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TEACH

MODULE BIOMECHANICS OF SPINE

Didactic Unit A

Topic: Biomechanics of the normal spine

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VNIVERSITAT DE VALÈNCIA

AMSE THE ASSOCIATION OF MEDICAL SCHOOLS IN EUROPE

A. Biomechanical of normal spine

1. Objectives
2. Normal biomechanics of the cervical spine
3. Normal biomechanics of the thoracic spine
4. Normal biomechanics of the lumbar, sacral and coccygeal spine
5. What load does the spine undergo when we are on different rest positions?
6. How is the biomechanics of the spine when we make functional motor gestures?
7. Conceptual maps
8. Bibliography

B. Biomechanical alterations of the spine

1. Objectives

1. OBJECTIVES

The objectives of this didactic unit are:

- To rework the biomechanics of the different segments of the spine in normal conditions and their kinematic possibilities.
- To review he biomechanics of the spine in normal condition in the main resting positions of the human being.
- To revise the biomechanics of spine in normal condition during usual daily functional gestures.

B. Biomechanical alterations of the spine

2. Normal biomechanics of the cervical spine

2. NORMAL BIOMECHANICS OF THE CERVICAL SPINE

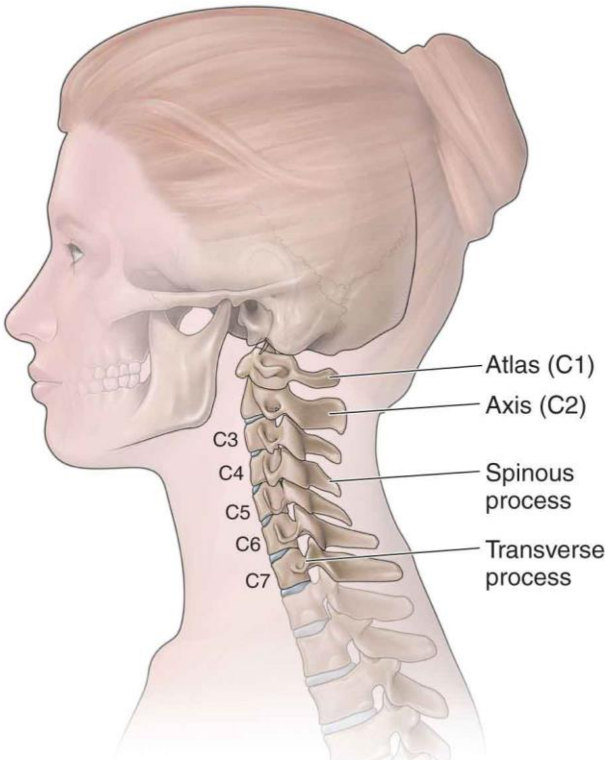


Figure 1. Cervical spine basic structures (extracted from www.muskuloskeletalkey.com)

- 7 vertebrae with lordotic curve.
- It is divided in upper cervical spine (C1-C2) and lower cervical spine (C3-C7).
- It has its own Functional Spine Unit (FSU) formed by:
  - Two adjacent vertebrae
  - The interconnecting soft tissue between them.
- FSU has 12 potential movements divided in 3 axes.

2.1. BIOMECHANICS OF UPPER CERVICAL SPINE

ATLANTO-OCCIPITAL JOINT

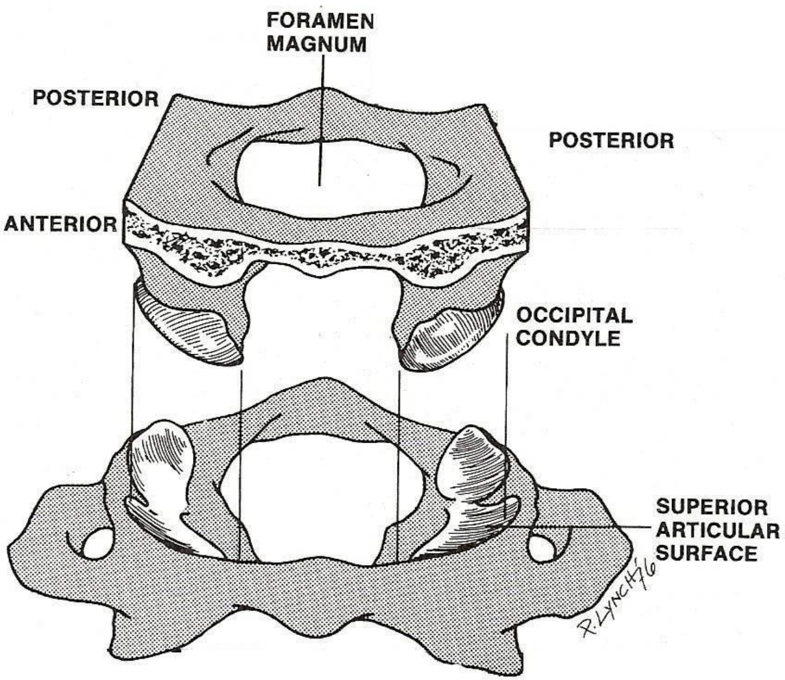


Figure 2. Atlanto-occipital joint (extracted from www.quiropracticagirona.com)

- Primary movements: flexion, extension and nodding movements.
- Movement restriction by:
  - Base of the skull.
  - Tension of posterior neck muscles.
  - Submandibular tissues.
  - Compression of suboccipital muscles.

2.1. BIOMECHANICS OF UPPER CERVICAL SPINE

ATLANTO-OCCIPITAL JOINT

ROTATION

LATERAL FLEXION

2.1. BIOMECHANICS OF UPPER CERVICAL SPINE

ATLANTO-AXIAL JOINT

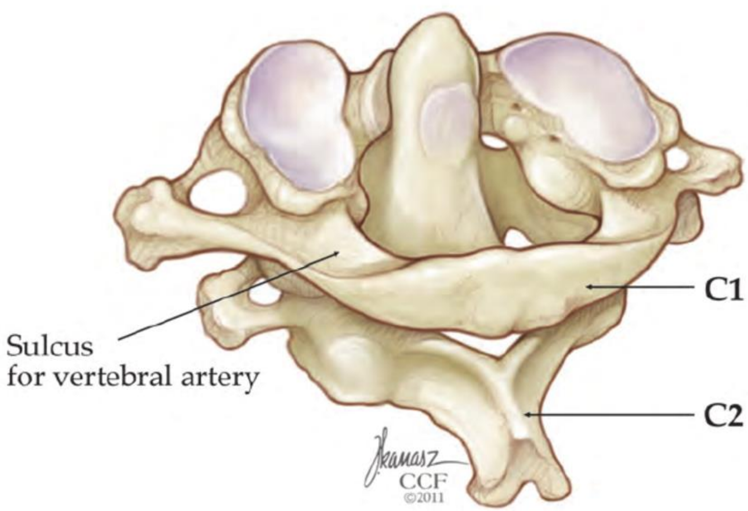


Figure 3. Atlanto-axial joint. Image from Clark JG. et al. 2011.

