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ANATOMY OF THE THORACOLUMBAR VERTEBRAL REGION

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VERTEBRAL COLUMN

The axial skeleton consists of the cranium, a segmented vertebral column, the ribs, and the sternum. In the horse, the thoracolumbar vertebral region consists of an average of 24 individual vertebrae based on the typical vertebral formula (C7, T18, L6, S5, Cd15–21).[9] Variations in the number of vertebrae within a vertebral 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, although 89% had a combined total of 11 lumbar and sacral vertebrae.[12] Variations in the number of vertebrae within one vertebral region are often compensated for by a reduction or increase in the number of vertebrae in an adjacent vertebral region.

The individual vertebrae are connected by an intricate system of ligaments and musculotendinous structures that provide stability and movement to the vertebral column. The three principal mechanical functions of the vertebral column are (1) protection of the spinal cord and associated nerve roots (i.e., vertebral arch), (2) provision of support for weight bearing and soft tissue attachment (i.e., vertebral body and vertebral processes), and (3) maintainence of 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. In general, spinal-related problems can be categorized as soft tissue, osseous, or neurological disorders. 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 ligaments, ligamenta flava, joint capsule of the zygapophyseal joints, intra-

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articular synovial folds, vertebral vasculature, spinal musculature, and periosteum of the vertebrae.[10]

VERTEBRAL MOTION SEGMENT

The structural and functional unit of the vertebral column is the vertebral motion segment. A vertebral motion segment consists of two adjoining vertebrae and interposed soft tissue structures (Fig. 1). The typical vertebra is characterized by a vertebral body, vertebral arch, and vertebral processes that vary in each vertebral region according to 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. Mamillary processes are additional vertebral processes found only in the thoracolumbar region that provide added paraspinal muscle attachment sites. Dorsally, the articular processes create bilateral synovial articulations (i.e., zygapophyseal joints) that provide segmental stability and mobility to the vertebral motion segment. Ventrally, the vertebral bodies and intervertebral disks form fibrocartilaginous joints that also provide segmental vertebral stability and mobility. Additional connecting soft tissues include both short and long spinal ligaments and muscles. The vertebrae, vertebral 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 principal functions of the vertebral motion segment are segmental protection of the spinal cord and associated nerve roots, support for weight bearing and soft tissue attachment, and provision of segmental flexibility.

The vertebral motion segments of the upper cervical region (i.e., occiput

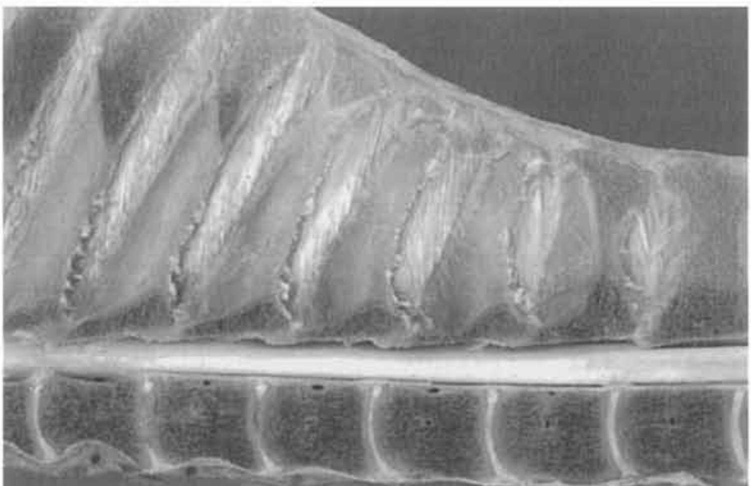

Figure 1. Sagittal section of the thoracic vertebral region (T8–T14) demonstrating osseous vertebral structures and supporting spinal ligaments.

C1–C2) are a highly mobile and specialized joint complex. The cervical vertebrae have rudimentary spinous processes and characteristic transverse foramina for the passage of vertebral vessels. The thoracic vertebrae are characterized by tall spinous processes (highest at T4–T5), costal articulations, and an anticlinal vertebra at T16. The lumbar vertebrae have long horizontally flattened transverse processes and intertransverse joints in the caudal region (L4–S1) that are unique to horses. The sacrum is usually made up of five 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.

