

THE DEVELOPMENT OF THE VERTEBRA AND THE INTERVERTEBRAL DISC

Precartilage Stage (mesenchimal stage)

The vertebral column develops from the mesenchimal cells that accumulated around the notochord during the 4th week of the embryonic period. At the end of the 4th week the mesenchimal cells that derive from the sclerotom of the somits accumulates in 3 major regions¹⁻³.

Region surrounding the Notochord

In the 4th week of the embryonic period the sclerotoms elgine around the notochord as paired mesenchial cells. Each of the sclerotoms cells are grouped loosely at cranial and compact at caudal levels. Some of the dense cells groups migrate cranially and form the intervertebral disc. The rest of the dens cell group together with the caudal loose sclerotom group unites and forms the mesenchimal vertebral centrum. Each centrum is formed by two adjacent sclerotom and forms an intersegmental structure.

The nerves are closely related to the intervertebral disc and the segmental arteies which are closely localized to the side of the body (corpus) of the vertebrae. At the thoracic levels the dorsal intersegmental arteries are converted to intercostal arteries.

The notochord around the developing vertebral body degenerates and vanishes. The notochord in between the vertebrae expands and forms jelatinous part of the intervertebral disc. This is called the 'nucleus pulposus'. The nucleus pulposus is surrounded by regular circular fibers called the 'anulus fibrosus'. The nucleus pulposus' plus the anulus fibrosus form the intervertebral disc. Some remnents of the notochord may remain within the intervertebral disc which can result as 'chordoma'. This neoplasm frequently occurs at the base of the skull and at lumbosacral region¹⁻³.

Region surrounding the neurol tube

The mesenchimal cells at this region gives rise to the vertebral archs.

Region surouunding the corpus

The mesenchimal cells at this region gives rise to the costal processes. The costal porocesses will give rise to the ribs at thoracic region¹⁻³.

Cartilage Stage

At the 6th week of the embryonal stage the mesenchimal cells forms the central cartilage of the vertebrae. At the end of this embryonic period the two centers of the centrum unites to form the cartilage centrum. At the same time the centrum of the arch of the vertebra unite with each other. The elongation of the cartilage centers of the arches forms the 'spinous processes' and 'transvers processes' (Figure 1).

Ossification Stage

The typical vertebra ossification begins at this embryonic period and continuous until 25 years of age¹⁻³.

Prenatal Stage

The centrum consists of two primary ossification centers (ventral and dorsal). The two ossification centers unite to form a single center. At the end of this embryonic period 3 basic ossification centers

develops. One of these is located at centrum and the other two at the vertebral arch of each vertebra half. The ossification of the arch becomes more prominent at the 8th week. At birth each vertebra is composed of 3 parts and each portion is connected to each other via cartilage¹⁻³ (**Figure 1**).

Postnatal Stage

The arch of each half of the vertebral fuses between 3-5 weeks. The fusion of the lumbar arches continuous until 6 years of age. First fusion takes place at the the arches of the lumbar levels and then the lamina of the upper level vertebrae fuses. The union of the arches of the vertebrae with the centrum forms the neurocentral joint. These joints allows the enlargement of the vertebral arches during development of the spinal cord (medulla spinalis). Between 3-6 years of age the union of centrum and the vertebral arch disappears. After puberty 5 ossification centers are defined; one at the tip of the spinous process and two at the tip of the transverse process and two at the epiphysis (anular epiphysis). The two epiphysis one is located on the superior and the other is located at the inferior surface of the body of the vertebrae (**Figure 2**). The superior and inferior surface of the body of vertebrae is formed by anular epyphysis and in between there is bony structure. The centrum present in the body of the vertebrae, part of the vertebral arch and costal heads contains articular facets. The secondary ossification centers ossifies by the end of the 25 years of age together with the vertebrae. The ossification age can show variations according to individuals. The secondary ossification centers should not be mixed with persistent epiphysis fractures¹⁻³ (**Figure 1**).

The variations in the number of Vertebrae

Approximately 90% of the people contain 12 thoracic, 5 lumbar, 5 sacral and 3-4 coccygeal vertebrae. In approximately 3% there may be 1 or 2 extra or less number of vertebrae (**Figure 2**). The vertebral column must evaluated as whole because less vertebrae at one segment level can be compensated with an extra vertebrae at other segment level. For example the number of thoracic vertebrae can be 11, however the number of lumbar vertebrae can be 6^{4,5} (**Figure 2**).

