# Functional Anatomy and Biomechanics of the Caudal Trunk and Pelvis

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**Take Home Message—Back pain and issues related to the sacroiliac joint region have been well documented as significant contributors to poor performance in ridden horses. To better understand how to manage these challenging issues, a working knowledge of structural and functional relationships of the caudal thoracolumbar spine, rib cage, abdominal musculature and sacropelvic is needed.**

## I. INTRODUCTION

A thorough understanding of the structure and function of the equine vertebral column can provide a clearer understanding of thoracolumbar and pelvic disorders. Osseous structures provide structural support and vary morphologically from one spinal region to another as functional requirements change. The dorsal and ventral trunk musculature produces complex spinal movements while the spinal ligaments and supporting connective tissues provide stability to the vertebral column. Proprioception and nociception are two important neurologic functions of the spinal articulations that support the truncal movements required for both unridden and ridden exercise.

## II. TOPOGRAPHIC ANATOMY

The thoracic region is characterized by the vertebral column dorsally, an expansive rib cage laterally and the sternum ventrally. The dorsal portion of the trunk is also called the back and can be divided into thoracic and lumbar regions. The dorsal spinous processes of the thoracolumbar vertebral region are readily palpable along the entire dorsal midline of the trunk. The dorsally-elongated spinous processes of the cranial thoracic vertebrae (T2-T12) form the withers, along with the dorsal scapula and associated thoracic limb musculature. The tallest thoracic vertebrae in the wither region are usually formed by T4-T5 and the base of the withers typically corresponds to the T12 vertebral level (Fig. 1). A flat or horizontal spinal conformation normally exists in the caudal thoracic and lumbar vertebral regions; however, the spinal curvature formed by the apices of the thoracolumbar dorsal spinous processes does not correspond to the curvature of the vertebral bodies, since the lengths of the spinous processes vary considerably in the thoracolumbar vertebral region. The supraspinous ligament attaches to the apices of the dorsal spinous processes and is often palpable along the dorsal midline. Large and powerful trunk muscles are palpable lateral to the thoracolumbar dorsal spinous processes (Fig. 2). The dorsal trunk muscles have variable tonicity, depending on the horse and the amount of muscle activity or injury present.

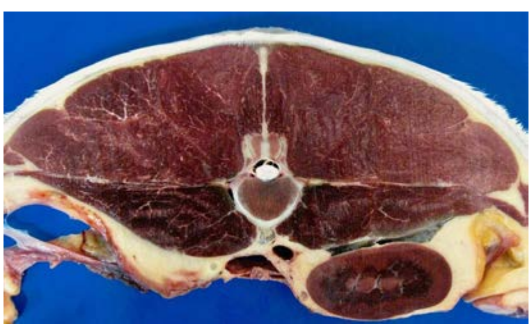
The ribs of the cranial thorax have a nearly vertical orientation; whereas the caudal ribs are more readily palpable and are angled caudoventrally toward the abdominal region. In ridden horses, the weight of the saddle and rider are carried primarily by the rib cage and less so by the thoracolumbar vertebrae as saddles are designed to provide clearance for movement of the epaxial muscle and underlying spinous processes. The elbow and the caudal border of the triceps brachii muscle are usually located at the fifth or sixth intercostal space which can be a site of girth pain in affected horses. The costal arch forms the caudoventral border of the rib cage and consists of the costal cartilages of the last 10 ribs. Caudal to the rib cage, a palpable depression in the lateral abdominal wall is divided into paralumbar fossa (dorsally) and flank (ventrally) regions. The paralumbar fossa is filled superficially with the internal abdominal oblique muscle which is thought to be an important muscle that functions in core stability.

The pelvic region of the horse has sacral (dorsal), ilial wing (lateral), and perineal regions (caudal). The croup forms the dorsal top line of the pelvic region. In horses, the slope of the croup is variable and dependent on the conformation of the dorsal pelvis and sacrum (Fig. 3). The tuber coxae are the palpable lateral prominences of the pelvis and are often erroneously referred to as the "point of the hip"; however, the tuber coxae are not actually associated with the hip (coxofemoral) joint. The tuber sacrale are palpable along the dorsal midline at the lumbosacral junction and often form the highest point of the croup (Fig. 4).[1] The dorsal spinous processes of the sacrum (S2-S5) are palpable along the dorsal midline caudal to the tuber sacrale and provide muscle attachment for the strong gluteal and hamstring muscles. The first sacral spinous process (S1) is not palpable, since the S1 process is short and lies deep to the tuber sacrale. The ischial tuberosities form the caudal prominences of the pelvis and are usually difficult to palpate in horses due to the large overlying semitendinosus and semimembranosus muscles. The greater trochanter of the femur is palpable in the lateral pelvic region along a line drawn from the tuber coxae (cranially) to the ischial tuberosity (caudally). The hip joint lies deep and cranioventral to the greater trochanter of the femur.

**Fig. 1. Lateral view of the thoracic vertebral column (T1-T18). Note the dorsal contour formed by the spinous processes compared to the horizontal line formed by the vertebral bodies.**

**2A. Cranial thoracic region.**

**2B. Caudal thoracic region.**



**2C. Middle lumbar region.**

**Figs. 2A-C. Transverse sections of the thoracolumbar spine.**

**3A**

**3B**

**3C**

**Fig. 3. Lateral views of trunk and pelvic conformation. A, Lordotic posture and horizontal croup conformation with wither and pelvic height nearly equal. B, Neutral trunk posture and croup conformation with wither height taller than pelvic height. C, Flexed lumbosacral and more vertical pelvic conformation with the pelvic height taller than the wither height.**