Developmental variations in the morphology of thoracolumbar vertebral bodies, processes, and joints in horses are known to occur.[9, 12, 16, 21, 27, 28, 30] Knowledge of normal vertebral morphology and developmental anomalies is important for distinction of pathological change from normal anatomical variations. Transitional vertebrae, by definition, are located between two adjacent vertebral regions and have morphological characteristics of both adjacent vertebral regions.[9] Transitional vertebrae can have right-to-left asymmetry or altered cranial-to-caudal gradation in vertebral morphology.[24] Alterations in vertebral morphology often affect the vertebral arches and transverse processes but only rarely affect the vertebral bodies.[9, 19] In a necropsy survey of 36 Thoroughbred racehorses, 22% of specimens had thoracolumbar transitional vertebrae and 36% had sacro-caudal transitional vertebrae characterized by sacral fusion with the first caudal vertebra (Cd1).[12] Older horses tend to have the first caudal vertebra fused with the sacrum.

Radiographic and gross anatomical descriptions of physes in portions of the trunk and pelvis have been reported.[9, 12, 14–16, 18] The primary ossification centers of the thoracolumbar vertebral bodies and vertebral arches (i.e., neurocentral joint) fuse shortly after birth.[16] Secondary vertebral ossification centers occur in the spinous process summits of the cranial thoracic vertebrae, transverse process extremities, and vertebral body epiphyses.[9] The summits of the cranial thoracic spinous processes (T2–T9) have secondary ossification centers that do not fuse until the horse is 7 to 15 years of age.[9, 14] The spinous processes of the caudal portion of the thoracic and lumbosacral vertebral regions do not contain secondary ossification centers but only fibrocartilaginous caps. Radiographically, newborn foals have well-defined cranial and caudal thoracolumbar vertebral body epiphyses, and physeal closure has been reported to occur at 3.0 to 3.5 years of age.[16] Gross anatomical evaluation of Thoroughbred racehorses revealed thoracolumbar vertebral body physeal closure between 4.9 and 6.7 years of age.[12] The discrepancy between radiographic and anatomical physeal closure times may be related to the limitation of radiographic techniques for documentation of the thin and irregularly shaped radiolucencies characteristic of vertebral physes.[25] The cranial vertebral body physes tend to close 1 to 2 years before the caudal vertebral physes. The sacral segments of the horse become completely fused at about 5.5 years of age.[12]

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 vertebral motion segment (i.e., synovial and fibrocartilaginous articulations). The amount of joint range of motion at any vertebral motion segment is small, but the cumulative vertebral movements can be considerable. The number of individual articulations per vertebra varies from no articulations present between the fused sacral segments, to two intervertebral disks on each caudal vertebra, to 6 articular surfaces on each cervical and cranial lumbar vertebra (2 intervertebral disks and 4 synovial articulations), to 10 articular surfaces on each caudal lumbar vertebra (4 additional intertransverse joints), to 12 articular surfaces on each thoracic vertebra (4 additional costovertebral and 2 costotransverse joints). The sacrum typically has 8 individual articular surfaces (5 at the lumbosacral joint, 2 at the sacroiliac joints, and 1 at the sacrocaudal junction). The number of synovial articulations in the vertebral column includes 13 in the cervical region, 104 in the thoracic region, 16 in the lumbar region, and 4 in the sacrum for a combined total of 137 separate synovial articulations in the vertebral column. Fibrocartilaginous articulations account for an additional 48 articulations for an overall total of 185 separate synovial and fibrocartilaginous articulations in the vertebral column. Because each synovial articulation consists of 2 or 3 opposing articular surfaces, approximately 344 hyaline-covered articular surfaces are found in the equine vertebral column. Localized or regional defects in the vertebral motion segment result in an alteration in the normal spinal curvature. Congenital abnormalities that affect the normal spinal curvature include scoliosis, lordosis, and kyphosis.