- Complex composed by:
  - Two lateral facet joints.
  - The arlantodental articulation.
  - Posterior odontoid's surface.
  - Transverse ligament.

2.1. BIOMECHANICS OF UPPER CERVICAL SPINE

ATLANTO-AXIAL JOINT

The atlanto-axial median joint allows the atlas spins and glides around the pivot.

Lateral atlanto-axial joints are plane joints.

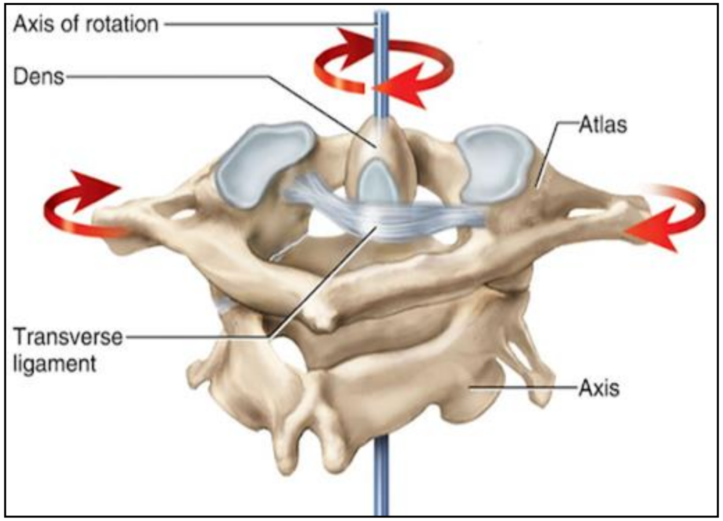


Figure 4. Odontoid pivot (extracted from www.imagequiz.co.uk)

Joint stabilization provided by transverse, alar and apical ligaments.

During rotation, the atlas can move forward or backwards.

2.1. BIOMECHANICS OF UPPER CERVICAL SPINE

ATLANTO-AXIAL JOINT

Atlas flexes when cervical spine extends and viceversa

During axial compression C1 starts to move passively.

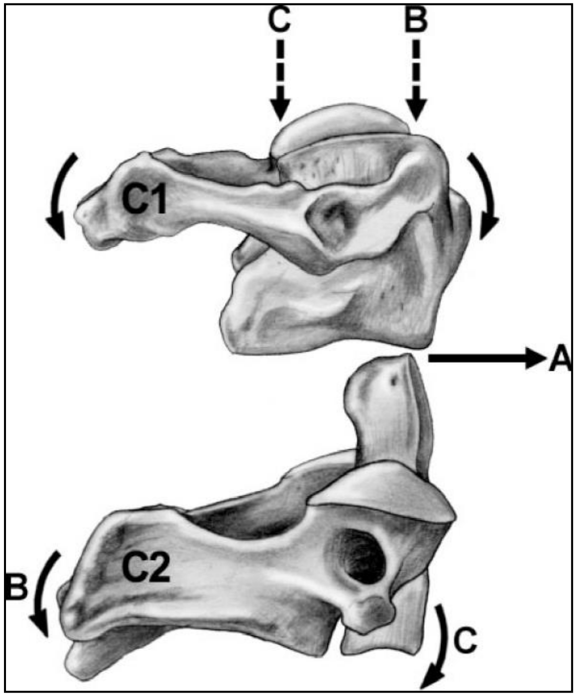


Figure 4. Odontoid pivot (extracted from www.imagequiz.co.uk)

Backward movement limited by odontoid process. Forward movement limited by transversal and alar ligaments.

Tectorial membrane provides stability in backward movements.

2.2. BIOMECHANICS OF LOWER CERVICAL SPINE

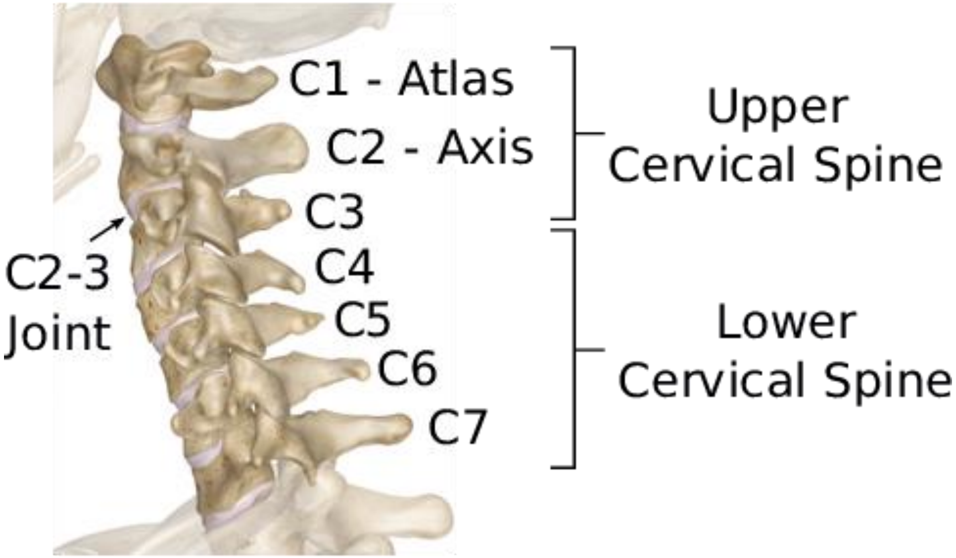


Figure 5. Cervical spine scheme.
Image from Barker S. et al. 2015.