Abnormal development of the vertebral column (Spina Bifida Occulta)

In the case of spina bifida the vertebral arches do not develop and does not unite in the mid-line. This congenital abnormality can occur in the form of total absence to partial absence of the vertebral arch^{2,3}. The stability of the vertebral column is achieved by the intervertebral disc, ligaments and the muscles. During the movements of the vertebral column the discs has a function of absorbing the shocks. For this reason the shape and volume of the vertebrae changes according to the segmental level. A typical vertebra anteriorly is composed of a body and posteriorly an arch. The projections extending posteriorly from the body is called the 'pedicles'. The pedicles extending further posteriorly become flat and they are called 'lamina'. The body, pedicle and the lamina encircle a foramen called the 'vertebral foramen'. In an articulated vertebral column the vertebral foramen pile one on top of the other and form a canal called the 'vertebral canal' (**Figure 3a,b**). Within this canal is located the spinal cord, meninx and the roots of the spinal nerves. Where the pedicle meets the lamina there are 3 pairs of processes these are called 'superior articular processes,' inferior articular processes and 'transverse process'. Where the two lamina meets there is a single process which extends posteriorly called the 'spinous processes. The superior articular process extends superiorly and has an articular surface on its posterior surface. This articular surface articulates with the articular surface on the inferior articular process of the vertebrae above. The inferior articular process extends inferiorly and has an articular surface on its anterior surface^{5,6} (**Figure 3a,b**). It articulates with the articular surface on the superior articular process of the vertebrae below. The movement (facet joint or zygapophysial joint) capacity of this joint is highly restricted and variations according to the vertebral level. The transvers process extends horizontally and it receives the attachments of the muscles which produce the rotation and lateral flexion of the trunk. The transverse processes of the thoracic vertebra has and articular surface which articulates with the ribs. The transverse processes are formed by the union of real transverse processes and costal elements^{5,6}. When we view the vertebrae from the side between the body, pedicle

and the superior articular process is a notch called 'superior vertebral notch'. Similarly between the body, pedicle and the inferior articular process is another notch called 'inferior vertebral notch' (**Figure 3a,b**). The inferior vertebral notch is deeper than the superior^{5,6}. In an articulated vertebral column the inferior vertebral notch of the vertebra above and the superior notch of the vertebrae below forms a complete foramen called the 'intervertebral foramen'. The roots of the spinal nerves exit from these foramina (Figure 3a,b).

