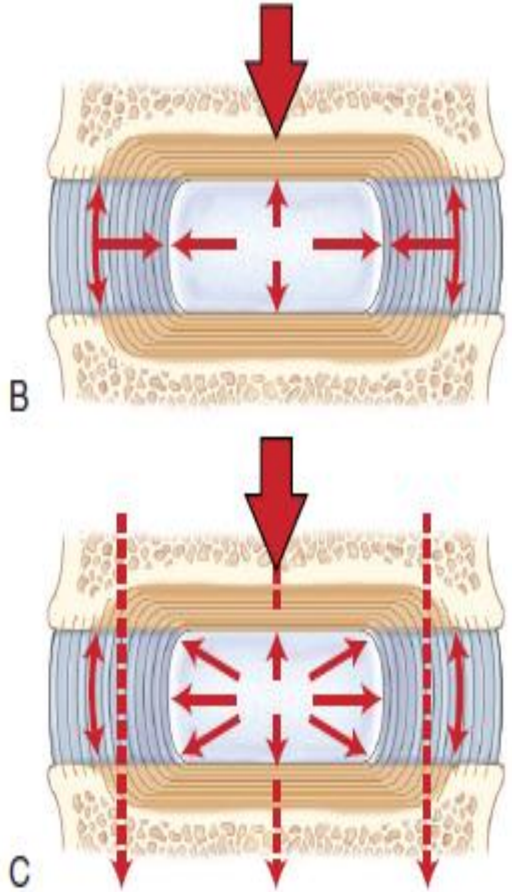


FIGURE 9-66. A graph summarizing the overall maximal range of motion (in degrees) allowed across three planes, throughout the cervical, thoracic, and lumbar regions. Data represent a compilation of several sources indicated in the text. (Styled after White AA, Panjabi MM: Kinematics of the spine. In White AA, Panjabi MM, eds: *Clinical biomechanics of the spine*, Philadelphia, 1990, Lippincott.)



