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TEACH

MODULE BIOMECHANICS OF SPINE

Didactic Unit A

Topic: Biomechanics of the normal spine

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1. Objectives and Introduction

In this Didactic Unit, it will review the most relevant aspects of the normal biomechanics of the spine. The objetives of this didact unit are:

1. To rework the biomechanics of the different segments of the spine in normal conditions.
2. To review the biomechanics of the spine in normal condition in the main resting positions of the human being.
3. To revise the biomechanics of spine in normal condition during usual daily functional gestures.

General concepts

The spine has four major interrelated functions: 1) suport, 2) mobility, 3) housing and protection, and 4) control. As a support structure, the spine functions as a framework fot the attachment of internal organs, the upper and lower extremities and the head. The mobility allows for the many physical task of daily living and work, but complicates spine structure. This, instead of a single rigid column, the spine is a flexible stack of 24 rigid vertebrae with flexible discs in between.

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 (Figure 1), using the standard Cartesian coordinate system for the spine, 12 potential movements about the instantaneous axis of rotation can be considered: 2 translational and 2 rotational along or around each axes (x, y, z). In summary, the range of motion (ROM) is expressed by translation and rotation in three planes. In the cervical spine, too much motion should be considered as structural damage of the spine, while too little motion may accompany stiffness and pain.

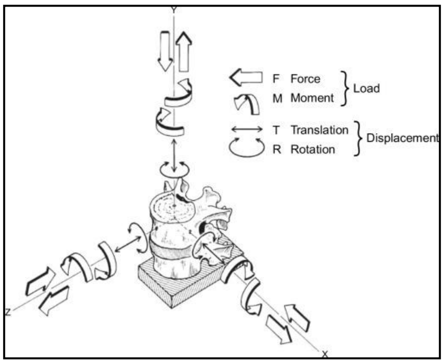

Figure 1 - The coordinate system for the spine developed by White and Panjabi (1990). The imagen shows the translation and rotation possible movement for x, y and z axes. From E.A. Friis et al. 2017.

2. Normal biomechanics of cervical spine

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 cervical section, “cervical vertebrae C1-C7”, whose length varies from 15 to 16 cm in women and from 18 to 19 cm in men which 1/4 is represented by the thickness of the intervertebral disks, presents a lordodic mobile anteriorly convex curvature of about 36° that varies according to modifications of the other spinal curves and it’s more accentuated in elderly. Cervical vertebrae, according to their peculiarities, can be grouped in upper cervical spine (C1-C2) and lower cervical spine (C3-C7).

2.1 Biomechanics of upper cervical spine

Atlanto-occipital joint

The atlas is the first cervical vertebrae and provides a cradle (also called socket or notches) for supporting the condylar part of the occipital bone. Its primary motions are flexion and extension or nodding movements. These movements are achieved by the rolling and gliding of the occiputal condyles on the concave surface of the socket. In flexion the condyles rolling forwards and sliding backward across the anterior walls of their sockets. In extension, a converse combination of the rolling and sliding occurs. Flexion and extension movements are restricted by the following:

- The atlanto-occipital joint is impaction of the rim of the socket against the base of the skull
- Flexion is limited by tension in the posterior neck muscles and by impaction of the submandibular tissues against the throat
- Extension is limited by the occiput compressing the suboccipital muscles.

Rotation and lateral flexion between the occiput and atlas is extremely limited or not possible due to the depth of the superior articular surface of lateral mass. In these movements, the head and atlas move and function essentially as one unit. During head rotation, the contralateral occipital condyle contact with the anterior wall of its atlantal socket and the ipsilateral condyle contact with the posterior wall of its respective atlantal socket. Instead, in the lateral head flexion, the tight atlanto-occipital joint capsule prevents the contralateral condyle from lifting out of its cavity. Indeed, the stability of the atlanto-occipital joint stems largely from the depth of the atlantial sockets.

Atlanto-axial joint

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.