It is considered as lower cervical spine C3 to C7

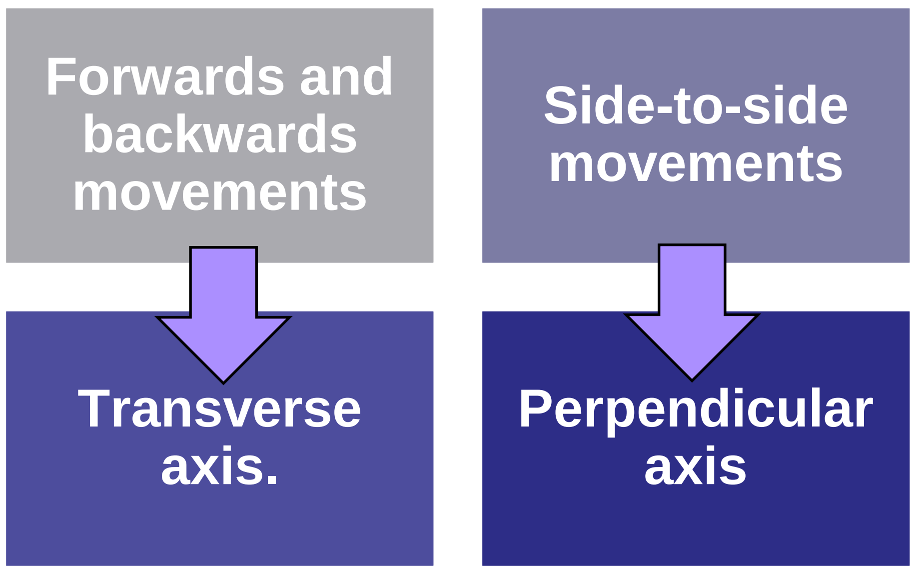
C3 superior facets allows medial movement

Axis processes rest in a socket form by superior processes of C3

C2-C3 performs an opposite lateral flexion

2.2. BIOMECHANICS OF LOWER CERVICAL SPINE

- Lower cervical vertebrae are separated by an intervertebral disc.
- Articular surfaces are similar to a saddle joint:
  - Inferior Surface of vertebral body is concave downward.
  - Superior Surface of vertebral body is concave upward.



B. Biomechanical alterations of the spine

3. Normal biomechanics of the thoracic spine

3. NORMAL BIOMECHANICS OF THORACIC SPINE

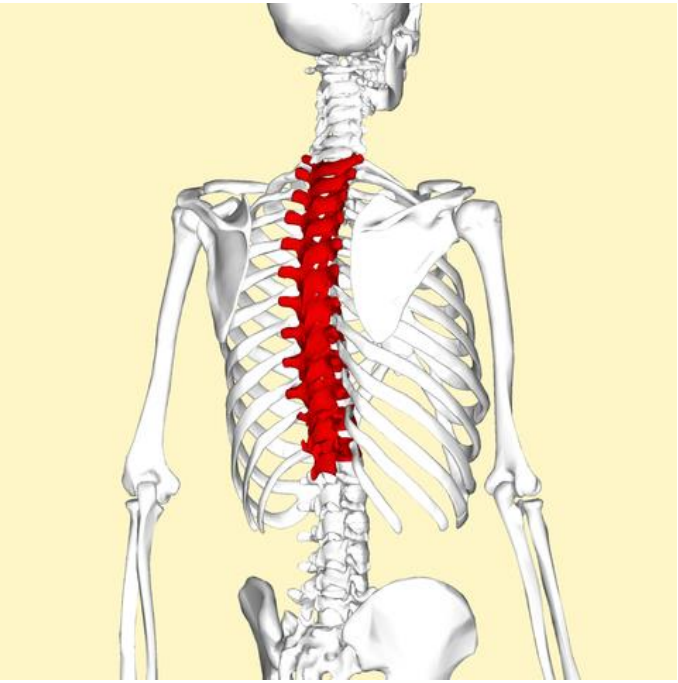


Figure 6. Posterior ¾ view of Thoracic spine (extracted from www.lifeder.com)

- Sagital balance of the spine through erector spinae and abdominal muscles.
- 3 dimentional motions.
- 12 vertebraes (T1-T12) with a concave curvature called kyphosis.
- Kyphosis normal angle of 45º:
  - Range of kyphosis of 20-70º asymptomatical.
- Kyphosis is determined by lumbar lordosis and lower cervical vertebrae position.

3. NORMAL BIOMECHANICS OF THORACIC SPINE

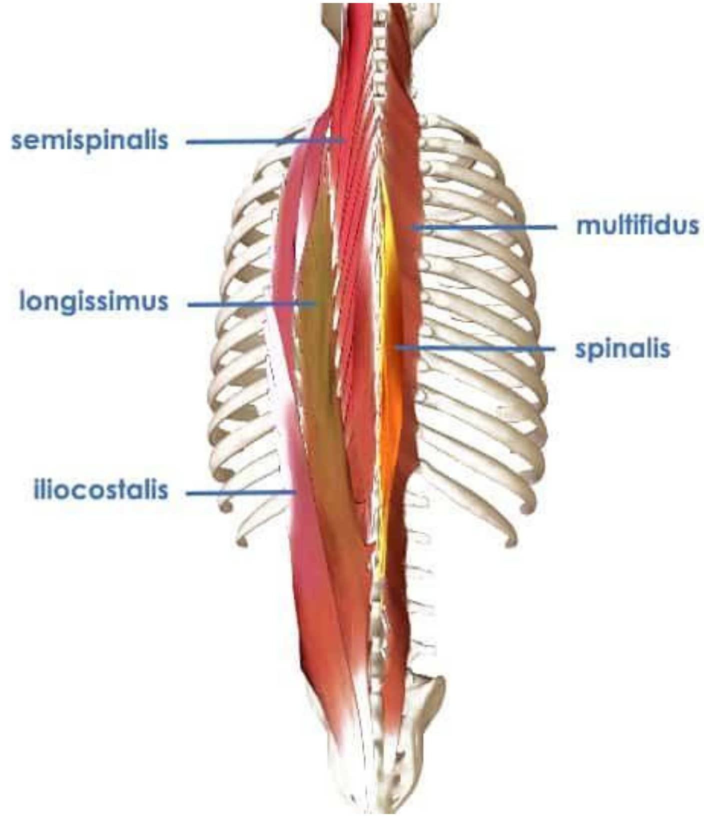


Figure 7. Muscular thoracic spine complex (extracted from www.precisionmovement.coach)

- The thoracic spine has a musculature complex that maintain upright spinal position.
- Axial loads increases in larger thoracic angles.
- Thoracic vertebraes:
    - Support compressive loads in the anterior body area.
    - Resist tensile loads in the posterior body área.