The anatomy of the lumbar vertebrae

The number of lumbar vertebra varies from 5 to 6. The characteristic features of the lumbar vertebra is that they are very large compared to the rest of the vertebrae. They do not have an articular surfaces on their transverse processes for the articulation with the ribs and do not have a foramen in their transverse processes. The transverse diameter of the corpus of the lumbar vertebra are larger compared to the other vertebrae. The vertebral foramen of the lumbar vertebrae is triangular in shape and it is larger than thoracic but smaller than cervical vertebrae. The pedicles of the lumbar vertebrae are small. The spinous processes are directed horizontally and are quadrangular in shape. The superior articular processes of the lumbar vertebrae contains a concave articular facet on its posteromedial surface. On the posterior surface of the superior articular processes is located the 'mamillar process'. On the anterolateral surface of the inferior articular process is a convex articular facet (**Figure 3a,b**). The transverse processes of the 5th lumbar vertebrae (L5) is thinner and longer compared to the other vertebrae. At the base of the transverse process is a small bony spine called the 'accessory process' (**Figure 3a,b**). Measurements were made on the 3rd (L3) and 4th (L4) lumbar vertebrae of 338 female and male subjects, age ranged between 20 to 90. The results of these measurements showed that in male the width of the body of the vertebrae showed reduction in relation to age. In both sex the anterior height of the body of the vertebrae showed reduction in relation to the width reduction⁷. Twomey et al.⁸ studied 93 adult vertebral column and reported loss of bone density in the body of the lumbar vertebrae in relation to age. The loss in the female was more pronounced compared to male. This loss can be due to the loss in the transverse trabecular bone. Amonoo-Kuofi^{9,10} measured the distance between the two pedicles (the width of the vertebrae) and compared the results of 150 male and 140 female subjects. These results showed significant difference between male and female, however in the negro races it was constant in the two sex. He concluded that the width of the vertebrae can show racial differences. Ratcliffe¹¹ performed a detailed study on the development of the body of the vertebrae from 29th prenatal week until 15 years of age. He has reported that the transverse processes of 5th (L5) lumbar vertebrae was the longest and the body was the largest among the lumbar vertebrae. Further, in order to contribute to the sacrovertebral angle the 5th lumbar vertebrae is placed more anteriorly compared to the rest of the lumbar vertebrae. To the anterior and posterior aspect of the body of the vertebrae is attached the 'longitudinal ligament'. The crus of the diaphragm is attached to the anterolateral aspect of the longitudinal ligaments of upper lumbar vertebrae (3rd on the right, 2nd on the left). The psoas major muscle is attached to the sides of the body of all lumbar vertebrae. The vertebral canal of the 1st (L1) lumbar vertebrae contains the cornu medullaris portion of the spinal cord, cauda equina and the meninx. Extending postero-laterally from the body is the paired pedicle. The superior vertebral notch of the lumbar vertebrae is shallow whereas the inferior vertebral notch is deep. The lamina of the lumbar vertebrae are large and short. The spinous processes do not overlap each other like the thoracic vertebrae. To the spinous processes of lumbar vertebrae attaches the thoracolumbar fascia, M. erector spinalis, M. spinalis thoracis, M. multifidus, M. interspinalis and interspinalis and supraspinous ligaments. The spinous process of the 5th (L5) is the smallest of the lumbar vertebrae and the tip of the spinous process is round and it is directed backwards. The distance between the two superior articular processes of the upper lumbar vertebrae is larger than the distance between the inferior articular processes. This difference between the distances is reduced at 4th lumbar vertebrae (L4), and almost disappears at 5th lumbar vertebrae (L5). The articular surfaces on the superior and inferior articular processes are opposite (concave on the superior articular process and convex the inferior articular process) to one another. This joint allows small amount of rotation, flexion and extension. Except for the 5th (L5) lumbar vertebrae the transverse processes are flat vertebrae extends dorsoventrally and elongated dorsolaterally^{5,6}. The lower border of the transverse processes of 5th (L5) vertebrae is angulated, it extends laterally then superolaterally. The angle at the

lower border of the transverse processes represents the costal elements and its lateral ends represents the real transverse processes. The transverse processes of 1st (L1) to 3rd (L3) lumbar vertebrae become larger from above downwards. However, the transverse processes of 4th (L4) and 5th (L5) lumbar vertebrae are smaller. On the anterior surface of the tip of the transverse processes of lumbar vertebrae is a vertical line which attaches the anterior layer of the thoracolumbar fascia. To the medial aspect of this vertical line attaches the psoas major muscle and to its lateral aspect attaches the quadratus lumborum muscle. The middle layer of the thoracolumbar fascia, the lateral and medial arcuate ligaments (lumbocostal arch) and the iliolumbar ligaments are attached to the tips of the transverse processes of lumbar vertebrae. To the posterior surface of the transverse processes the muscular fibers of the deep back muscles and the longissimus muscles are attached. To the lower and upper border of the transverse processes attaches the lateral intertransversus muscles. The mammillary process is homolog to the 12th superior tubercle of the 12th thoracic vertebrae, to which the multifidus and the medial intertransversus muscles are attached. It is hard to define the accessory process, if present the medial intertransversus muscle is attached^{5,6}.

The anatomy of the lumbar vertebrae disc

There are totally 23 intervertebral disc, 6 cervical, 12 thoracic, 5 lumbar^{5,6}. There are no intervertebral disc between atlas (C1), axis (C2) and between coccygeal vertebrae. The lumbar intervertebral disc in human subjects forms approximately one fourth of the length of the vertebral column. The lumbar intervertebral disc is approximately 7-8 mm thick and has a diameter of 4 cm. The shape of the intervertebral disc corresponds to the shape of the body of the vertebrae. The thickness of the intervertebral disc varies according to the segmental levels. Further, the thickness of the intervertebral disc shows regional difference within each disc. The intervertebral disc of cervical and lumbar is anteriorly thick and posteriorly thin. This structure increases the convexity of the vertebral column at the cervical and lumbar regions. The thickness of the intervertebral disc of the thoracic segments is even within the disc. The anterior concavity of this region is formed by the body of the vertebrae. The intervertebral disc at the upper thoracic levels are thin, at lumbar levels are the thickest. The upper and lower surfaces of the intervertebral discs are covered with hyaline cartilage. Externally the intervertebral discs are composed of 'annulus fibrosus' and internally 'nucleus pulposus'. The external (annulus fibrosus) portion of the intervertebral disc is supplied by the peripheral vessels. However, internal portion is avascular and is supplied by diffusion from the trabecular bone of the body of the vertebrae. The reaction to trauma of the vascular and avascular portions of the intervertebral disc shows difference. The annulus fibrosus is attached to the edges of the body of the vertebrae and to the anterior and posterior longitudinal ligaments. The nucleus pulposus is attached to the hyaline joint cartilage. The nucleus pulposus absorbs the axial shocks and becomes flattened when squeezed. During flexion, extension and lateral flexion of the vertebral column the disc resembles a ball semi filled with liquid.