The weight of the head is transferred to the cervical spine through the lateral atlanto-axial articulations of C2, the axis. The odontoid process extends from the body of C2 vertebra to the facet on the atlas located in the anterior arch, acts as the “pivot” and forms the atlanto-axial median joint. This atlanto-axial median joint allows the anterior arch of the atlas spins and glides around the pivot (Figure 2), allowing the atlas and head to rotate from side to side as one unit. The unilateral rotation of this joint is about of 40°. In such a mobile joint there must be a great stabilization that, in this case, is given by the transverse, alar and apical ligaments (Figure 2), which hold the dens while atlas rotates. Likewise, at the end of the rotation, movement will be limited by the lateral atlanto-axial joints, which are much more lax than the C0-C1 joint capsules. Rotation in this level is also possible because of the particular anatomy of the lateral atlanto-axial joints. In some texts, this joint is described as biconcave and others as biconvex, depending on whether the text refers to the shape of the joint surfaces or the joint cartilage between them, respectively. Technically, this is a plane joint, allowing sliding and rotating movements. This means that on the articular surfaces of the C2, the inferior and lateral articular surfaces of the atlas can move forward or backward during rotation. As the C1 rotates, the ipsilateral atlantial facet slides down the posterior slope of the respective axial facet, while the contralateral one slides down the anterior slope of axial facet.

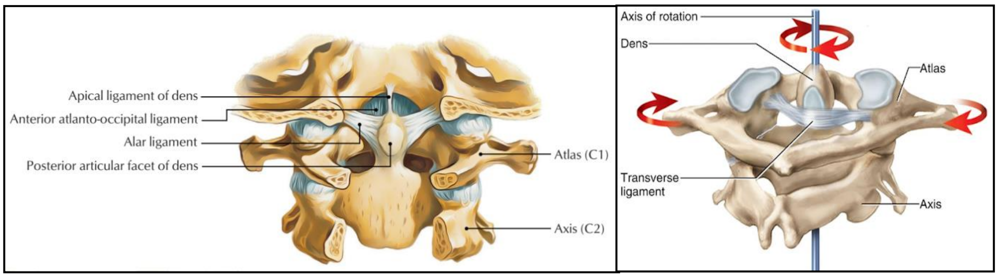

Figure 2 - Apical, Alar and Transverse ligament of the odontoid process of the Axis vertebra. Image from (left) www.earthslab.com and (right) www.imagequiz.co.uk.

The atlanto-axial lateral joint also produces a coupling motion during flexion and extension of the cervical spine (Figure 3), *i.e.* when the cervical spine is flexing, the atlas extends, and when the cervical spine extends, the atlas flexes. In neutral position, C1 is balanced precariously on the convexities of its articular cartilages, but when an axial compression load is applied, C1 starts to move passively. Atlas backward sliding is limited by the impaction of its anterior arch against the odontoid process, while forward slipping is prevented by the transverse and the alar ligaments. Up to 3 mm of anterior translation of C1 on C2, as measured by anterior atlantodental interval, is considered normal.

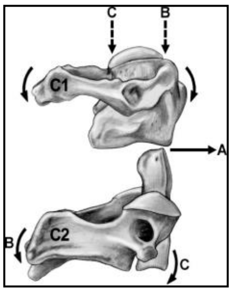

Figure 3 - The biconvex nature of C1 and C2. A, Translation. B, Extension of C1 creating flexion in C2. C, Flexion of C1 creating extension in C2. Image from Swartz E. et al. 2005.

The integrity of the occipitoatlantoaxial joint complex articulation not only depends on the ligaments that we have already mentioned above but also the tectorial membrane play a fundamental role in the stability of these segments. The tectorial membrane is a broad continuation of the posterior longitudinal ligament and is attached between the posterior body of C2 and the basiocciput. Its main role is to limit extension at the occipitoatlantal joints.