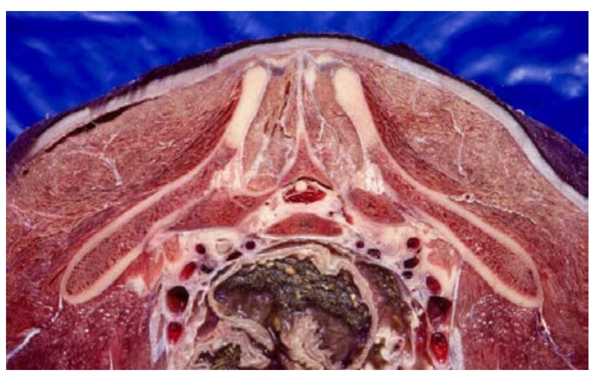
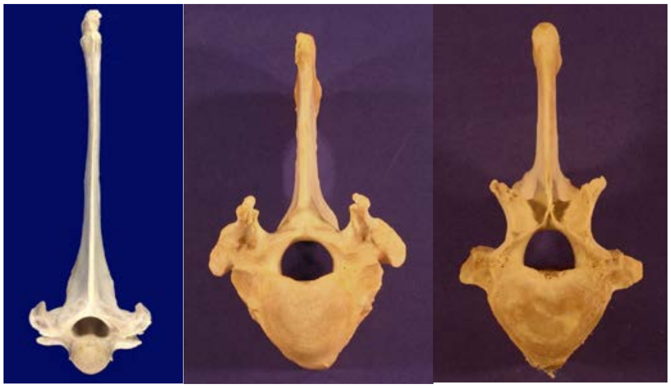


**Fig. 4. Transverse section of the pelvic region at the level of the sacroiliac joints and tuber sacralia.**

## III. THORACOLUMBAR VERTEBRAL COLUMN

The thoracic vertebrae are characterized by tall spinous processes and costal articulations (Fig. 5). The lumbar vertebrae have long, horizontally flattened transverse processes and intertransverse joints in the caudal region (L4-S1) that are unique to horses (Fig. 6). The sacrum is usually made up of 5 fused segments and has bilateral sacroiliac joints for articulation with the pelvis. The caudal vertebrae are characterized by progressively rudimentary vertebral arches and vertebral processes.



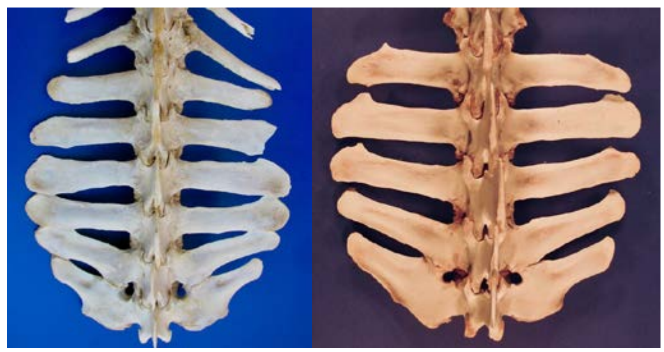
**5A 5B 5C**

**Fig. 5. Cranial views of individual thoracic vertebrae. A, T4. B, T14. C, T18. Note the horizontal articular surfaces on T4 and T14 and the vertically-oriented articular surfaces on T18.**

**Fig. 6. Dorsal view of the lumbar vertebral region illustrating the intertransverse joints present in the caudal lumbar vertebrae and at the lumbosacral junction.**

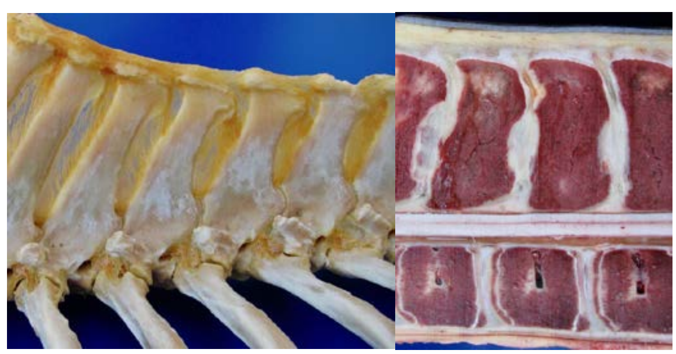
In the horse, the thoracolumbar spinal region consists of an average of 24 individual vertebrae, based on the typical vertebral formula (C7, T18, L6, S5, Cd15-21).[2] Variations in the number of vertebrae within a spinal region are common. In a necropsy survey of 36 Thoroughbred racehorses, only 61% of specimens had the expected number of 6 lumbar and 5 sacral vertebrae, while 89% had a combined total of 11 lumbar and sacral vertebrae (Fig. 7).[3] Variations in the number of vertebrae within one spinal region are often compensated by a reduction or increase in the number of vertebrae within an adjacent spinal region which may affect regional spinal biomechanics and predispose affected horse to an increased risk of injures.

The structural and functional unit of the vertebral column is the spinal motion segment, which consists of two adjoining vertebrae and interposed soft tissue structures. The typical vertebra is characterized by a vertebral body, vertebral arch and vertebral processes that vary in size and shape within each spinal region according to specific structural and functional demands. The vertebral body is a ventral cylindrical structure covered dorsally by the vertebral arch, which includes bilateral pedicles and laminae. Vertebral processes include one spinous process, two transverse processes and two pairs of cranial and caudal articular processes on each vertebra. Mammillary processes are additional vertebral processes located only in the thoracolumbar region that provide added paraspinal muscle attachment sites. Dorsally, the articular processes create bilateral synovial articulations that provide segmental stability and mobility to the spinal motion segment. Ventrally, the vertebral bodies and intervertebral disks form fibrocartilaginous joints that also provide segmental spinal stability and mobility. Additional connecting soft tissues include both short and long spinal ligaments and adjacent epaxial or hypaxial musculature (Fig. 8).