The development of the disc

Nucleus pulposus is derived from primitive notochord, annulus fibrosus and the vertebrae are derived from the end plate. It is formed by proteoglycans, collagens and water in varying compositions. All intervertebral discs are attached to the anterior and posterior longitudinal ligaments. The intervertebral discs at the thoracic segments also attached to the head of the rib laterally via intra-articular ligaments.

The nucleus pulposus

The nucleus pulposus is more developed at cervical and lumbar segments. It is localized at the central and posterior surface of the disc^{5,6}. At birth it is composed of soft gelatinous and mucoid material. It can possess few notochord cells and fibers from the annulus fibrosus. Later in the development the notochord cells disappear and in time the mucoid material develops the hyaline cartilage. With increasing age the nucleus pulposus cannot be separated from the rest of the disc and becomes less hydrated and more fibrous in structure. Cross bandings are formed between collagen and the proteoglycan. Also reduces the water holding capacity of the discs and becomes more hard and more

vulnerable to trauma (**Figure 4**). The nucleus pulposus is in the form of gelatinous structure and it is under high pressure in sitting position. It has a function of transferring the load in an axial direction and in lower body movements it acts as movement axis. The third function is to act like ligament to hold the vertebrae together.

Anulus fibrosus

Anulus fibrosus is more fibrous and possess less water and more collagen than nucleus pulposus^{5,6}. It surrounds the nucleus pulposus which is under high pressure and holds it in its appropriate position (**Figure 4**). Anulus fibrosus is composed of approximately 15-25 collagen rings and are called 'lamella'. Between this lamellar structures are located elastin fibers. These elastin fibers support the disc during bending. These lamellar fibers are aligned parallel to each other and aligned vertically forming 65° between vertebrae. The vertical fibers may be loose on the posterior aspect may be vulnerable to trauma. This standard structure of the annulus fibrosus may not be present in all levels of the vertebral column (**Figure 5**).

The arterial supply of the intervertebral disc

It is supplied by 2 sources: First is by way of bone marrow diffusion from small foramina located on the hyaline cartilage overlying the body of the vertebrae and the second source is by way of diffusion from peripheral blood vessels. Due to the two different structures of the intervertebral disc their reactions to trauma are different¹¹.

The ligaments of the vertebral column

The ligaments of the vertebral column are divided into 3 groups as external craniocervical, internal craniocervical and vertebral ligaments.

External craniocervical ligaments

These ligaments connects cranium to the atlas (C1) and axis (C2). These ligaments are quite loose so that the cranium can move freely^{5,6}.

The anterior atlantooccipital membrane

It extends between the upper borders of the anterior arch of the atlas and the anterior border of the foramen magnum. It is a thick fibroelastic membrane. Laterally this ligament continuous with the capsule of the atlantooccipital joint. Anteriorly this ligament is strengthened by the course of the anterior longitudinal ligament^{5,6}.

The posterior atlantooccipital membrane

It is larger and thinner than the anterior atlantooccipital membrane. It extends between the upper borders of the posterior arch of the atlas and the posterior border of the foramen magnum. This membrane on each side arches over the vertebral artery and forms an opening for the course of the vertebral artery towards the atlas and for the exit of the the 1st (C1) cervical spinal nerves^{5,6}.

Joint capsule

The joint capsule extends between the condyles of the occipital bone and superior articular facets of the atlas. The capsule is quite loose and allows the movement of the head. The joint capsule is thin at the center and thick on the sides. The thickening on the sides are also called 'lateral atlantooccipital ligament'. The lateral atlantooccipital ligament restricts the lateral flexion of the head.

Anterior longitudinal ligament

The anterior longitudinal ligament extends from the base of the skull to the sacrum (**Figure 6**). The upper part of this ligament, medially supports the anterior atlantooccipital membrane in the midline. The part between the anterior tubercle of the atlas and the anterior median ridge on the axis have lateral extension called the 'atlantoaxial' ligament (epistrophic ligament).