2.2 Biomechanics of lower cervical spine

To describe the lower cervical spine, it is usually considered from C3. However, the C2-C3 joint has important biomechanical characteristics that differ from the joints of the rest of the lower cervical vertebrae:

- Unlike the typical zygapophysial joints whose planes are transverse, the superior articular processes of C3 face not only upwards and backwards but also medially, by about 40°. Unlike the typical zygapophysial joints whose planes are transverse.
- Together, the processes of both sides form a socket into which the inferior articular processes of the axis are nestled. Furthermore, the superior articular processes of C3 lie lower, with respect to their vertebral body, than the processes of lower segments.
- During axial rotation of the neck, the direction of coupling with lateral flexion at C2-C3 is opposite to that seen at lower segments. Instead of bending towards the same side as rotation, C2 rotates away from that side, on the average. The lower location of the superior articular process of C3 correlates with the lower location of the axis of sagittal rotation of C2.

The characteristics of the lower vertebrae are more uniform. They are separated by an intervertebral disc in the intervertebral joint. The articulating surfaces of the inferior and superior interbody joints are similar to a saddle joint, this mean that they consist of two concavities facing one another and set at right angles to one another. The inferior surface of the upper vertebral body is concave downwards in the sagittal plane and the superior surface of the lower vertebral body is concave upwards in the transverse plane. These characteristics allow that the vertebral body can move forwards and backwards around a transverse axis (Figure 4, Axis I) and side-to-side around a perpendicular axis to the facets and cradled by the uncinate processes (Figure 4, Axis II). Motion around a oblique anterior - posterior axis (Figure 4, Axis III) is precluded by the orientation of the facets.

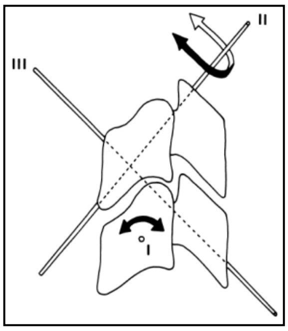

Figure 4 - The planes of motion of a cervical motion segment. Flexion and extension occur around a transverse axis (axis I). Axial rotation occurs around a modified axis (axis II) passing perpendicular to the plane of the zygapophysial joints. In the third axis (axis III) no motion can occur. Image from Bogduk N. et al. 2000.

3. Normal biomechanics of thoracic spine

Connecting the cervical and lumbar spinal sections, the thoracic spine must ensure high stability for the muscle-controlled sagittal balance of the spine through the erector spinae and abdominal muscles, for an optimum force transmission from the upper body to the lower spinal sections, and for flexibility adequate for performing three-dimensional motions. Where the intersegmental stability of the cervical and lumbar spine is determined mainly by the adjacent musculature, the thoracic spinal segments are stabilized primarily by the additional bony and ligamentous structures of the rib cage.

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 (Figure 5), whose angle is 45° and varies between 20° and 70° in asymptomatic spine. The kyphosis depend on the lumbar lordosis angle and the posititioning of the lower cervical vetebrae, *i.e.* flat lumbar lordosis induces a decreased lower thoracic curve and both leading to an effect in the position of lower cervical vertebrae in order to keep them balanced. The initial spinal curvature, and the body-weight, determine the above location of the center of gravity. Due to the thoracic spine is generally bent forward, exist continuous posterior muscle forces necessary to maintain upright spinal position, especially by the longissimus dorsi muscle. With the increase axial load, the thoracic curvature straightens for low initial angles and increases for larger angles. 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.

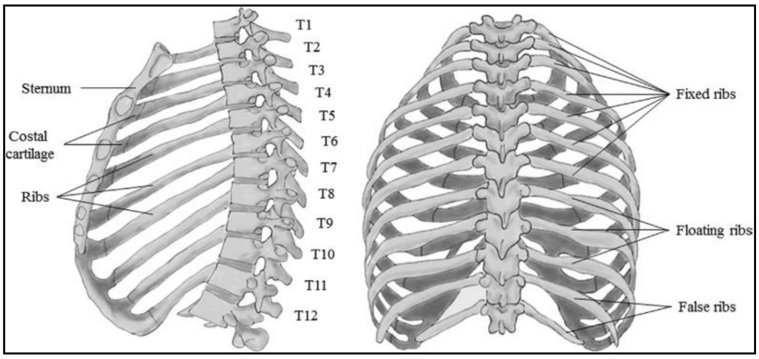

Figure 5 – The bony and cartilaginous thoracic spine and rib cage in sagittal view without the left ribs *(left)* and in back view *(right)*. Image from Galbusera F. et al. 2018.