3. NORMAL BIOMECHANICS OF THORACIC SPINE

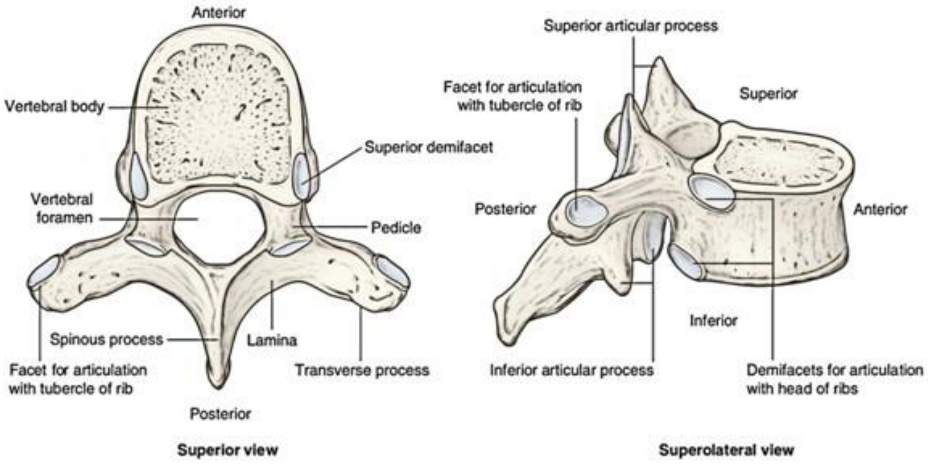


Figure 8. A thoracic vertebrae type (extracted from www.earthslab.coach)
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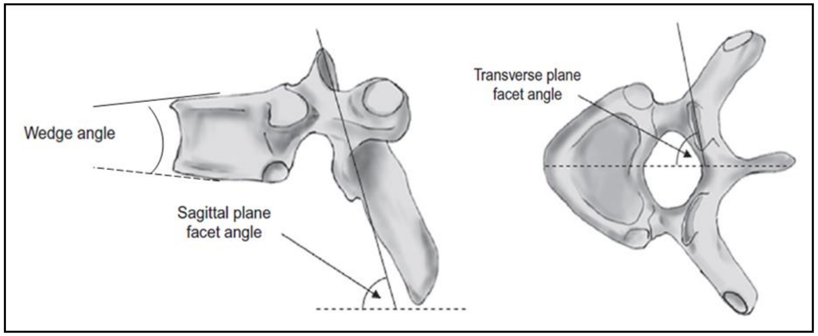

Figure 9. Wedge angle and Facet joint angles of the thoracic spinal motion segments. Image from Galbusera F. et al. 2018..

3. NORMAL BIOMECHANICS OF THORACIC SPINE

- Vertebral morphology due to kyphosis
- Wedge angle ingrease till midthoracic vertebral bodies
- Facets's inclination limits F/E and rotation
- Facets almost have a coronal orientation
- Facets's tilt angle increase gradually toward the lumbar spine
- Resistance to translation and axial loads

3. NORMAL BIOMECHANICS OF THORACIC SPINE

Thoracolumbar transition zone

Facets's orientation change in transverse plane from frontal toward sagital plane.

Cervico-thoracic transition zone

Sagital plane facets's angle tends to decrease. Transverse angle tends to increase in superior direction.

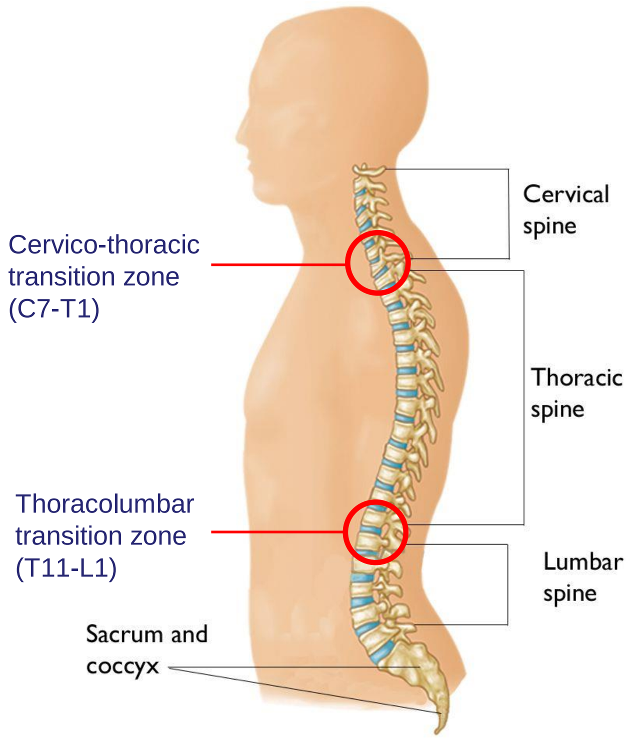

Figure 10. Spine's transition zones (edited from www.orthoinfor.aaos.org)

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3. NORMAL BIOMECHANICS OF THORACIC SPINE

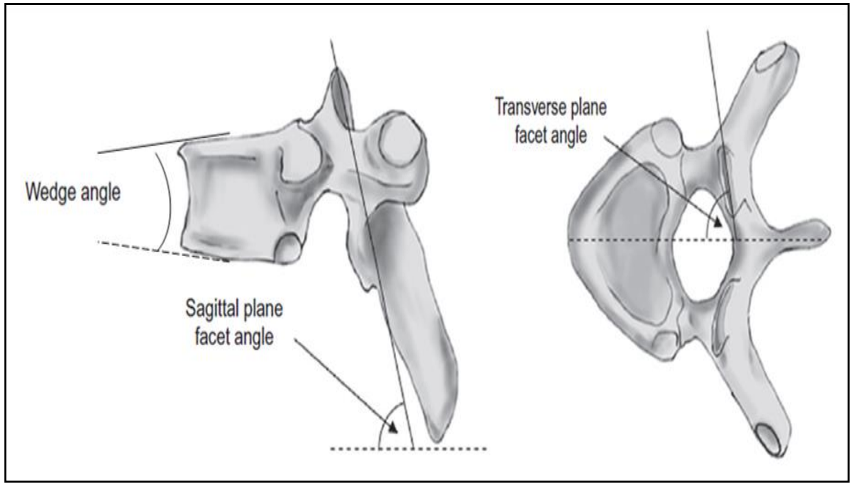

Figure 9. Wedge angle and Facet joint angles of the thoracic spinal motion segments. Image from Galbusera F. et al. 2018..