Nuchael ligament

It is a fibroelastic membrane which extends between the external occipital protuberance of the occipital bone and the posterior tubercle of atlas and spinous processes of cervical vertebrae. This ligament forms a septum in the midline and provides muscle attachments^{5,6}.

Ligamentum flavum

It is a yellowish elastic membrane that extends between lamina of the vertebrae of two neighboring vertebrae. It extends between the posterior arch of the atlas and the lamina of the axis. It is absent between the atlas and the occipital bone^{5,6} (**Figure 6**).

Internal cranoicervical ligaments

Internal cranoicervical ligaments are located at the posterior surface of the body of the vertebrae. They strengthen the cranoicervical region and prevents the extensive movements of the head. They restrict the medial and lateral rotation of the head around the atlantoaxial joint^{5,6}.

Tectorial membrane

Tectorial membrane is located within the vertebral canal. It is the upper continuation of the posterior longitudinal ligament. It extends from the posterior surface of the body of the axis to the anterior and lateral edge of the foramen magnum, and superiorly blends with the dura mater. The tectorial membrane addition to the other ligaments has a supportive functions to the spinal cord and medulla oblongate^{5,6}.

Transverse ligament of atlas

Transverse ligament of atlas is a strong ligament passing transversely posterior to the dens of the axis. On each side it attaches to the tubercle on the medial aspect of the lateral mass of the atlas. From the midpoint of the dens extending upwards and downwards to the base of the occipital to be fixed respectively, to the basilar part of the occipital bone between the tectorial membrane and the apical ligament of the dens and the posterior surface of the of the body of the axis- the superior and inferior longitudinal fascicles. The transverse and the vertical bands are collectively called 'cruciform ligament'^{5,6}.

Apical ligament

The apical ligament extends from the apex of the dens to the anterior mid portion of the foramen magnum. Extends between the atlantooccipital membrane and the superior longitudinal fibers of the cruciform ligament.

Alar ligament

The alar ligament extends upwards and laterally from the superolateral aspect of dens to the medial surface of the condyles of the occipital bone. It controls the excessive rotation of the around the atlantooccipital joint.

Accessory ligament

It extends from the base of the dens to the lateral masses (close to the attachments of the transverse ligament) of he of the atlas. It restricts the excessive rotation of the around the atlantoaxial joint.

Vertebral ligaments

Anterior longitudinal ligament

It is a band shape ligament extending between the anterior tubercle of the atlas and sacrum. It becomes wider from above downwards. The anterior longitudinal ligament during its course it is closely attached to the anterior surface of the body of the vertebrae and to the intervertebral disc. It is composed of superficial and deep fibers. The short fibers connect the neighboring two body of the vertebrae and the intervertebral disc, whereas long fibers connect several vertebrae. The anterior longitudinal ligament is thickest at thoracic segments. This ligament prevents the hyperextension of the vertebral column (**Figure 6**).

Posterior Longitudinal Ligament

The posterior longitudinal ligament is wide at upper vertebral levels and narrow at the lower segments of the vertebral column. It is located at the posterior aspect of the body of the vertebrae within the vertebral canal. It extends between the axis and the sacrum. The upper portion of the posterior longitudinal ligament continuous with the tectorial membrane. The sides of the posterior longitudinal ligament specially at thoracic and lumbar regions extends laterally and fuses with the annulus fibrosus fibers of the intervertebral disc. Between the posterior longitudinal ligament and the posterior surface of the body of the vertebrae is located the basivertebral vein. The posterior longitudinal ligament prevents the hyperflexion of the vertebral column ^{5,6} (**Figure 6**).

Ligamentum flavum

Ligamentum flavum connects two neighboring lamina of the vertebrae. It extends between the anteroinferior border of the lamina of the vertebrae above and the posterosuperior border of the lamina of the vertebrae below. The medial aspect of the ligament contains openings for the exit of the external and internal venous plexus. The thickness of the ligamentum flavum increases from cervical to lumbar levels ^{5,6} (**Figure 6**).

Supraspinal ligaments

Supraspinal ligaments extends between the spinous processes of 7th (C7) cervical vertebrae to the sacrum. The supraspinal ligaments superiorly continuous with the ligamentum nuchae, anteriorly with the anterior interspinal ligaments. The thickness of the supraspinal ligaments increases from cervical to lumbar levels ^{5,6} (**Figure 6**).