The vertebral morphology is attributed to the inclined configuration of the thoracic spine. The average wedge angle (Figure 6) is about 4 degree, which shows a trend for a more pronounced wedge configuration of the midthoracic vertebral bodies. The inclination of the articular facets limits the flexion/extension and axial rotation range of motion as well as altering the instantaneous rotational axis in the transverse plane. The facets are almost coronal in orientation in the thoracic column (T1–T10). The tilt angles of the facets increase gradually in inferior direction toward the lumbar spine by converging to the frontal plane, especially in the sagittal plane, where the angles vary from 55-60º in T1 to 70-75º in T10. (Figure 6-A). In the transversal plane the facerts angle vary from 70-80º. Because all of the thoracic facets are primary oriented parallel to the frontal plane, they provide a distinct resistance to anteroposterior translation and, to a lesser extent, to axial compression loads. In the thoracolumbar transition zone (T11 to L1), there is usually an abrupt or segmental change of the facet orientation in the transverse plane from frontal toward sagittal plane orientation of the articular surfaces; in the cervico-thoracic transition zone, the sagittal plane angle tends to decrease and the transverse angle tends to increase in superior direction.

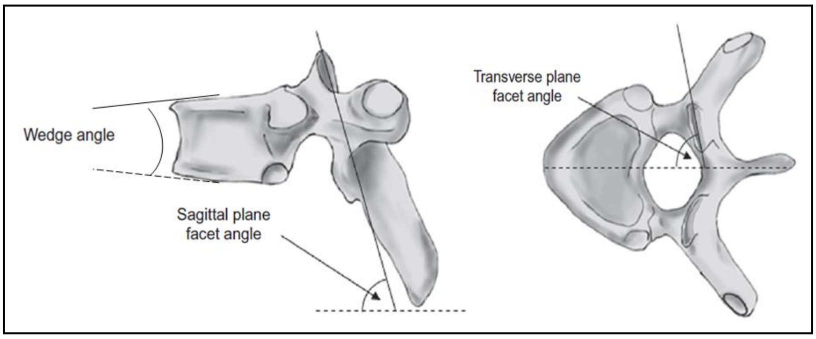

Figure 6 – Wedge angle and Facet joint angles of the thoracic spinal motion segments. Image from Galbusera F. et al. 2018.

Because of the kyphotic curvature of the thoracic spine and the increasing bending moment in upright position, the anterior portion of the thoracic disc is compressed by the body weight, whereas the disc shows a wedge shape in uncompressed condition. This wedge shape, resulting from a higher anterior disc height, is especially present in the lower thoracic spine (T7 – T12) by approximately 20%, whereas in the upper thoracic spine, the discs are either quite flat (T1 – T4, T5– T7) or exhibit a larger posterior disc height (T4 – T5). The average disc height decreases in inferior direction to a minimum at T4-T5 before increasing to reach a maximum height at T10-T11. Compared with the cervical or lumbar spine, the disc height is generally decreased, but the anulus fibrosus is thicker and stronger, especially in the posterior section, leading to limited rotation motions, whereas the nucleus is relatively small , indicating that axial compression loads are absorbed by other structures, such as the facet joints or the rib cage structures. In the transverse plane, the cross-sectional areas of the discs of the upper thoracic spine are relatively smaller than those in the lower thoracic spine and increase inferiorly by more than 100% from T1-T2 to T11-T12.