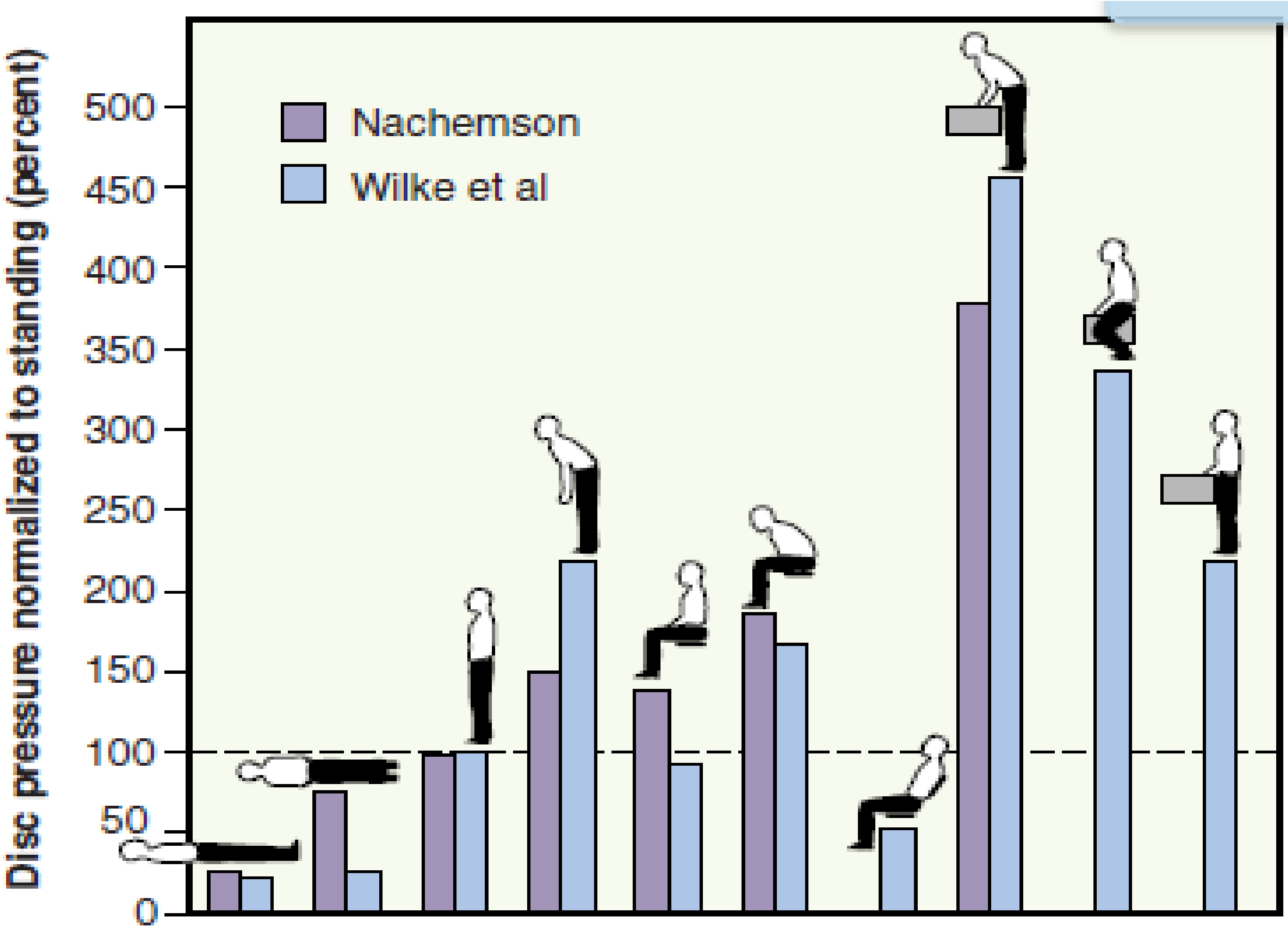


FIGURE 9-37. A comparison between data from two intradiscal pressure studies (see text). Each study measured in vivo pressures from a lumbar nucleus pulposus in a 70-kg subject during common postures and activities. The pressures are normalized to standing. (Modi-

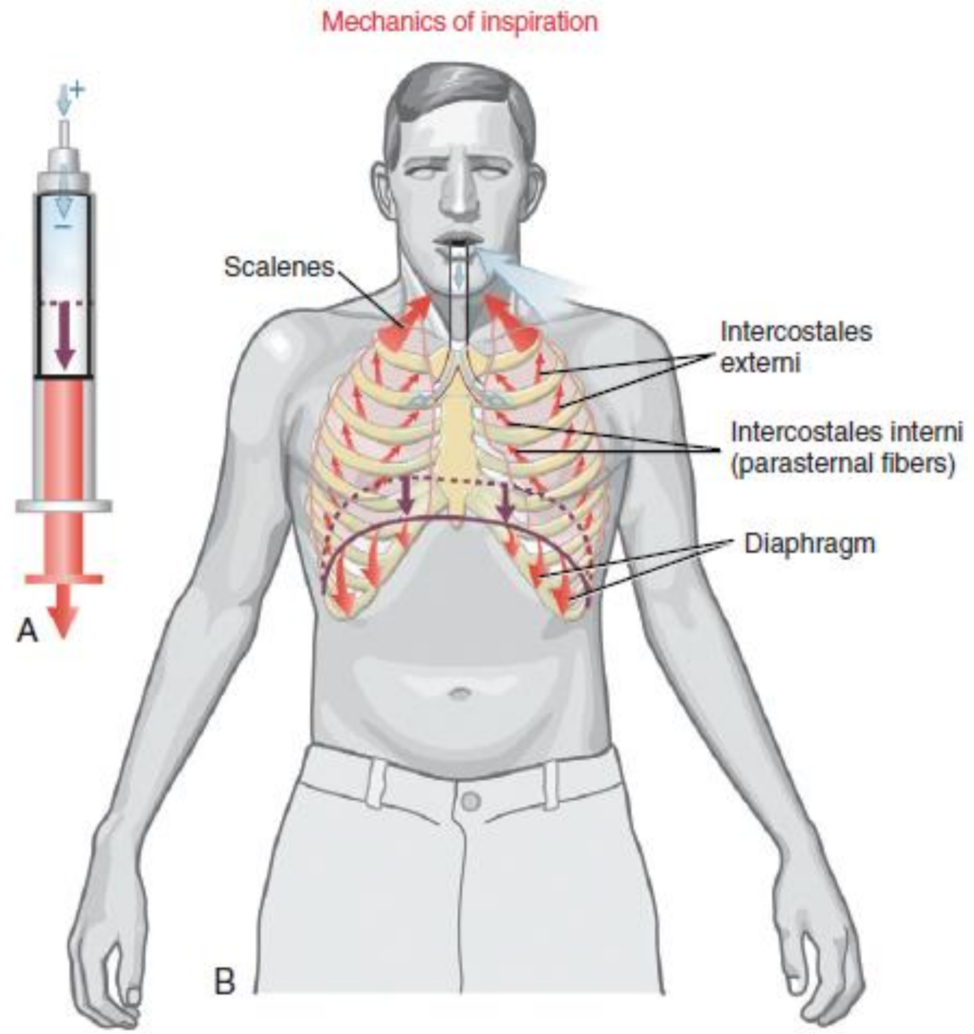
Mechanics of breathing

Ventilation

Ventilation is the mechanical process by which air is inhaled and exhaled through the lungs and airways. This rhythmic process occurs 12 to 20 times per minute at rest and is essential to the maintenance of life.