Interspinous ligaments

Interspinous ligaments fills the space between two spinous processes. The interspinous ligaments is most developed at lumbar levels ^{5,6} (**Figure 6**).

Intertransverse ligaments

Intertransverse ligaments fills the space between two transverse processes. This ligament is in the form of filamentous structure at lumbar levels, however, at thoracic levels it is in the form of dense thick bands ^{5,6} (**Figure 6**).

Ligaments of the coccyx and sacrum

Ventral sacroiliac ligament (anterior sacroiliac ligament)

It arises from the pelvic and alar surface of the sacrum and attaches to the ilium. This ligament is thin and fibrous in structure and has a function of strengthening the joint capsule.

Dorsal sacroiliac ligament (posterior sacroiliac ligament)

It extends on the dorsal surface. Superficially it is composed of long and deeply composed of ligamentous bundles. The long superficial bundles of the sacroiliac ligaments extends from the posterior superior iliac spine and attaches to the lateral aspects of 3rd and 4th of sacral segments. The

fibers of this ligament which are externally located fuses with the sacrotuberous ligament. The deep short fibers of the dorsal sacroiliac ligament extends from the medial surface of the ilium and attaches to the lateral surface of the 1st and 2nd sacral vertebrae. The deep short fibers of the dorsal sacroiliac ligament are also called interosseus ligament.

Interosseous sacroiliac ligament

It is composed of short thick fiber bundles. It extends between the tubercles of the ilium. Forms a firm band between the two bones. It is located deep to the dorsal sacroiliac ligament and is one of the strongest ligament within the body.

Sacrotuberal and sacrospinal ligaments

Sacrotuberal and sacrospinal ligaments are accessory ligaments of the sacroiliac joint. Both ligaments assists the movements of this joint. Anterior, dorsal and lateral sacrococcygeal ligament binds the sacrum to the coccyx.

Joints of the vertebral column

The joint between the bodies of the vertebrae between C2 and S1 is cartilaginous. The joint is between articular processes are of synovial type (zygapophyses) and the joint between the lamina, transverse processes and spinous processes are fibrous type.

The joint between the body of the vertebrae

The bodies of the vertebrae articulates with the anterior, posterior longitudinal ligament and the fibrocartilaginous intervertebral discs.

Facet (Zygapophysial) joint

This joint takes place between the superior and inferior articular process. This joint is also called zygapophysial joint. The articular surfaces are flat and covered with hyaline cartilage. The facet joints have thin articular capsule. These capsules are long and loose at cervical region compared to thoracic and lumbar levels. This enables the cervical levels to produce large amount of flexion and extension. The facet joints of the cervical and lumbar vertebrae together with the intervertebral disc has a function of carrying the weight. Further, controls the flexion, extension and rotation movements of the cervical and lumbar levels. The facet joints are innervated by the medial branches of the dorsal ramus of the spinal nerves.

Atlantooccipital joint

It is the joint between the lateral masses of the atlas and the condyle of the occipital bone. The articular surface of the atlas is concave and sometimes this articular surface is divided into two. The joint capsule enclosing the two bone fuses with the anterior and posterior atlantooccipital membrane. The nodding movement of the head is achieved by this joint.

Atlantoaxial joint

There are two synovial joint between the atlas and axis. The lateral atlantoaxial joint is a plane type of joint, located between the atlas and the body of the axis. It takes place between the inferior articular surface of the atlas and the superior articular surface of the axis. The medial atlantoaxial joint takes place between the anterior arch of the atlas and the dens of the axis and it is a pivot type of joint.

Lumbosacral joint

Lumbosacral joint takes place between the 5th (L5) lumbar and the 1st (S1) sacral vertebrae and the intervertebral disc. Lumbosacral joint is supported anteriorly and posteriorly by the anterior and posterior longitudinal ligament. Additionally, the 5th (L5) lumbar vertebrae is connected to the ilium and sacrum by the iliolumbar ligament.

Sacrococcygeal joint

Sacrococcygeal joint takes place between the apex of the sacrum and the base of the coccyx. It is composed of lateral, dorsal and ventral ligaments.