The ligaments in this area will be briefly described, it should be considered that they are common to other regions. The anterior longitudinal ligament, located to the front of each vertebrae, in the thoracic spine has a higher cross-sectional area and is about three times stronger in the upper than in the lower thoracic spine, due to limit excessive extension motions. On the other hand, the posterior longitudinal ligament is situated within the vertebral canal and extends along the posterior surfaces of the bodies of the vertebrae; in midthoracic region is stronger than other regions. These ligaments are thicker in the thoracic spine than in the other sections because they have to prevent hyperflexion and hyperextension movements. The flavum ligament is defined as each of the yellow colored sections of elastic tissue located between the lamina of an upper and a lower vertebra; Its function is to maintain or recover the erect position. In the lower thoracic segment, the flavum ligament exhibits a high tensile failure load of about 300 N and also has a high cross-sectional area (100 mm^2). The intertransverse ligaments are found in the thoracic spine and in the upper lumbar spine, and exert a restriction on lateral inclination and axial rotation, while the interspinous and supraspinous ligaments serve to limit hyperflexion. However, the supraspinous ligament is stronger than interspinous ligament because of the higher lever arm during flexion motion.

Thoracic spinal motion segment

In general, the relationship between range of motion and neutral zone were found to decrease in inferior direction for equal bending moments. The neutral zone is a zone of mobility, close to the neutral position of the joint in which the osteoligamentous structures offer minimal resistance. In vivo, higher ranges of motion were found in the lower segments due to the floating and false ribs of the lower rib cage have a smaller effect on motion restriction. The segmental motion occurs as follow:

- During forward bending, the superior vertebral flexes relative to the inferior vertebra. Between T3 and T10, the superior articular process is inclined slightly anterior in the coronal plane and a small amount of anterior translation of the superior vertebra occurs during flexion.
- During backward bending, the superior vertebra extends relative to the inferior vertebra. Between T3 and T10, the superior articular process is inclined slightly anterior in the coronal plane and a small amount of posterior translation of the superio vertebra occurs in conjunction with extension.
- During lateral bending, the superior vertebral should laterally flex relative to the inferior vertebra and rotation may be segmentally coulpled in an ipsilateral or contralateral directions. If the superior vertebra is free to follow the orientation of the zygapophyseal joints, then the pattern is often ipsilateral.
- During axial rotation, the superior vertebra rotates in the same direction as the axial rotation. If the superior vertebra is free to follow the orientation of the zygapophyseal joints, then the pattern of coupling with lateral flexion is ipsilateral. There is also a slight contralateral translation in the transverse plane of the superior vertebra relative to the inferior.

The instantaneous rotational axes are influenced by, among other elements, the rib cage, which was found to shift the position of the rotational axis posteriorly in the sagittal plane during flexion/extension motions. The instantaneous rotational axes of the thoracic spinal motion segment run through the lower vertebra during flexion/extension and lateral bending. But, in axial rotation, the rotational axis is located in the spinal canal close to the posterior part of the vertebral body. It is worth mentioning that in the thoracic region, the Functional Spinal Unit does not consider the anterior portions o the ribs nor the anterior costochondral/sternochondral joints or the sternum. Therefore, the study of the segmental motion could be through the ring unit, i.e. the thoracic vertebrae and the respective ribs, and this approach could change the rotation of the axes.

4. Normal biomechanics of lumbar, sacral and coccygeal spine

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. The vertebral body has a structural design that supports axial loads. The vertebral body is the major load-bearing structure of the lumbar spine and are frequently described as being drum-shaped with a transverse cross-section resembling the shape of a kidney. The cranial and caudal surfaces of the vertebral bodies, termed bony vertebral endplates, are slightly concave and provide attachment for the intervertebral discs. To support the high loads acting on the lumbar vertebrae, they are comparatively large with their size increasing toward the sacrum. While the two uppermost lumbar vertebral bodies are moderately lower anteriorly than posteriorly (between about 4% at L2 and 12% at L1 at the sagittal midsection), the endplates of the L3 vertebra are almost parallel. This relation reverses for the L4 and L5 vertebrae, where the anterior height is greater than the posterior height (between approximately 7% at L4 and 14% at L5 at the sagittal midsection). In contrast, all lumbar intervertebral discs (L1/L2 to L5/S1) are at least twice as high anteriorly than posteriorly, meaning that the lumbar lordosis of approximately 60 degrees is mainly constituted by the intervertebral discs rather than vertebrae.