Kyphosis make vertebral body adopt a wedge shape

Presented towards lower thoracic spine

Disc's máximum height reach at T10-T11

Discs heights decrease, but anulus fibrosus gets thicker and stronger

3. NORMAL BIOMECHANICS OF THORACIC SPINE

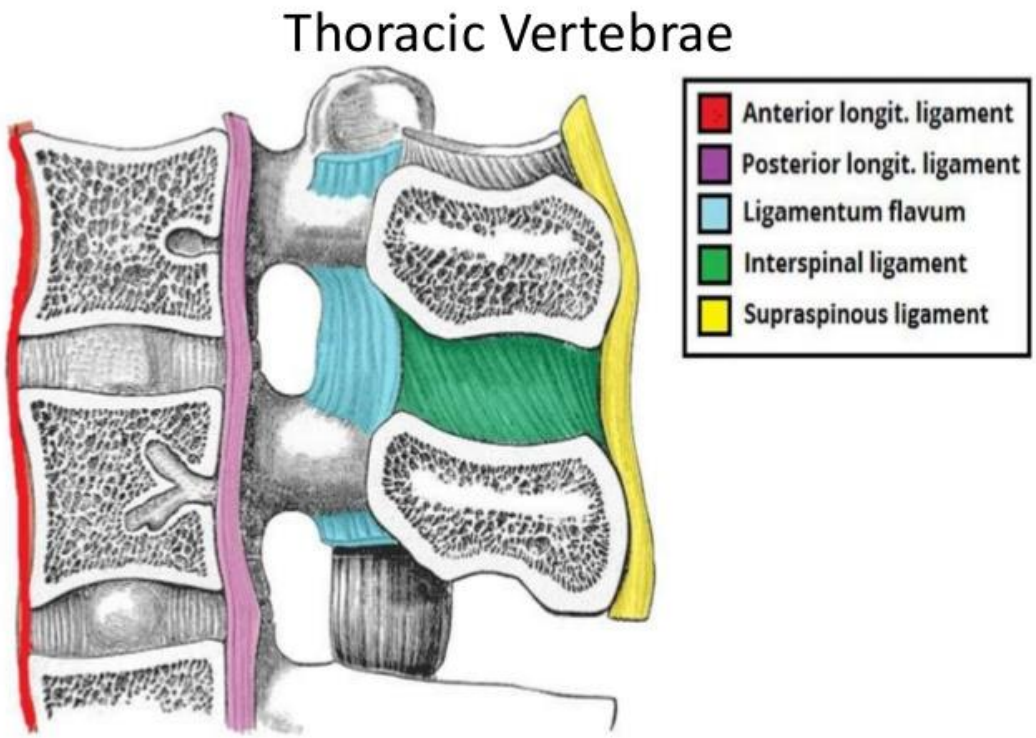

Figure 11. Thoracic ligament complex
(extracted from www.slideshare.com)

3. NORMAL BIOMECHANICS OF THORACIC SPINE

THORACIC SPINAL MOTION SEGMENT

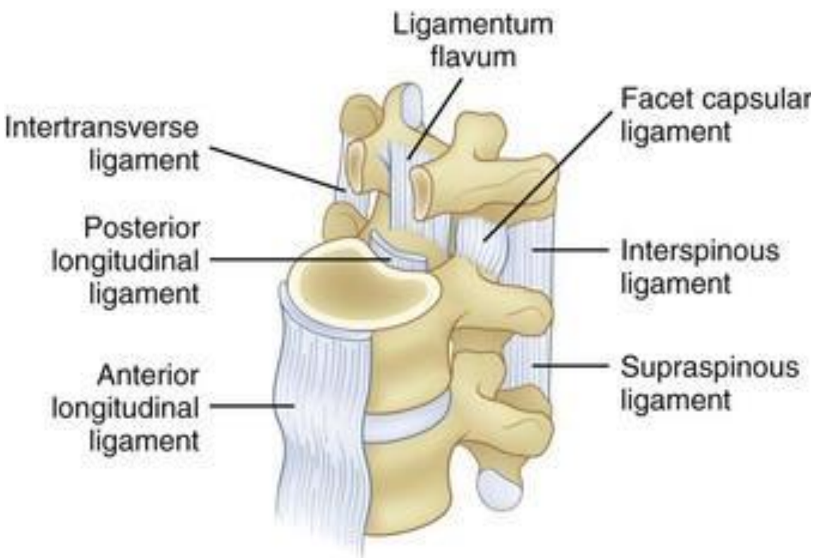

Figure 12. Thoracic ligament complex (extracted from www.clinicalgate.com)

Neutral zone

Close to neutral position

Bone and ligament structures offer minimal resistance

3. NORMAL BIOMECHANICS OF THORACIC SPINE

THORACIC SPINAL MOTION SEGMENT

During forward bending	During backward bending	During lateral bending	During axial rotation
The superior vertebra flexes relative to inferior vertebra	The superior vertebra extends relative to the inferior vertebra	The superior vertebra should laterally flex relative to the inferior vertebra. Rotation coupled in ipsi/contralateral directions	The superior vertebra rotates in the same direction as the axial rotation

3. NORMAL BIOMECHANICS OF THORACIC SPINE

THORACIC SPINAL MOTION SEGMENT

- Rib cage influence instantaneous rotational axes.
  - In flexion/extension motions, rotational axis shifts to posterior in the sagittal plane.
  - In flexion/extension and lateral bending, instantaneous rotational axes run through the lower vertebra,
  - In axial rotation, rotation axis is located close to the posterior part of vertebral body.
- Functional spinal unit does not consider the anterior portions of the ribs nor costocondral/sternochondral joints or sternum.
  - Study through ring unit.