The curvatures of the vertebral column

The vertebral column in male is approximately 70 cm and in female is 60 cm in length. The 12 cm is cervical, 28 cm is thoracic, 18 cm lumbar and 12 cm is sacral and coccygeal. The vertebral column anteroposteriorly consists of 4 curvatures. When the vertebral column is viewed from anterior the thoracic and sacral segments are concave and at cervical and lumbar segments are convex. The thoracic and sacral curvatures develop at embryonic period called 'primary curvatures' (**Figure 7**). Cervical and lumbar curvatures start developing at fetal period and become prominent at childhood and are called 'secondary curvatures' (**Figure 7**). The cervical curvature develops when the child keeps the head erect and the lumbar curvature develops when the child starts walking. The abnormal development of the curvature results in excessive kyphosis, lordosis and scoliosis.

The movements of the vertebral column

The movements of the vertebral column are achieved by the nucleus pulposus of the intervertebral disc and the facet joints. Although the capacity of the movements of the vertebrae are highly restricted by the ligaments, however, various movements do occur around these joints. The cervical and lumbar portions of the vertebral column are the most mobile portions. The vertebral column can produce flexion, extension, lateral flexion, rotation and circumduction.

Flexion movement

The anterior longitudinal ligament relaxes and the posterior longitudinal ligaments, ligamentum flavum, interspinous and subspinous ligaments produce flexion as much as these ligaments allow. At the same time the anterior border of the intervertebral disc is compressed and the distance between the lamina increases and the superior articular processes glide on the inferior articular processes. The tension of the extensor muscles is important in limiting the flexion movement. Cervical segments can produce extensive flexion.

Extension movement

Exactly the opposite events occur in the case of extension movement. The anterior longitudinal ligament contracts, posterior borders of the intervertebral disc are compressed, the distance between the spinous processes decreases. The extension movement is present at cervical and lumbar segments. At thoracic levels due to the thin intervertebral disc and inappropriate muscular and skeletal structure limited amount of extension occurs.

Lateral flexion movement

During lateral flexion the intervertebral disc of one side compresses while the other side tenses. The antagonist muscles and ligaments limit the lateral flexion. Lateral flexion can occur together with rotation. Lateral flexion can occur at cervical and lumbar levels.

Rotation movement

This movement occurs by the rotation of the vertebrae body one on top of the other. Most of the rotation occurs at upper thoracic levels least rotation occurs at the cervical and lumbar level.

Circumduction movement

It is limited movement of the vertebral column. It is the combination of flexion, lateral flexion and extension movements^{5,6}.

Muscles producing movements of the vertebral column

The movements of the vertebral column are produced by 2 groups of muscles. The first group of muscles are the ones that are attached directly to the vertebral column they are called 'intrinsic muscles'. The

second group of muscles are attached to the bony structures other than the vertebral column, these muscles indirectly assist the movements of the vertebral column and are called 'extrinsic muscles'. The flexion movement is achieved by M. longus coli, M. sternocleidomastoid, M. rectus abdominus muscles. The extension movement is achieved by M. erector spinalis, M. splenius, M. semispinalis capitis, M. trapezius muscle^{4,5} (**Figure 8**).

The arterial supply and the venous drainage of the lumbar vertebrae

The arterial supply

The vertebral column and the soft tissue is supplied by the dorsal ramus of the embryonic intersegmental somatic arteries^{11,12} (**Figure 9**). Thoracic segments are supplied by posterior intercostal arteries of the descending aorta. The abdominal segments are supplied by lumbar arteries from the abdominal aorta. Both lumbar arteries surround the body of the vertebrae and give the periosteal and equatorial branches. These arteries also give the dorsal branches and from the dorsal branches arises spinal branches. The spinal branches enters through the intervertebral foramen and supplies the facet joints, posterior surface of the lamina, muscles, skin and subcutaneous tissue¹¹⁻¹⁴ (**Figure 9**). At cervical and the sacral segments there are longitudinally oriented spinal arteries. These spinal arteries supplies the bony vertebrae, dura and epidural structures. Additionally, the radicular arteries supplies the spinal cord and roots of the spinal nerves (**Figure 9**). The spinal arteries entering vertebral canal divides into postcentral, prelaminar and radicular arteries. The postcentral branch supply the surface of the vertebrae body and the intervertebral disc and anastomosis with the similar arteries of the opposite side. This artery also supplies the anterior epidural tissue and dura (**Figure 9**). The posterior vertebral arch, posterior epidural tissue, dura, posterior wall of the vertebral canal and ligamentum flavum are supplied by prelaminar and anastomotic branches¹¹⁻¹⁴.