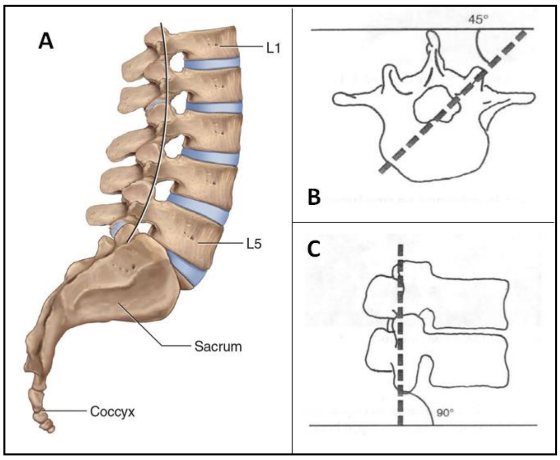

Figure 7 - A: Lumbar spine, sacrum and coccyx. Image from Joseph E. Muscolino 2015. B: orientation of the lumbar faces with respect to the sagittal plane. C: orientation of the lumbar faces with respect to the transverse plane. Image B and C from Nordin M. 2001.

The lumbar facet joints have a sagittal orientation of 90 degree and 45 degree in the transversal plane. These characteristics play an important role in the biomechanics of the lumbar spine because they determine the load sharing between the intervertebral disc and the facet joints, as well as the resistance against translational and rotational movement. In fact, the facet joints resist about 16% of the compressive force in upright standing. On the other hand, the lumbar facet ortientation facilitates more flexion and extension than rotation, which increase in range from the top to the bottom.

Lumbar spinal motion segment

During the flexion movement (Figure 8-A), the vertebral body of the upper vertebra of FSU tilts and slides slightly forward, modifying the thickness of the intervertebral disc in its anterior part and increasing it in the posterior part, which displaces the nucleus pulposus backward, so that the posterior fibers of the fibrous ring increases its pressure. At the same time, the lower articular facet of the upper vertebra slide upward, making the capsule and ligaments as tight as the posterior ligaments: flavum, interspinous, supraspinatus, and the posterior longitudinal ligament. This tensioning limits the flexing movement. In the opposite movement (Figure 8-B), *i.e.* extension, the vertebral body of the superior vertebra leans back and the interverbral disc becomes thinner at its posterior zone, pushing the nucleus of the intervertebral disc forward, tightening the anterior fibers of the fibrous ring . At the same time, the anterior longitudinal ligament is stretched and the posterior ligaments are distended. In addition, during the extension, the lower articular facet of the upper vertebra fit more deeply between the upper articular facet of the lower vertebra, while the spinous processes contacts each other. In this way, the extension movement is limited by the bony contacts of the posterior arch and by the tensioning of the anterior longitudinal ligament.

It should be noted that it is in the movements of extension and flexion where the most vertebral translation is observed, which makes the measurement of lumbar translation a determining factor of spinal instability. Current literature suggests that 2 mm of translation is normal for the lumbar spine and translation beyond 4 mm should be evaluated for clinical instability.