3. NORMAL BIOMECHANICS OF THORACIC SPINE

THORACIC SPINAL MOTION SEGMENT

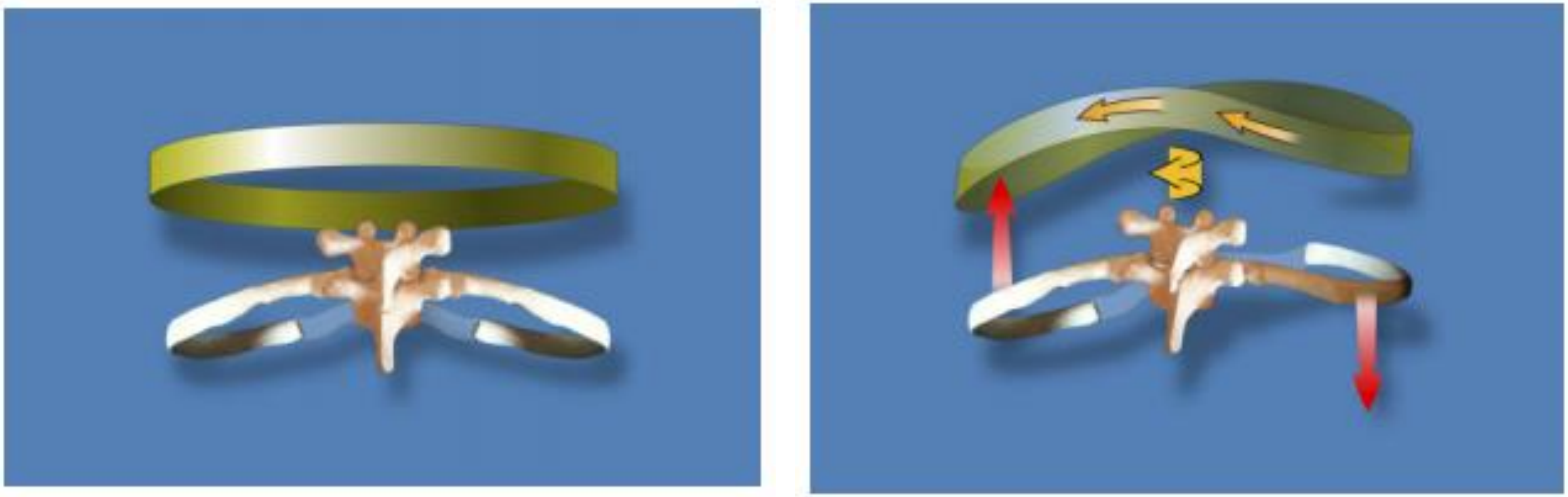

Figure 13. (Left) A typical thoracic ring (Right) kinematics of typical thoracic ring. Image from Lee DG. et al. 2015.

B. Biomechanical alterations of the spine

4. Normal biomechanics of the lumbar, sacral and coccygeal spine

4. NORMAL BIOMECHANICS OF THE LUMBAR, SACRAL AND COCCYGEAL SPINE

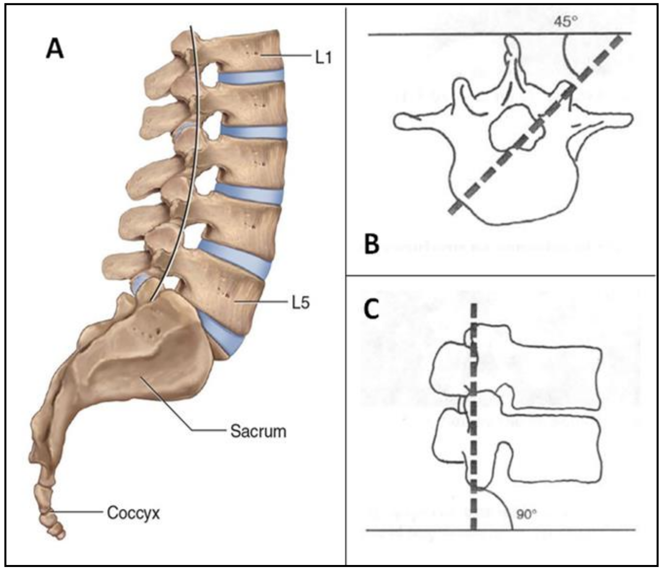

Figure 14. A: Lumbar spine, sacrum and coccyx. Image from Joseph E. Muscolino 2015. B-C: orientation of the lumbar faces respect sagital and transverse plane. Image B and C from Nordin M. 2001.

- 5 lumbar vertebrae, 5 fused sacral vertebrae, 4-5 coccygeal vertebrae.
- Lumbar's posterior concavity (lordosis), sacrum's anterior concavity.
- Lumbar vertebrae characteristics:
  - Widest and biggest vertebral body to bear high loads.
  - With terminar bony endplates.
  - Vertebral bodies with different heights depending anterior or posterior zone.

4. NORMAL BIOMECHANICS OF THE LUMBAR, SACRAL AND COCCYGEAL SPINE

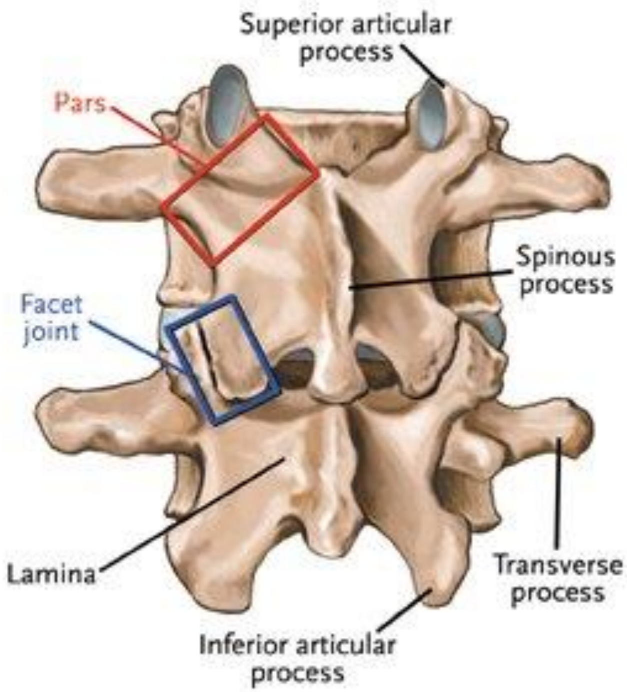

Figure 15. Lumbar vertebrae structures (extracted from www.joint-pain-solutions.com)

- Lumbar vertebrae facets:
  - 90º and 45º orientation in transverse plane.
  - Load sharing with intervertebral discs (IVD).
  - Determine high resistance with translational and rotational movements.
  - Facilitate flexion and extension movements.