The muscular mechanics of inspiration.

A, Using an expanding piston and air to show an analogy using Boyle's law. Increasing the volume within a piston
reduces the air pressure within the chamber of the piston.
The negative air pressure creates suction that draws the outside, higher-pressure air into the piston through an aperture
at the top of the piston.
B, A healthy adult shows how contraction of the primary muscles of inspiration (diaphragm, scalenes, and intercostales) increases intrathoracic volume, which in turn expands the lungs and reduces alveolar pressure.
The negative alveolar pressure draws air into the lungs. The descent of the diaphragm is indicated by the pair of thick, purple, vertical arrows.



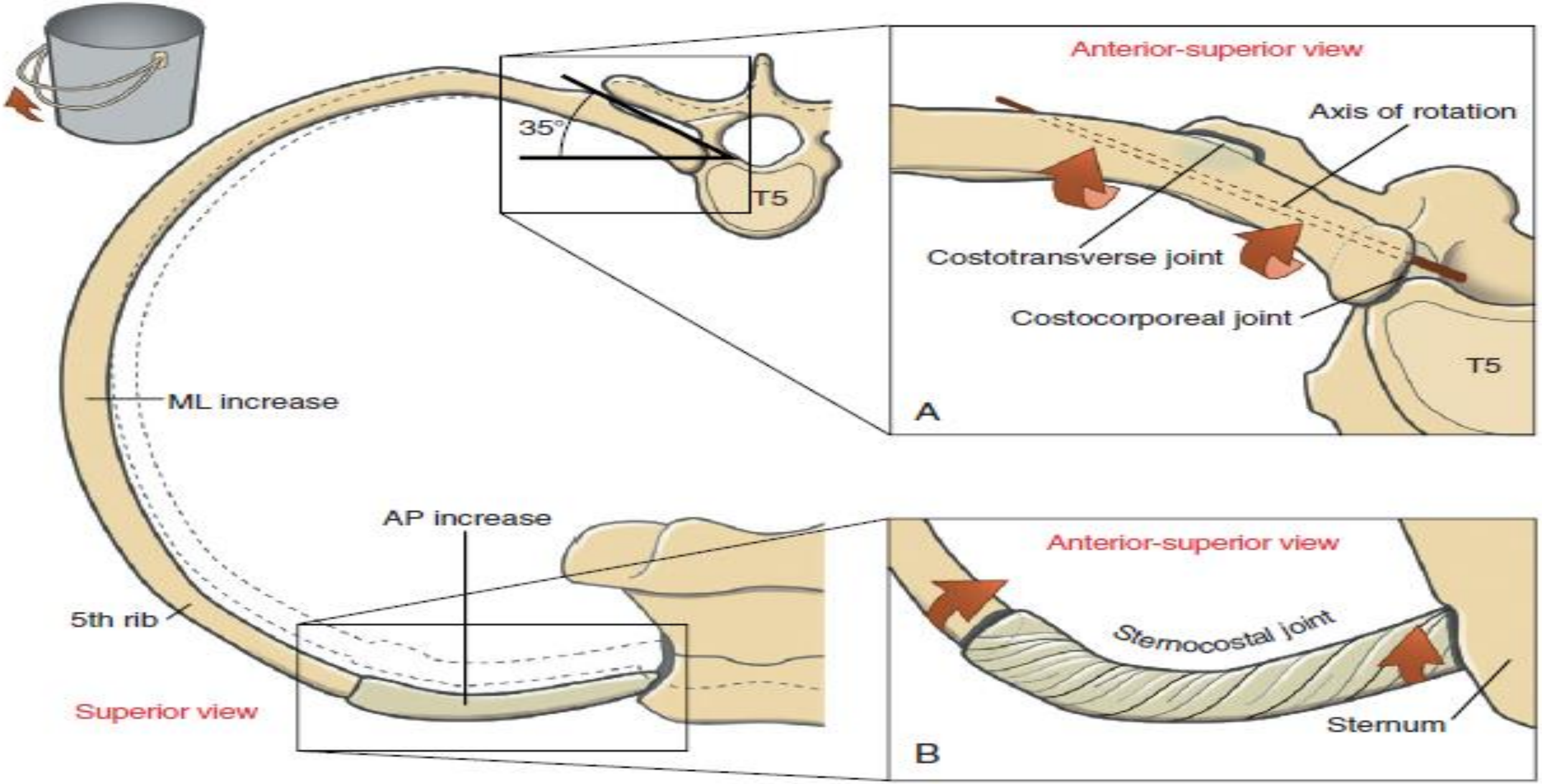


FIGURE 11-26. A top view of the fifth rib shows the "bucket-handle" mechanism of elevation of the ribs during inspiration. The ghosted outline of the rib indicates its position before inspiration. Elevation of the rib increases both the anterior-posterior *(AP)* and medial-lateral *(ML)* diameters of the thorax. The rib connects to the vertebral column via the costotransverse and costocorporeal joints **(A)** and to the sternum via the sternocostal joint **(B)**. During elevation, the neck of the rib moves around an axis of rotation that courses between the costotransverse and costocorporeal joints. The elevating rib creates a twist or torsion in the cartilage associated with the sternocostal joint.

TABLE 11-4. Primary Muscles of Inspiration

Muscle	Mode of Action	Innervation
Diaphragm	*Primary:* The dome of the contracting diaphragm lowers and flattens during inspiration. This movement increases the vertical diameter of the thorax. *Secondary:* The descent of the diaphragm is resisted by the abdomen, which in turn stabilizes the position of the dome of the diaphragm. Further diaphragmatic contraction can *elevate* the lower ribs.	Phrenic nerve (C^3-C^5)
Scalenes	The scalene anterior, medius, and posterior increase intrathoracic volume by elevating the ribs and the sternum.	Ventral rami of spinal nerve roots (C^3-C^7)