**7A 7B**

**Fig. 7. Dorsal views of the lumbar vertebral region. A, Specimen with six lumbar vertebrae. B, Specimen with a total of five lumbar vertebrae.**



**8A 8B**

**Fig. 8. Lateral views of spinal ligaments. A, Dried specimen showing supraspinous and interspinous ligaments within the cranial thoracic region. Note also the costal ligaments located at the costotransverse and costovertebral articulations. B, Mid-sagittal section from the caudal thoracic region showing supraspinous, interspinous, and dorsal and ventral longitudinal ligaments.**

The vertebral bodies form the foundation on which the remaining vertebral structures are placed. The cranial vertebral body is convex in shape and the caudal vertebral body is concave. Therefore, the thoracolumbar intercentral joints resemble a shallow ball-and-socket configuration, which provides stability without restricting mobility (Fig. 8B). The vertebral bodies in the caudal lumbar spinal region and sacrum are horizontally flattened, which limits lateral intersegmental motion but not dorsoventral movement. Vertebral bodies provide support for weight bearing, connective tissue attachment, and muscular attachment sites for the diaphragm and psoas muscles in the lumbar spinal region. Prominent ventral crests on the vertebral body are found in the cranial thoracic spinal region at the longus thoracic muscle insertion and at the last 3 to 4 thoracic vertebrae and first 3 lumbar vertebrae (T15-L3), which corresponds to the region of tendinous insertion of the crura of the diaphragm.[3] Typically, five sacral segments form the sacrum. The wings of the sacrum originate from the first sacral vertebra and articulate with the transverse processes of the last lumbar vertebrae at the intertransverse joints and the wing of the ilium at the sacroiliac joints (Fig. 6).

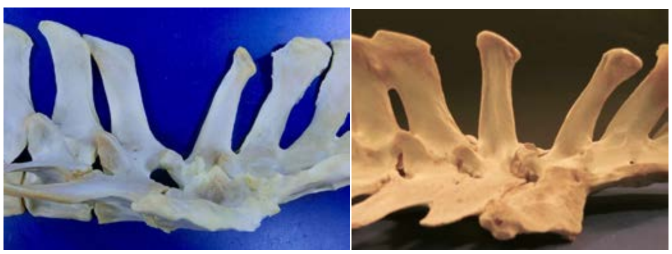
The vertebral arch can be visualized as a house for the spinal cord and its associated structures: the vertebral body is the floor of the house, the two pedicles are the walls, and the lamina forms the gable roof. The laminae are bilateral structures that are united dorsally at the junction of the spinous process. The central opening of each vertebral arch (i.e., vertebral foramina) form the continuous vertebral canal which contains and protects the spinal cord and nerve roots, meninges, epidural fat and vertebral vasculature. The equine spinal cord terminates in the cranial portion of the sacrum.[2] Ventral notches occur at the cranial and caudal margins of the vertebral arch which form the intervertebral foramen. Within the sacrum, dorsal and ventral intervertebral foramen are present due to the fused sacral segments.

The spinous processes project dorsally from the vertebral arch and vary in size, shape, and orientation in different vertebrae and spinal regions (Fig. 1). The spinous processes function as a series of levers for muscle and ligamentous attachment that provide support and movement to the vertebral column. Spinal extension and rotation are produced by contraction of muscles that attach to the spinous processes. The supraspinous ligament stabilizes the apex of the spinous processes and aids in resisting excessive spinal flexion. The spinous processes in the cranial thoracic spinal region are angled caudally and elongated in the region of T2 to T12 to form the withers. The summits of the cranial thoracic spinous processes (T2-T9) have secondary ossification centers and are expanded laterally for muscular and nuchal and supraspinous ligamentous attachments.[2,4] The summits of the S2-S5 spinous processes are laterally-expanded and sometimes bifid and covered with fibrocartilaginous caps (Fig. 9). Anatomically, the summits of the S2-S5 spinous processes serve as strong attachment sites for the gluteal muscles, gluteal fascia, and the dorsal sacroiliac ligaments. The S1 spinous process must be short and narrow to prevent impingement at the sacropelvic junction.

**Fig. 9. Dorsolaterocaudal view of the sacrum articulating with the wing of the ilium.**

The angulation of the thoracolumbar spinous processes change, theoretically in response attached soft tissue interactions. The T1-T15 spinous processes are angled dorsocaudal; transition to vertical at the anticlinal vertebrae (T16); and are angled dorsocranial from T17 to L6 (Fig. 1). The anticlinal vertebra occurs at a site of changing spinous process orientation, from a dorsocaudal direction to dorsocranial direction, indicating a regional difference in the orientation of muscular or ligamentous forces acting on the vertebral column. The cranial thoracic spinal regional must resist forces produced by the head, neck, and fore limbs, whereas, the caudal thoracic and lumbosacral spinal region has to resist significant forces associated with the rear limbs and locomotion. Another change in spinous process angulation occurs in the sacrum, where a dorsocaudal inclination is present. The divergent spinous processes of the lumbosacral junction produce a wide interspinous space (Fig. 10), compared with the adjacent interspinous spaces.[5,6] The lumbosacral spinous process divergence is thought to allow an increased range of motion without the risk of spinous process impingement. A significant number of horses with 6 lumbar vertebrae were found to have additional divergent spinous processes at the L5-L6 interspinous space that produced an isolated L6 spinous process spaced equally between the L5 and S1 spinous processes (Fig. 10B).[3] Variations in the lumbosacral interspinous spaces may primarily affect muscular and ligamentous insertions and secondarily produce changes in spinal or pelvic biomechanics, overall performance, or potential morbidity.[6]

The transverse processes provide support and movement to the vertebral column via muscular and ligamentous attachments. Transverse processes are used as lever arms by the deep spinal muscles to maintain posture, induce rotation and lateral flexion of the spine.[7] The transverse processes in the cranial thoracic spinal region are large but gradually diminish in size in the caudal thoracic and lumbar spinal regions. In the thoracic region, the transverse processes contain articular surfaces that contribute to the costotransverse articulations (Fig. 11). The lumbar spinal region has elongated, horizontally flattened transverse processes that provide attachment sites for the large dorsally-located epaxial muscles and the ventrally-located hypaxial muscles. Intertransverse synovial articulations are typically found between the transverse processes of the last 2 or 3 lumbar vertebrae and at the lumbosacral junction (Fig. 6).[5,6] The overall size and width of the intertransverse joints are largest at the lumbosacral joint and decrease incrementally in size cranially. Biomechanically, the intertransverse joints aid in the transfer of propulsive forces from the hind limbs to vertebral column and provide resistance to lateral bending and axial rotation of the spine. Intertransverse joints are not present at birth but develop soon thereafter.[5] The number of intertransverse joints seem to depend on the length (i.e., number of vertebrae) of the lumbar spinal region, where a reduced number of lumbar vertebrae have fewer intertransverse joints. Most of the lumbar intertransverse joints occur in pairs, although asymmetric distributions of intertransverse joints have been reported.[3,5] Unilateral or bilateral intertransverse joint ankylosis is common but probably not a significant cause of back pain in horses.[6] Within the sacrum the fused transverse processes form the lateral sacral crest.