4. NORMAL BIOMECHANICS OF THE LUMBAR, SACRAL AND COCCYGEAL SPINE

LUMBAR SPINAL MOTION SEGMENT

Flexion movements

- IVD increase its thick in the posterior part.
- Nucleus pulposus goes backward.
- Capsule and ligaments get tighter.

Extension movements

- IVD increase its thin in the posterior part.
- Nucleus pulposus goes forward.
- Anterior longitudinal ligament strech and posterior ligaments distend.
- Limited by bone and tensión.

4. NORMAL BIOMECHANICS OF THE LUMBAR, SACRAL AND COCCYGEAL SPINE

LUMBAR SPINAL MOTION SEGMENT

Lateral bending

- IVD increase its thick on the contralateral side.
- Nucleus pulposus shifts slightly to ipsilateral side.
- Facets rise in contralateral side.
- Facets drop in ipsilateral side.

4. NORMAL BIOMECHANICS OF THE LUMBAR, SACRAL AND COCCYGEAL SPINE

LUMBAR SPINAL MOTION SEGMENT

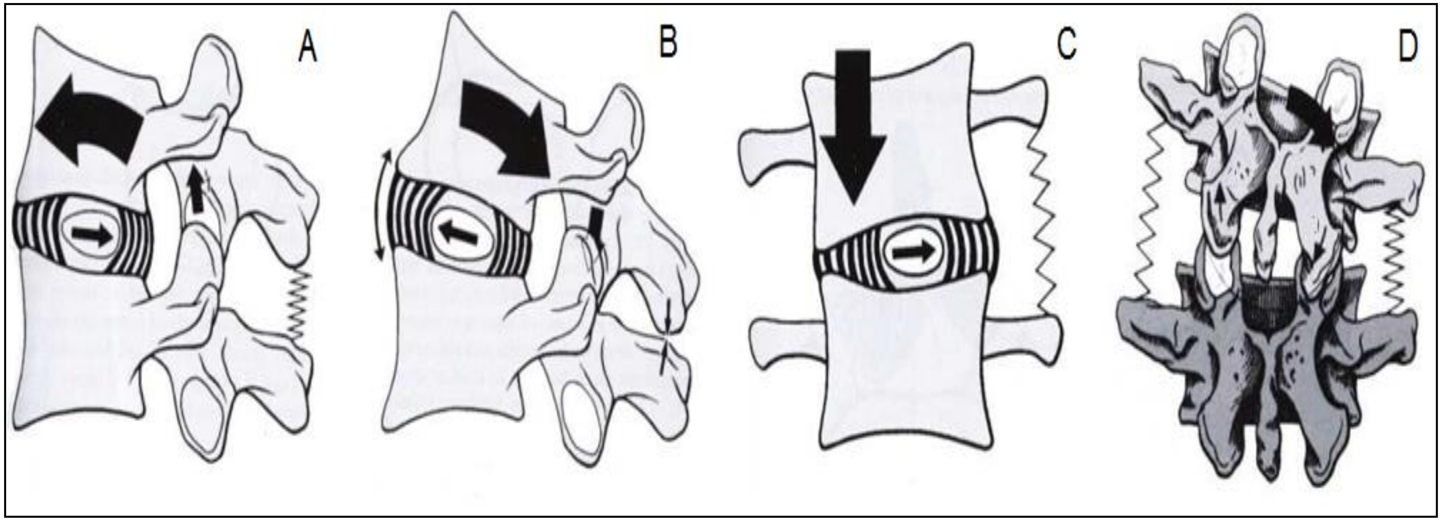

Figure 16. Segmental motion of lumbar spine. A: flexion, B: extension, C: anterior view of lateral bending, D: posterior view of lateral bending. Images from Kapandji A.I. 1998

4. NORMAL BIOMECHANICS OF THE LUMBAR, SACRAL AND COCCYGEAL SPINE

THE SACRUM AND COCCYX

Sacrum

- Articulates with 5º lumbar vertebrae, coccyx and iliac bones.
- With intervertebral discs.
- Iliolumbar ligament limitates movement at lumbosacral and sacroiliac joints.

Coccyx

- Articulates with sacrum with a fibrocartilaginous joint.
- Anterior and posterior lateral sacrococcygeal ligament, intercornual ligaments and IVD bound the sacrococcygeal joints.

4. NORMAL BIOMECHANICS OF THE LUMBAR, SACRAL AND COCCYGEAL SPINE

THE SACRUM AND COCCYX

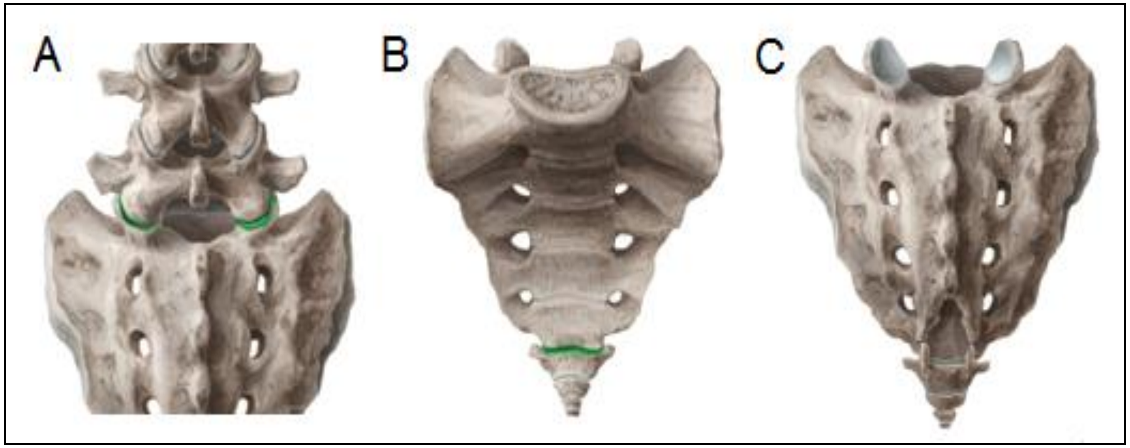

Figure 17. The lumbosacral and sacrococcygeal joint. A: zygapopohyseal joints from lumbosacral union. B: Anterior view of sacrococcygeal joint. C: Posterior view of sacrococcygeal joint. Images from KenHub web site.