Intercostales	The parasternal fibers of intercostales interni and the intercostales externi increase intrathoracic volume by elevating the ribs. During inspiration, all intercostales stabilize the intercostal spaces to prevent an inward collapse of the thoracic wall.	Intercostal nerves (T^2-T^{12})

TABLE 11-5. A Sample of Muscles of Forced Inspiration

Muscle	Mode of Action	Innervation
Serratus posterior superior	Increases intrathoracic volume by elevating the upper ribs.	Intercostal nerves (T^2-T^5)
Serratus posterior inferior	Stabilizes the lower ribs for initial contraction of the diaphragm.	Intercostal nerves (T^9-T^{12})
Levator costarum (longus and brevis)	Increase intrathoracic volume by elevating the ribs.	Dorsi rami of adjacent thoracic spinal nerve roots (C^7-T^{11})
Sternocleidomastoid	Increases intrathoracic volume by elevating the sternum and upper ribs.	Primary source: spinal accessory nerve (cranial nerve XI)
Latissimus dorsi	Increases intrathoracic volume by elevating the lower ribs; requires the arms to be fixed.	Thoracodorsal nerve (C^6-C^8)
Iliocostalis thoracis and cervicis (erector spinae)	Increase intrathoracic volume by extending the trunk.	Adjacent dorsal rami of spinal nerve roots
Pectoralis minor	Increases intrathoracic volume by elevating the upper ribs; requires activation from muscles such as trapezius and levator scapulae to stabilize the scapula.	Medial pectoral nerve (C^8-T^1)
Pectoralis major (sternocostal head)	Increases intrathoracic volume by elevating the middle ribs and sternum; requires the arms to be fixed. Greater flexion or abduction of the shoulders increases the vertical line of force of the muscle fibers relative to the muscle's thoracic attachments; this strategy increases the effectiveness of this muscle in increasing intrathoracic volume.	Medial pectoral nerve (C^8-T^1)
Quadratus lumborum	Stabilizes the lower ribs for contraction of the diaphragm during early forced inspiration.	Ventral rami of spinal nerve roots (T^{12}-L^3)