**10A** **10B**

**Fig. 10. Lateral views of the lumbosacral junction. A, Divergent L6 and S1 spinous processes. B, Divergent L5, L6 and S1 spinous processes.**

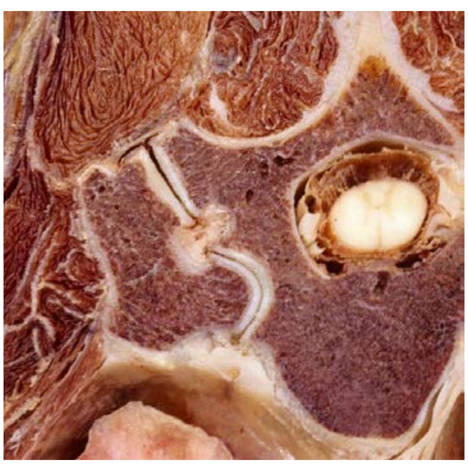


**Fig. 11. Transverse section at the costal articulations with the thoracic vertebra. Note the costotransverse joint dorsally and the costovertebral joint ventrally.**

## IV. INTERVERTEBRAL ARTICULATIONS

Two pairs of cranial and caudal articular processes arise dorsolaterally from the vertebral arch. An articular surface on the articular processes contributes to the formation of bilateral synovial articulations. The size, shape, and orientation of the articular processes and articular surfaces vary in the different spinal regions.[2,8] The articular surfaces in the thoracic spinal region lie horizontally (i.e., dorsal plane) with the cranial articular surfaces facing dorsally and the caudal articular surfaces facing ventrally. Spinal motion in the thoracic spinal region is limited mostly to rotation and lateral flexion (Table 1). The second thoracic vertebra (T2) is a site of abrupt transition of articular surface orientation from 45 degrees to horizontal. A second, more subtle transition occurs at T16 where articular surface orientation changes from horizontal to vertical. The lumbar spinal region has articular surfaces that predominately lie vertically (i.e., sagittal plane) where the cranial articular surfaces are dorsally concave and the caudal articular surfaces are ventrally convex. Spinal motion in the lumbosacral spinal region is limited mostly to dorsoventral flexion. In the sacrum the fused articular processes form the intermediate sacral crest.

**Table 1. In Vitro Thoracic and Lumbosacral Segmental Vertebral Motion in Horses (in Degrees)[16,17]**

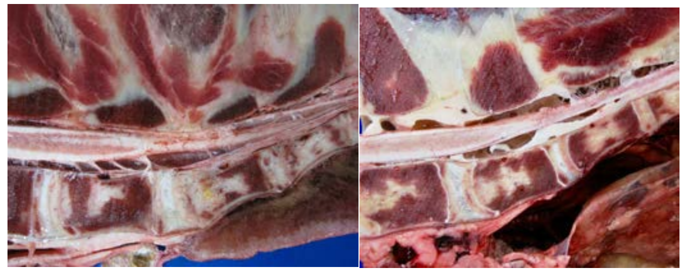
| Vertebral Level | Flexion - Extension | Lateral Bending | Axial Rotation |
|---|---|---|---|
| T1-2 | 7 | 2 | 3 |
| T2-3 | 1 | 4 | 3 |
| T3-4 | 1 | 3 | 2 |
| T4-5 | 1 | 3 | 3 |
| T5-6 | 1 | 4 | 3 |
| T6-7 | 1 | 4 | 3 |
| T7-8 | 2 | 6 | 3 |
| T8-9 | 2 | 7 | 3 |
| T9-10 | 3 | 8 | 4 |
| T10-11 | 2 | 10 | 4 |
| T11-12 | 3 | 11 | 5 |
| T12-13 | 3 | 11 | 5 |
| T13-14 | 2 | 10 | 4 |
| T14-15 | 3 | 8 | 5 |
| T15-16 | 2 | 6 | 4 |
| T16-17 | 4 | 5 | 3 |
| T17-18 | 3 | 5 | 2 |
| **Thoracic region** | 39 | 106 | 57 |
| T18-L1 | 4 | 5 | 2 |
| L1-2 | 2 | 4 | 2 |
| L2-3 | 2 | 3 | 1 |
| L3-4 | 2 | 3 | 1 |
| L4-5 | 1 | 2 | 1 |
| L5-6 | 2 | 1 | 2 |
| **Lumbar region** | 13 | 18 | 9 |
| L6-S1 | 23 | 1 | 3 |

Apart from the normal transitional changes between spinal regions, 83% of Thoroughbred racehorses in a necropsy survey had obvious asymmetries in the individual articular processes with an average of 2 vertebral segments affected per specimen.[3] Most articular process shape and orientation asymmetries appear to be developmental because they are unilateral and not associated with obvious osseous lesions. Severe articular surface asymmetry or hypoplasia has been identified as the primary morphologic abnormality in cases of torticollis, scoliosis, and lordosis in horses.[9-11] Several authors suggest that congenital articular process hypoplasia is caused by malpositioning or in-utero postural restrictions.[9-11] Articular process abnormalities may induce asymmetries in spinal mobility with subsequent joint instability, muscle shortening, and bone modeling.[10]