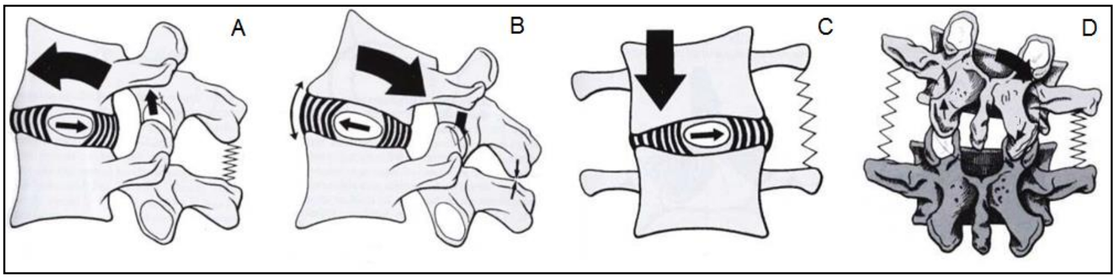

Figure 8 - Segmental motion of lumbar spine. A: flexion, B: extension, C: anterior view of lateral bending, D: posterior view of lateral bending. Images from Kapandji A.I. 1998.

During the lateral bending, the superior vertebral body tilt to the side of the bending, the disc becomes thicker on the opposite side of the lateral bending, and the nucleus of the intervertebral disc shifts slightly to that side; at the same time the intertransverse ligament is tightened (Figure 8-C). In a posterior view (Figure 8-D), the uneven sliding of the articular facets can be described: while the articular facet on the opposite side of the tilt rises, the articular facet on the tilt side drops. This causes the flavum ligament and the zygapophyseal joint capsule on the incline side to distend, while on the opposite side these same elements are tightened.

The unique coupling patterns associated with the lumbar spine, may directly or indirectly contribute to the higher incidence of clinical instability at the L4-L5 segment. The upper lumbar segments L1-L2, L2-L3, and L3-L4 share a coupling pattern different from that of L4-L5 and L5-S1.1 In the upper lumbar spine, side bend and rotation occurs in opposite directions, while in the lower lumbar segments, side bend and rotation occur in the same direction.

The sacrum and coccyx

The sacrum is composed of five vertebral bodies fused together by four ossified intervertebral disk. The sacrum articulates above with the fifth lumbar vertebra, below with the coccyx, and laterally from the auricular surfaces with the two iliac bones of the hip to form the sacroiliac joints. The projecting anterior edge of the first sacral vertebra is called the sacral promontory and the two sides are the sacrum alas. The sacral promontory is used as a landmark for making pelvic measurements. The vertebral bodies are connected with a large intervertebral disc, and the zygapopohyseal joints (Figure 9-A) have a wider interval than above. The joint is strengthened posteriorly by interosseous and dorsal sacro-iliac ligaments. The iliolumbar ligament originates from the transverse process of L5 and inserts to the iliac crest. It has a ventral and a dorsal part. This ligament is important for restraining movement at the lumbosacral and the sacroiliac joints. The sacrum has a deep forward angulation relative to the final or 5th lumbar vertebra, wich angle is almost 30 degrees on average with the horizontal plane.

The coccyx is a small triangular bone at the bottom of thevertebral column consisting of three to five (usually four) fused rudimentary vertebrae. The lower end of the sacrum articulates as a fibrocartilaginous joint or often fuses with the coccyx (Figure 9-B). The first coccygeal vertebra has short transverse processes that connect with the sacrum and two coccygeal cornua or horns that connect to the sacral cornua (Figure 9-C). The coccygeal vertebrae lack pedicles and spinous processes, but the first three have a primitive body and transverse processes. The second, third, and fourth coccygeal vertebrae diminish successively in size and the last vertebra is a mere small nodule of bone. The sacrococcygeal joint is bound together with the anterior and posterior (superficial and deep), lateral sacrococcygeal ligaments, the intercornual ligaments and the intervertebral disc.