B. Biomechanical alterations of the spine

5. What load does the spine undergo when we are on different rest positions?

5. WHAT LOAD DOES THE SPINE UNDERGO WHEN WE ARE ON DIFFERENT REST POSITIONS?

Standing position

- Weight transmission through sacrum, ilium to femur.
- Relaxed standing preassure of 0.48 to 0.5 Mpa.

Figure 18. Standing and sitting model (extracted from www.shutterstock.com)

Sitting position

- Weight transmisión through sacrum, ilium to ischial tuberosities.
- Lumbar supporthas the greatest infuence on lumbar lordosis.

5. WHAT LOAD DOES THE SPINE UNDERGO WHEN WE ARE ON DIFFERENT REST POSITIONS?

Supine or lying position

- Flexing legs in lying position increase L4-L5 preassure in 0.08MPa.
- Coughing or sneezing increase preassure in 0.38 MPa .
- Laughing increase preassure in 0.15 MPa.

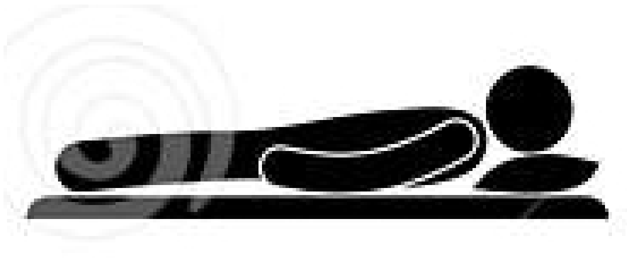

Figure 19. Lying model (extracted from www.es.dreamstime.com)

B. Biomechanical alterations of the spine

6. How is the biomechanics of the spine when we make functional motor gestures?

5. HOW IS THE BIOMECHANICS OF THE SPINE WHEN WE MAKE FUNCTIONAL MOTOR GESTURES?

Lift and carry objects

- Lifting techniques are important to reduce intradiscal pressure.
- 50% more pressure during bent forward.
- More lumbar stability and balance during lifting.
- Importance of facets

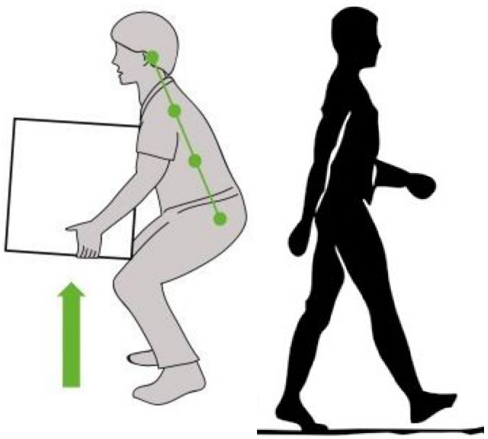

Figure 20. Lifting and gait model (extracted from www.neurospinewellnesscenter.com & www.brightmindcenter.com)

Gait

- Intradiscal load increase 0.2 to 2.5 times in L3-L4.
- Máximum load in takeoff phase.
- Exists a linear coorelation between intradiscal load and walking speed.

B. Biomechanical alterations of the spine

7. Key ideas

7. KEY IDEAS

- The spine has four major interrelated functions: support, mobility, housing and protection, and control.
- Motion segment is the "Functional Spine Unit" (FSU) that consists of two adjacent vertebrae and the interconnecting soft tissue, devoid of musculature. Each FSU has six grades of freedom.
- The cervical section is made up of 7 vertebrae and form one of two lordosis of the spine, which greatly increase the resistance to the stress of axial compressions compared to a rectilinear column (up to ten times).
- The Atlanto-occipital joint is formed for atlas and the condylar part of the occipital bone, allows the nodding movements by the rolling and gliding of the occiputal condyles on the concave surface of the socket, located in the superior face of the lateral mass of the atlas.

7. KEY IDEAS

- The atlanto-axial complex is composed by two lateral facet joints, the unique atlantodental articulation and the joint between the posterior surface of the odontoid and the transverse ligament and allows the anterior arch of the atlas spins and glides around the pivot, allowing the atlas and head to rotate from side to side as one unit.
- The thoracic spine have 12 vertebrae from T1 to T12 that form a concave curvature to the ventral direction in the sagittal plane call kyphosis. The kyphotic nature of the spine further leads to a primary compressive load distribution in anterior direction toward the vertebral body, whereas the posterior mainly have to resist tensile loads.
- The distal region of the spine is made up of the lumbar section of 5 vertebrae, the sacral section of 5 fused vertebrae and the coccygeal section, made up of 4–5 vertebrae. While the lumbar spine has a posterior concavity lordosis, the sacrum has an anterior concavity.

7. KEY IDEAS

- In the movements of lumbar extension and flexion, is observed the most vertebral translation, which makes the measurement of lumbar translation a determining factor of spinal instability.
- The load on the intervertebral discs changes depending on the position of the body and the actions performed. In the supine position, the intradiscal pressure at the lumbar level is around 0.08 MPa, while during relaxed standing, the pressure varies between 0.48 and 0.5 MPa. In a sitting position, the pressure is similar to biped position, but the inclination of the backrest greatly influences the decrease in this pressure, as does the use of arm rest.
- During gait the intradiscal lumbar load increase between 0.2 to 2.5 times with respect to the intradiscal pressure at rest. However, during the gesture of lifting a weight from the ground, the pressure rose further by 70% to 220%, especially if it does it with the back bent and the knees extended. It will also influence this intradiscal pressure if the weight that is lifted is away from the body.

B. Biomechanical alterations of the spine

8. Bibliography

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