The articular joint capsule has a dense outer fibrous layer, vascular central layer, and an inner layer consisting of the synovial membrane. The joint capsule spans the cranial and caudal articular processes and is reinforced by the multifidi muscles dorsally and the ligamentum flavum ventrally. The joint capsule is richly innervated with sensory nerve fibers from the medial branch of the dorsal rami of several adjacent nerve roots. Proprioception and nociception are two important neurologic functions of the spinal articualtions.[12,13] Multilevel innervation of the articular processes and associated joint capsules may contribute to non-localized pain patterns.[7]

One often-overlooked aspect of the vertebral column is the large number of articulations present. The vertebral column is unique because of the presence of two types of articulations at each spinal motion segment (i.e., synovial and fibrocartilaginous articulations). The amount of joint range of motion at any spinal motion segment is small, but the cumulative spinal movements can be considerable. The number of individual articulations per vertebrae varies from no articulations present between the fused sacral segments; 2 intervertebral disks on each caudal vertebra; 6 articulations on each cervical and cranial lumbar vertebrae (2 intervertebral disks and 4 synovial articulations); 10 on each caudal lumbar vertebrae (4 additional intertransverse joints); to 12 articulations on each thoracic vertebrae (4 additional costovertebral and 2 costotransverse joints). The sacrum typically has 8 individual articulations (5 at the lumbosacral joint, 2 at the sacroiliac joints and one at the sacrocaudal junction).

The intervertebral disks connect adjacent vertebral bodies and together are classified as fibrocartilaginous articulations. The annulus fibrosus is formed by concentric layers of fibers alternating at 60 degrees that act to provide rotational stability to the intervertebral joint. The nucleus pulposus is rudimentary in horses. The thickness of the intervertebral disk is a contributing factor to spinal mobility where thinner intervertebral disks provide less mobility than thicker disks. The intervertebral disks of the thoracolumbar spinal region are thin compared to the cervical and caudal spinal regions (Fig. 8B). However, the lumbosacral junction has a wider intervertebral disk; an area of increased dorsoventral spinal mobility (Fig. 12). The dorsal and ventral longitudinal ligaments, as well as the costovertebral ligaments, provide additional reinforcement to the periphery of the intervertebral disk. The intervertebral disk is active in weight bearing, axial shock absorption and maintaining spinal flexibility.



**12A** **12B**

**Fig. 12. Mid-sagittal views of the lumbosacral intervertebral disk. A, Wider L6-S1 intervertebral disk space compared to L5-L6. B, Wider L5-L6 intervertebral disk space compared to L6-S1.**

The individual vertebrae are connected by an intricate system of ligaments and musculotendinous structures that provide stability and movement to the vertebral column (Fig. 8). The three described principle functions of the vertebral column, from a biomechanical perspective, are 1) protection of the spinal cord and associated nerve roots (i.e., vertebral arch); 2) providing support for weight bearing and soft tissue attachment (i.e., vertebral body and vertebral processes); and 3) maintaining movement for flexibility and locomotion (i.e., articulations, ligaments, and muscles). A basic knowledge of the structure and function of the vertebral column can provide a clearer understanding of thoracolumbar spinal disorders.

## V. NEURAL TISSUES AND SPINAL INNERVATION

The contents of the intervertebral foramen include the following structures: spinal nerve, two to four recurrent meningeal nerves, dural root sleeve, lymphatics, spinal branch of a segmental artery, communicating branches of the vertebral venous plexuses, and adipose tissue.[7] In some specimens there is also the formation of a lateral foramen which forms due to a ligamentous or osseous bridge that encloses the caudal vertebral notch.[14] Lateral foramina occur more often in the thoracic spinal region (T5-T16) and often encircle the spinal nerves and vessels that enter or exit the vertebral canal. The intervertebral foramen of the caudal lumbar vertebrae resembles the sacral foramina due to the presence of the caudal lumbar intertransverse joints. The fused vertebral arches of the sacrum contain dorsal sacral foramina for passage of the dorsal branches of sacral spinal nerves (Fig. 9). The ventral sacral foramina communicate with the vertebral canal ventrally and contain the ventral branches of sacral spinal nerves.

The spinal cord is surrounded by cerebrospinal fluid (CSF), meninges, fat, and vascular plexuses within the vertebral canal. The spinal cord is characterized by segmental, paired dorsal (sensory) and ventral (motor) nerve roots that converge within the intervertebral foramen to form spinal nerves. The cauda equina is formed from spinal nerve roots within the terminal spinal canal. The conus medullaris is the tapered distal end of the spinal cord which continues caudally within the sacrum as the filum terminale (Fig. 12B).[15] The meninges, consisting of the dura mater, arachnoid mater and pia mater, provide protection and support to the spinal cord. The dura mater is separated from the vertebrae by the epidural space, which contains epidural adipose, loose connective tissue and a venous plexus. The dura mater surrounds the nerve roots as they enter the intervertebral foramen and is continued distally as epineurium around the peripheral nerves. The subarachnoid space is filled with cerebrospinal fluid that forms the fluid media that protects the spinal cord. Two specialized structures that anchor the spinal cord within the vertebral canal and the dural sheath are the filum terminale and the denticulate ligaments, respectively.[7] The filum terminale is the caudal continuation of the conus medullaris and provides axial support to the spinal cord. The denticulate ligaments originate from the pia mater on the lateral surface of the spinal cord and extend laterally to both walls of the dura. The denticulate ligaments are found segmentally between the nerve roots and provide segmental support to the spinal cord.

The vertebrae, spinal articulations and ligaments are innervated directly by sensory branches of the dorsal rami and recurrent meningeal nerves. These nerves mediate nociception and proprioception within the vertebral column. The principle functions of the spinal motion segment are segmental protection of the spinal cord and associated nerve roots, support for weight bearing and soft tissue attachment and providing segmental flexibility. In humans, pain-sensitive structures of the low back and pelvis include the following: nerve roots, posterior fibers of the annulus fibrosus, dorsal and ventral longitudinal ligaments, supraspinous ligament, interspinous ligament, ligamentum flavum, joint capsule of the zygapophyseal joints, intra-articular synovial folds, vertebral vasculature, spinal musculature, and periosteum of the vertebrae.[12] By extension, it can only be assumed that disease processes affecting these same spinal tissues would cause nociceptive stimulation and produce clinical signs of back pack and dysfunction in horses.