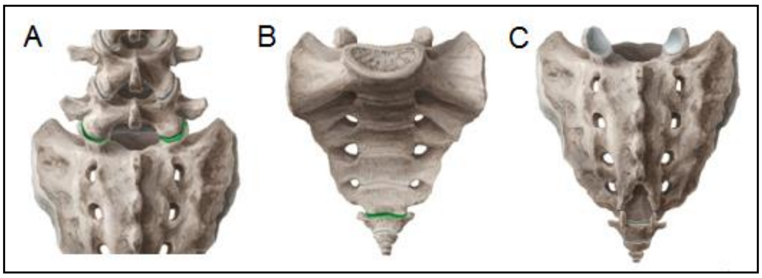

Figure 9 - The lumbosacral and sacrococcygeal joint. A: zygapopohyseal joints from lumbosacral union. B: Anterior view of sacrococcygeal joint. C: Posterior view of sacrococcygeal joint. Images from KenHub web site.

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

In this section we will review the biomechanical changes studied in the literature when the spine is kept in different resting positions.

Standing position

- The weight of the body is transmitted through the sacrum and ilium to the femur during standing.
- During relaxed standing, the pressure vary between 0.48 and 0.5 MPa. Abdominal pressing raised it to 0.92 MPa and increased with forward bending to 1.1 MPa.

Sitting position

- The weight of the body is transmitted through the sacrum and ilium to the ischial tuberosities in sitting.
- Sitting on a chair with a normal, straight back produced a pressure of 0.45 to 0.5 MPa.
- Lumbar support has the greatest influence on lumbar lordosis and the inclination of the backrest had the most influence in reducing pressure within the lumbar disc (0.27 MPa).
- As the inclination of the lumbar support increases, more weight is distributed on the backrest and less muscle activation is required from the erector spinae muscles of the spine.
- The use an arm rest to support the trunk can further decrease the amount of load placed upon the vertebral discs during sitting.

Supine or lying position

- During lying supine with slightly flexed legs, an intradical pressure at the L4-L5 level of 0.08 MPa has been detected. With legs totally extended, the pressure change to 1.11 MPa. Rotation into the lateral position raised the pressure only slightly to 0.12 MPa.
- Coughing and sneezing in a supine position produced pressures as high as 0.38 MPa, but heartily laughing raised the pressure only up to 0.15 MPa.

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

In this section we will review the biomechanical changes studied in the literature when the spine is kept in different functional motor gestures.

To lift and carry and object

- The intradiscal pressures increase when heavy weights are lifted, but the proper lifting techniques reduce the disc load. A protruding abdomen acts as a weight carried further away from the body.
- The intradiscal pressure increase 50% during bent forward. With weights in the hands, the pressure rose further by 70% to 220%. Studies have shown that the lumbar intradiscal pressure increases to 2.3 MPa during lifting a weight of 19.8 kg with a rounded back and straight knees. While lifting the same weight keeping the back straight and bending at the hip and knee, it reduced the peak pressure to 1.7 MPa.
- In a normal disc, the annular fibers will be tensed by increased intra-discal pressure from the trunk flexing forward. The annular fiber orientation in a normal disc is 60 degrees from vertical as compared to a degenerative disc, whose annular fibers become more horizontal.
- The lumbar spine achieves stability and balance during lifting because as the spine flexes forward, the accompanying counternutation of the sacrum increases tension in the thoraco-lumbar fascia.
- Forward flexion of the lumbar spine also triggers contraction of the pelvic floor and transversus abdominus muscles, which biomechanically tightens the thoraco-lumbar fascia. This combined action on the posterior ligamentous system acts as an anti-shearing force on the lumbar spine.
- If the erector spinae muscles are contracted in a flexed lumbar spine, the effect is an increased compression on the zygapophyseal joints. This would facilitate transference of load through the cortical bone of the neural arches, decreasing compression on the lumbar vertebrae, and thereby countering the intradiscal pressure.

Gait

- An intradiscal load increase between L3-L4 occurs between 0.2 to 2.5 times with respect to the intradiscal pressure at rest.
- The maximum load is reached during takeoff.
- There is a linear increase in intradiscal load with respect to walking speed.

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.
- 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. To support the high loads acting on the lumbar vertebrae, they are comparatively large with their size increasing toward the sacrum.
- 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 pressure, 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.

8. References

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