Venous drainage of lumbar vertebrae

The venous drainage of the vertebral column is via external and internal venous plexus which extends throughout the vertebral column¹¹⁻¹⁴. There are no valves in both external and internal venous plexus. Both external and internal venous plexus have anastomosis with each other and drains into the intervertebral veins. In the early fetal period the external and internal venous plexus have connection with the longitudinal veins. After the completion of the development these plexi drains into the caval and lumbar azygos system. These veins are also connected to the cranial venous sinuses, deep veins of the neck and pelvis¹¹⁻¹⁴. The veins of the vertebral column has large amount of dilatation capacity. Further, patients with major obstruction of the thoracic, abdominal veins can develop alternative drainage pathways. Because there are no valves the malign diseases or sepsis can spread to large areas. The pressure difference in the body cavities can be conveyed to the cerebrospinal fluid (CSF) via the venous plexi. However, the spinal cord can protect itself from this kind of congestions by the small veins that drain into the internal venous plexus.

The external vertebral plexus

The external vertebral plexi are divided into anterior and posterior groups. These veins have free anastomosis and are mostly developed at cervical levels (**Figure 9**). The anterior external vertebral plexi are located at the anterior aspect of the body of the vertebrae. They are connected to the basivertebral and intervertebral veins. Drains the venous blood from the body of the vertebrae. The posterior external vertebral plexus are located at the posterior aspect of the vertebral lamina, spinal processes, transverse processes and the articular processes. They have anastomosis with the internal venous plexus. It has connections with the vertebral veins, posterior intercostal vein, and lumbar vein.

The internal vertebral plexus

The internal vertebral plexus are located between the dura mater and the vertebrae. It collects the venous blood from the bone marrow and the spinal cord (**Figure 9**). The external plexi forms more dense plexi. There are 4 vertical coursing longitudinal veins (2 anterior and 2 posterior), which have interconnections with each other. The anterior external plexi are large venous plexi that are located on

the posterior surface of the body of the vertebrae and the intervertebral disc. These veins drain into the basivertebral veins via the transverse veins. The posterior internal plexi anastomosis with the external plexi. The internal venous plexi forms a ring around the vertebrae and anastomosis with each other. It is connected to the vertebral vein around the foramen magnum, occipital and sigmoid sinus, basilar plexus, venous plexus around the hypoglossal canal and emissary veins¹¹⁻¹⁴.

Basivertebral veins

The basivertebral veins are located within the bone and are similar to the diploic veins of the cranium having a tortuous structure¹¹⁻¹⁴. They exit through the small foramen located at the body of the vertebrae and drain into the anterior external vertebral plexus located within the vertebral foramen (**Figure 9**). They form one or two trunks that connects the posterior transverse and anterior internal vertebral plexus. The basivertebral veins show dilations at elderly ages.

Intervertebral veins

The intervertebral veins accompany the spinal nerves within the intervertebral foramen. They collect the venous blood from the internal and external vertebral plexi and drain into the posterior intercostal vein, lumbar vein, lateral sacral vein (**Figure 9**). The upper levels the posterior intercostal veins drain into the brachiocephalic veins then to the caval system, the intercostal veins of the lower levels drain into the azygos system. The lumbar veins, drain into the ascending lumbar veins which course longitudinally on the anterior surface of the transverse processes. They may sometimes encircle the body of the vertebrae and drain into the inferior vena cava. It is not known that the basivertebral and the intervertebral veins have an active functioning valves. Experimental researches have shown that the blood can flow in a backwards direction. This explains how prostate cancer or pelvic neoplasm can cause metastasis to the body of the vertebrae. The cancer cells can spread by the connections of the internal vertebral plexus with the pelvic veins. Due to postural changes or an increase in the intraabdominal pressure may cause reverse flow of the blood and result in spread of the cancer cells.

Lymphatic drainage

The lymphatic vessels drain into the deep lymphatic vessels which accompany the arteries. The cervical portion of the vertebral column drains into the deep cervical lymph nodes, thoracic portion to the posterior intercostal lymph nodes, lumbar portion lateral aortic or retroaortic lymph nodes. The pelvic portion of the vertebral column drains into the lateral sacral and internal iliac lymph nodes¹¹⁻¹⁴.

Innervation of the vertebral column

The innervation of the vertebral column and the soft tissue surrounding it at lumbar levels is via segmental spinal nerves. Also, branches from the gray ramus communicans of the thoracic sympathetic ganglia supplies the sympathetic innervations. Important nerve fibers innervating the vertebral column are dorsal ramus of spinal nerves, recurrent branches from the meningeal branches and from sinovertebral nerves.