The spinal nerves of the trunk emerge from the intervertebral foramen caudal to the vertebra of the same number.[16] In the thoracolumbar vertebral region, the dorsal branches of the spinal nerves provide motor innervation to the epaxial trunk muscles and sensory innervation via dorsolateral cutaneous branches that exit between the longissimus and iliocostalis muscles and within the latissimus dorsi muscle and thoracolumbar fascia. Soft tissue inflammation, localized pain, or muscle hypertonicity in the thoracolumbar spinal region can produce an exaggerated or prolonged cutaneus trunci reflex. The ventral branches of the thoracolumbar spinal nerves provide motor innervation to the intercostal, hypaxial, and abdominal musculature, and sensory innervation via ventrolateral cutaneous branches that exit at several levels along the ventrolateral trunk. The equine lumbosacral intumescence of the spinal cord is contained within the L4-L5 vertebrae and gives rise to the lumbosacral plexus (L4-S2 nerve roots). In horses, the spinal cord terminates within the cranial sacrum at the S2 vertebral segment (Fig. 12).[16]

## VI. SPINAL KINEMATICS

The articular processes function in support and movement of the vertebral arch. The amplitude and direction of segmental spinal motion is related to the size, shape, and orientation of the articular surfaces and functional status of the articulations.[5,6] As with any synovial articulation, loss of motion or aberrant joint physiology can be a primary source of pain.[7] Small amounts of segmental vertebral motion are collectively capable of producing large amounts of regional vertebral motion.[17-20] The three primary vertebral movements include flexion and extension, left and right lateral bending, and left and right axial rotation.[21] Within the thoracic region, lateral bending is the most prominent spinal motion, whereas, flexion-extension is maximal at the lumbosacral junction (Table 1).[20]

The structure and function of the quadrupedal axial skeleton has been compared to a bridge or bow string that spans the distance between the thoracic and pelvic limbs.[22] The trunk is composed of a relatively rigid vertebral column dorsally and a series of ventral abdominal muscles that contract and flex the dorsal bow structures. Static and dynamic spinal motions are dependent on the integration and balance of forces from the dorsal, ventral and lateral muscular chains with the trunk and pelvic regions. Spinal function requires weight bearing, but also flexibility and protection of the central nervous system. The weight of the abdominal viscera is supported primarily by the ventral abdominal musculature and dorsal spinal structures. Spinal flexibility is provided by the segmental nature of the vertebral column and the action of the interconnecting intervertebral disks, ligaments, and paraspinal musculature. The vertebral bodies and intervertebral disks form the axis (compressive element or foundation of the bridge) about which vertebral motion occurs. The articular processes guide segmental vertebral motion based on the size, shape, and orientation of the articular surfaces. The dorsal spinous processes and transverse processes provide lever arms for musculotendinous attachment (tensile elements) to provide either segmental stabilization or vertebral movement. The slopes of the dorsal spinous processes are designed to optimally resist tensile forces. Therefore, the caudad slope of the cranial thoracic dorsal spinous processes in the withers is thought to have developed to resist the muscular and ligamentous forces required to hold up the heavy head and neck (Fig. 1). The craniad slope of the caudal thoracic and lumbar vertebrae provides resistance to the pull of the soft tissues associated with the propulsive forces of the pelvic limbs. The vertebral arch provides direct protection of the spinal cord and its associated dural membranes and vasculature.

Equine locomotion is accomplished primarily by rotational motion (i.e., limb protraction and retraction) about the thoracic and pelvic limb girdle attachment sites and flexion-extension at the lumbosacral junction. During the symmetrical gaits of walk and trot, the spinal movements are also symmetrical.[23] In horses, the vertebral column is elevated during the mid-stance of each limb and falls slightly during the swing phase of the limb at the walk and trot. Therefore, there are 2 (i.e., biphasic) dorsoventral rises and falls in the center of gravity during each stride of the walk and trot. Since the pelvic limbs move together at faster gaits the dorsoventral vertebral column motion rises and falls only once (i.e., monophasic) for each stride of the canter and gallop. The different gaits produce characteristically different spinal movements and muscle activities.[23] During the walk, the thoracolumbar spine is largely under the influence of passive mechanisms associated with movement of the limbs, head, and neck. Axial rotation is the predominant spinal movement noted at the walk, which is primarily produced by rhythmic pelvic limb motion during alternating limb advancement and retraction. During the trot, the spine is typically held rigid, with minimal amounts of movement, due to constraint by the supporting spinal musculature. At the canter, spinal mobility is again influenced by passive mechanisms associated with high-speed movement of the limbs, head, and neck, as well as active muscular contractions of the abdominal and proximal pelvic limb musculature.[23] Thoracolumbar flexion and extension is generally limited during the walk and trot but maximized while jumping at speed. Horses with back problems may have difficulty with gait transitions or resist the large spinal movements associated with the canter and gallop. Different breeds or uses of horses have different spinal requirements. Advanced dressage horses, barrel-racing Quarter Horses, and 3-day event horses all require large ranges of spinal flexibility and fine motor control. Racing Standardbreds tend to hold their vertebral columns more rigidly and require smaller ranges of spinal motion while trotting or pacing for long distances. Arabian horses used for endurance require both spinal flexibility and fatigue-resistant spinal musculature.