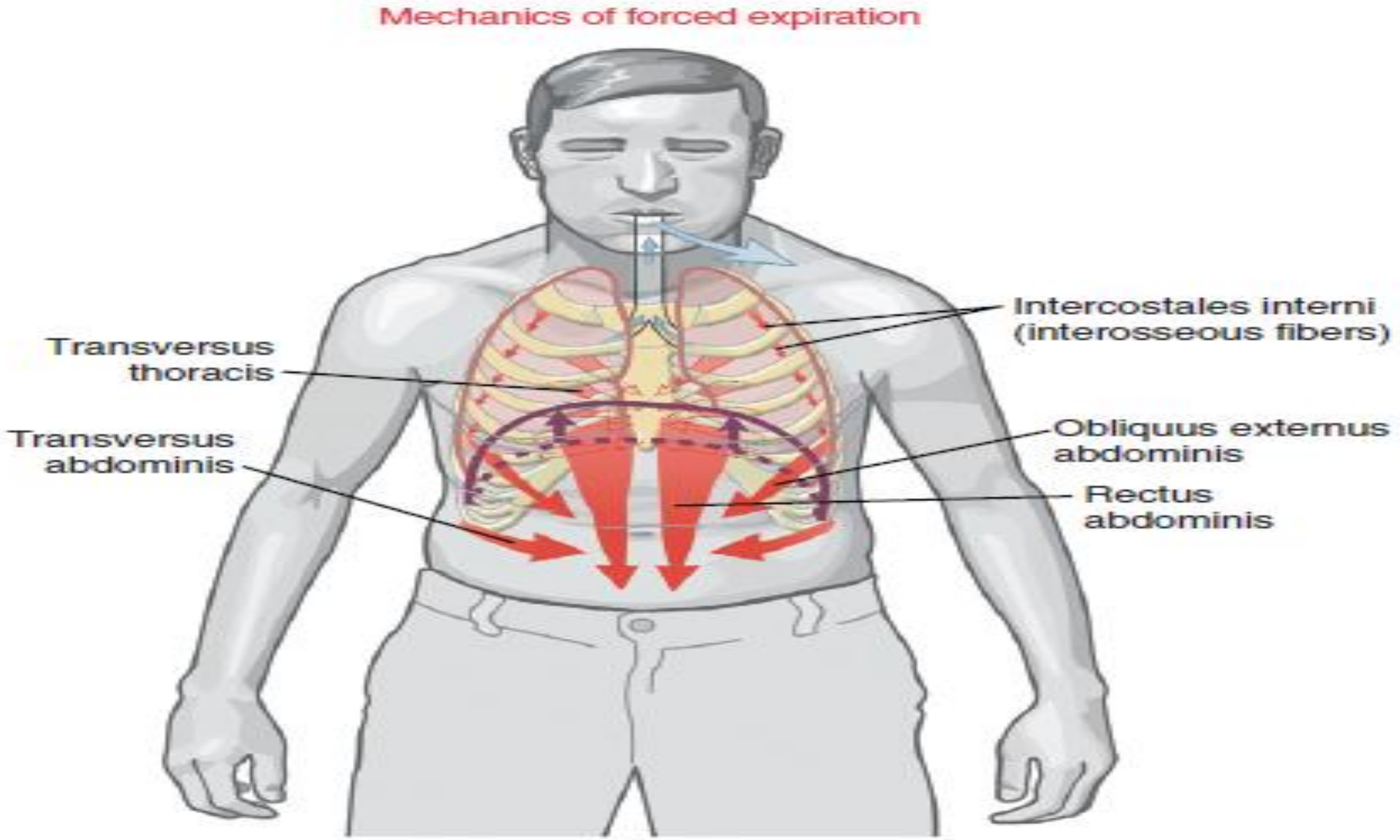


FIGURE 11-30. Muscle activation during forced expiration. Contraction of "abdominal" muscles, transversus thoracis, and intercostales interni (interosseous fibers) increases intrathoracic and intra-abdominal pressures. The passive recoil of the diaphragm is indicated by the pair of thick, purple, vertical arrows.

TABLE 11-6. Muscles of Forced Expiration

Muscle	Mode of Action	Innervation
Abdominal muscles: Rectus abdominis Obliquus externus abdominis Obliquus internus abdominis Transversus abdominis	1. Decrease intrathoracic volume by flexing the trunk and depressing the ribs. 2. Compress the abdominal wall and contents, which increases intra-abdominal pressure; as a result, the relaxed diaphragm is pushed upward, decreasing intrathoracic volume.	Intercostal nerves (T^7-L^1)
Transversus thoracis	Decreases intrathoracic volume by depressing the ribs.	Adjacent intercostal nerves
Intercostales interni (interosseous fibers)	The interosseous fibers of the intercostales interni decrease intrathoracic volume by depressing the ribs.	Intercostal nerves (T^2-T^{12})


Thank
you