## VII. PELVIS AND SACROILIAC JOINT

The pelvis articulates with the sacrum and associated vertebral column at bilateral sacroiliac articulations (Fig. 13). The sacroiliac joint is a synovial articulation between the sacrum and ilial wing with unique characteristics; hyaline cartilage covers the sacral articular surface and fibrocartilage is present at the ilial articulation articular surface.[24,25] In humans, the sacroiliac joint is richly innervated with both nociceptors and proprioceptors that function in the recognition of pain, movement and joint position.[7] The sacroiliac ligaments are well developed in horses and consist of paired dorsal, interosseous, and ventral components (Fig. 14). The dorsal sacroiliac ligaments, comprised of a dorsal and lateral portion, connect the tuber sacrale to the sacrum. The dorsal portion consists of two strong bands that attach the summits of the tuber sacrale and the sacral spinous processes. The lateral portion is comprised of a flat sheet of connective tissue that connects the caudal ilial wing to the lateral border of the sacrum. The lateral portion of the dorsal sacroiliac ligament is continuous with the sacrosciatic ligament. The interosseous sacroiliac ligaments are the most robust of the sacroiliac ligaments. They span the space between the ventral wing of ilium and the dorsal wing of the sacrum. The ventral sacroiliac ligaments connect the ventral wings of the sacrum to the ilium. The stability of the sacroiliac joints is enhanced by the sacrosciatic ligament that is formed by a wide sheet of dense connective tissue that spans ventrally from the lateral border of the sacrum to the ischiatic spine and ischial tuberosity of the pelvis. Dynamically, the sacroiliac and sacrosciatic ligaments provide pelvic attachment to the axial skeleton and help to transfer propulsive forces from the pelvic limb to the vertebral column.[8]

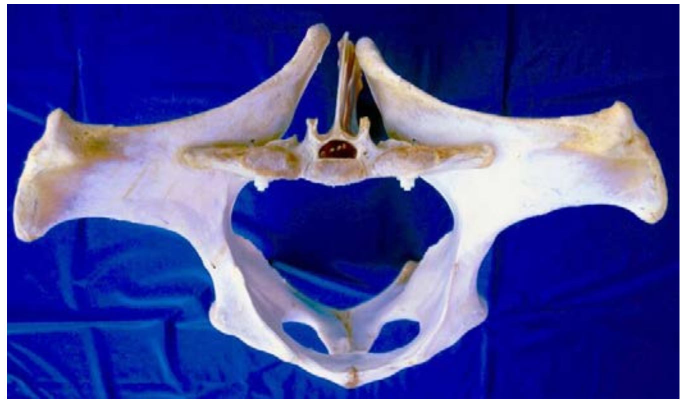


**Fig. 13. Cranial view of a sacropelvic specimen. Note the bilateral sacroiliac articulations located ventral to the wings of the ilium.**

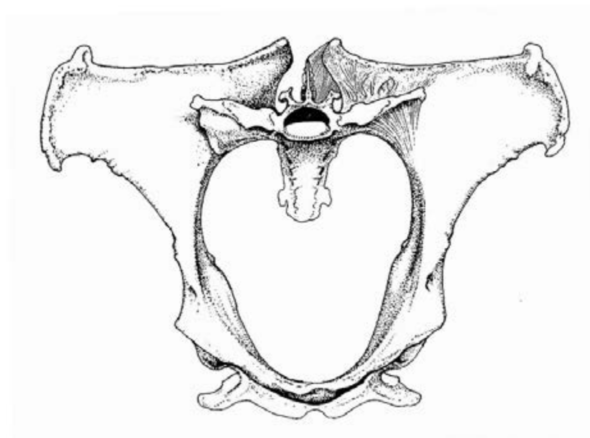


**Fig. 14. Cranial view of the sacroiliac region illustrating the dorsal, interosseous, and ventral sacroiliac ligaments.**

## VIII. SPINAL LIGAMENTS

A series of long and short spinal ligaments contribute to vertebral column stability. Three separate longitudinal spinal ligaments span the length of the vertebral column and provide regional spinal stability (Fig. 8). The supraspinous ligament is an extension of the nuchal ligament in the cervical spinal region. In the thoracolumbar spinal region, the supraspinous ligament joins the tips of the spinous processes. The dorsal longitudinal ligament connects the dorsal vertebral bodies within vertebral canal and acts to reinforce the intervertebral disk. The ventral longitudinal ligament attaches to the ventral vertebral bodies and also blends with fibers of the intervertebral disk.

The short spinal ligaments interconnect individual vertebral structures and function to protect the spinal cord and to provide segmental spinal stability. Interspinous ligaments connect adjacent spinous processes. Fibers in the dorsal portion of the interspinous ligaments are ventrocaudal continuations of the supraspinous ligament into the interspinous space. In humans, ligamentous disruption has been noted in the mid-portion of the interspinous ligaments, where bone-ligament-bone attachments are present.[26] The ventral most fibers of the interspinous ligaments fuse with the ligamenta flava ventrally. The ligamentum flava interconnect the vertebral lamina of adjacent vertebrae and provide dorsal vertebral canal stability and resistance to extreme vertebral flexion. A high elastin/collagen ratio (70-80% elastin) ensures that the ligamenta flava does not bulge into the dorsal vertebral canal during maximal spinal extension.[13] The elastin also contributes to the stabilizing function and potential energy storage of the spinal column. A wide interarcuate space at the lumbosacral junction is used clinically to access the subarachnoid space in the collection of cerebrospinal fluid (CSF). Specialized costovertebral and costotransverse ligaments provide additional stability to the thoracic spinal region and ribs. The intertransverse ligaments connect adjacent transverse processes in the lumbar spinal region and limit lateral flexion.

## IX. TRUNK MUSCLES

Horses have an extensive thoracolumbar fascia that covers and provides aponeurotic attachment for most of the dorsal trunk muscles (Fig. 15). Superficial spinal muscles tend to be long and span several vertebral regions, whereas deep spinal muscles are short and only span a few vertebrae.[21] Epaxial muscles, by definition, are intrinsic spinal muscles located dorsal to the transverse processes and are innervated by dorsal branches of the spinal nerves. The epaxial trunk muscles produce spinal extension when activated bilaterally and lateral bending when the muscles are contracted unilaterally. The epaxial trunk muscles can be categorized into 3 parallel columns (lateral, intermediate, and medial) of muscles. The narrow iliocostalis muscle forms the most lateral muscle group and is attached to the proximal ribs cranially and to the lumbar transverse processes caudally. In the thoracolumbar vertebral region, the longissimus muscle (the intermediate group) is the largest and most clinically significant muscle in horses with back problems. The transversospinalis muscle group consists of the most medial and deepest back muscles. Included in the transversospinalis muscle group is the spinalis muscle, which extends between dorsal spinous processes in the cervical and thoracic vertebral regions. The thoracic portion of the spinalis muscle is the primary muscle in the wither region that can be compromised or injured due to a poor fitting saddle. The multifidi muscles form the deepest muscle group and extend from articular processes to dorsal spinous processes of adjacent vertebrae (Fig. 15). In the thoracolumbar region, the multifidus muscle segments are longer and span up to 6 vertebrae, compared to the cervical region where the individual muscles only span 1 intervertebral level.[15] The short, deep spinal muscles contribute to static spinal functions such as segmental stabilization, proprioception, and posture. The long superficial spinal muscles are responsible for the dynamic functions of regional spinal motion, energy storage, and force distribution.

Muscles of the lateral thoracic wall include the cutaneus trunci, latissimus dorsi, external and internal intercostal, and serratus dorsalis muscles. The latissimus dorsi muscle originates from the thoracolumbar fascia caudally and converges at the axillary region of the thoracic limb cranially. The latissimus dorsi muscle produces thoracic limb retraction and shoulder flexion. The external intercostal muscles are located superficially with fibers oriented in a caudoventral direction. The internal intercostal muscles are located deeper with fibers oriented in a cranioventral direction. The external and internal intercostal muscles function to stabilize the rib cage and to assist in respiration. The serratus dorsalis muscle consists of a series of thin serrated muscle with cranial and caudal portions that enclose the thoracic iliocostalis muscle.

**Fig. 15. Sagittal view of the middle thoracic region showing the thick thoracolumbar fascia dorsally and the longissimus and multifidi muscles attaching to the dorsal aspect of the neural arch.**

In horses, the strong abdominal muscles are covered by deep fascia and a highly elastic abdominal tunic that help to support the weight of the abdominal viscera.[27] The abdominal muscles are important trunk flexors and, if contracted unilaterally, can produce lateral bending. The lateral abdominal wall consists primarily of the external and internal abdominal oblique muscles. The external abdominal oblique muscle is also active during expiration and may become hypertrophied in horses with chronic obstructive pulmonary disease (e.g., heaves). The aponeurosis of the internal abdominal oblique muscle has a large elastic component, which assists in supporting the weight of the heavy abdominal viscera. The rectus abdominis muscle is confined to the ventral abdominal wall and attaches to the sternum cranially and the ventral brim of the pelvis caudally. The connective-tissue covering of the rectus abdominis muscles join at the ventral midline to form a well-developed linea alba. Caudally, the rectus abdominis muscle joins the robust prepubic tendon, which inserts on the ventral brim of the pelvis. Occasionally, the prepubic tendon may rupture in pregnant mares due to excessive strain associated with carrying the additional weight of a heavy fetus.

Hypaxial (sublumbar) muscles in the caudal thoracolumbar vertebral region include the psoas major, psoas minor, and iliacus muscles (Fig. 16). The psoas major and iliacus muscles unite to form the iliopsoas muscle. The large psoas major muscle extends from the ventral surface of the lumbar transverse processes and the last 2 ribs and attaches to the medial proximal femur.[2] The iliacus originates from the ventral surface of the ilial wing and forms a common tendon with the psoas major at the medial femur. The iliopsoas muscle produces pelvic limb protraction, hip flexion, and external rotation of the pelvic limb. The psoas minor extends from the ventral surface of caudal thoracic and lumbar vertebral bodies and attaches to the psoas tubercle on the shaft of the ilium. The psoas minor muscle contributes to flexion of the lumbosacral joint.

**Fig. 16. Ventral view of the hypaxial (sublumbar) muscles in the lumbosacral vertebral region. Note the psoas minor medially and the paired psoas major and iliacus muscles that join and insert on the lesser trochanter of the femur.**

## X. EXTRINSIC PELVIC LIMB MUSCULATURE

The pelvic girdle muscles are best characterized as cranial-caudal and lateral-medial muscle groups.[15] The cranial muscles of the pelvic girdle produce pelvic limb protraction and hip flexion. Muscles in this group include the sartorius, iliopsoas, tensor fascia lata and rectus femoris. The iliopsoas muscle is the only muscle of this group that directly attaches to the vertebral column. The sartorius and rectus femoris muscles assist in pelvic limb protraction and hip flexion but do not extend proximally beyond the pelvis. The caudal pelvic girdle muscles are active in pelvic limb retraction and hip extension. The muscles of this group include the biceps femoris, semitendinosus, and semimembranosus muscles. In horses, portions of these strong and well-developed muscles have additional proximal attachments to the sacrum, caudal vertebrae, and sacrosciatic ligament. The middle gluteal muscle is the only muscle of the lateral pelvic girdle group that attaches to the axial skeleton. The middle gluteal muscle originates dorsally on the lumbar portion of the longissimus muscle and may extend cranially to the back edge of the saddle. The middle gluteal and caudal thigh musculature provide the powerful hip extension and pelvic limb retraction required for many athletic demands in horses. The other lateral pelvic girdle muscles originate on the pelvis and include the tensor fasciae latae, superficial gluteal, accessory gluteal, and deep gluteal muscles. The medial muscles of the pelvic girdle do not have any direct connections to the axial skeleton. The medial muscle group includes the gracilis, adductor, and pectineus, which are responsible for pelvic limb adduction. Clinical considerations of the pelvic limb girdle muscles include muscle injury or fatigue that produces an altered gait with a shortened cranial or caudal swing phase of the affected limb.

## XI. SUMMARY

A better understanding of the structural and functional interactions of the thoracolumbar spine and pelvis contribute to improved diagnostic skills, development of individualized treatment plans, and use of objective measures of trunk and pelvic function and performance.

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