VERTEBRAL BODY

The vertebral bodies form the foundation on which the remaining vertebral structures are based. The cranial vertebral body is convex in shape, and the caudal vertebral body is concave (see Fig. 1). Therefore, most equine intervertebral joints resemble a ball-and-socket configuration which provides stability without restricting mobility. The vertebral bodies in the caudal lumbar vertebral region and the sacrum are horizontally flattened, which limits lateral intersegmental motion but not dorsoventral movement. Vertebral bodies provide support for weight bearing and connective tissue attachment as well as muscular attachment sites for the diaphragm and psoas muscles in the lumbar vertebral region. Prominent ventral crests on the vertebral body are found in the cranial thoracic vertebral region and at the last three to four thoracic vertebrae and first three lumbar vertebrae (T15–L3).[12] The thoracolumbar ventral crest corresponds to the region of tendinous insertion of the crura of the diaphragm. 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.

Congenital malformations of the vertebral body can produce significant vertebral deformities. Block vertebrae are a developmental disorder of the vertebral body characterized by the fusion of two adjacent vertebrae, whereas hemivertebrae are wedge-shaped vertebrae caused by the abnormal development of vertebral body ossification centers. Vertebral body fractures at open vertebral body physes may occur in foals that experience significant spinal trauma. Spondylosis is a form of vertebral body arthritis that produces the large osteophytes that span intervertebral disks between affected vertebral bodies. Initially, spondylosis may be painful as the bony prominences form and impinge on each other. More commonly, spondylosis is a nonpainful osseous bridge formed between two or more vertebral bodies, resulting in restricted vertebral mobility in older horses.

INTERVERTEBRAL DISK

The intervertebral disks connect adjacent vertebral bodies; together, they are classified as fibrocartilaginous articulations. An intervertebral disk consists of an outer annulus fibrosus and a central nucleus pulposus. The annulus fibrosus is formed by concentrical layers of fibers alternating at 60° which act to provide rotational stability to the intervertebral joint. The nucleus pulposus is gelatinous but rudimentary in the thoracolumbar vertebral regions compared to the cervical and caudal vertebral regions (see Fig. 1). The lumbosacral junction has a wider intervertebral disk which is an area of increased dorsoventral vertebral mobility. The thickness of the intervertebral disk is a contributing factor to vertebral mobility; thinner intervertebral disks provide less mobility than thicker disks. 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 the maintenance of vertebral flexibility. The outer one third of the intervertebral disk is innervated by both proprioceptive and nociceptive fibers. Clinical conditions affecting the intervertebral disk in horses include discospondylitis and intervertebral disk degeneration. Discospondylitis is an infection of the intervertebral disk and adjacent vertebral body and is usually a life-threatening infection that is difficult to treat. Intervertebral disk degeneration is a common finding in horses; however, intervertebral disk herniation is rare in horses (compared to dogs or humans) due to a thin intervertebral disk and poorly developed nucleus pulposus.[29, 34]

VERTEBRAL ARCH

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 roof. The laminae are bilateral structures united dorsally at the junction of the spinous process. The central opening of each vertebral arch (i.e., vertebral foramen) forms the continuous vertebral canal that 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.[9] Ventral notches occur at the cranial and caudal margins of the vertebral arch, which form the intervertebral foramen. 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.[5] In some specimens, a lateral foramen forms due to a ligamentous or osseous bridge that encloses the caudal vertebral notch.[11] 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 foramina of the caudal lumbar vertebrae resemble the dorsal and pelvic sacral foramina found in the sacrum due to the presence of intertransverse joints. The fused vertebral arches of the sacrum contain dorsal sacral foramina for passage of the dorsal branches of sacral spinal nerves. The pelvic sacral foramina communicate with the vertebral canal ventrally and contain the ventral branches of sacral spinal nerves.

The ligamenta flava interconnect the vertebral lamina of adjacent vertebrae. A wide interarcuate space at the lumbosacral junction is used clinically to access the contents of the vertebral canal. A clinical condition affecting the vertebral lamina is spina bifida, an uncommon developmental disorder characterized by a defect in the closure of the vertebral arch. Variations occur in the extent of the osseous defect, where milder cases are asymptomatic and more severe cases have significant neural defects.

VERTEBRAL CANAL CONTENTS

The spinal cord is surrounded by cerebrospinal fluid, 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 foramina 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 that continues caudally within the sacrum as the filum terminale.[4] 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 foramina and is continued distally as epineurium around the peripheral nerves. The subarachnoid space is filled with cerebrospinal fluid which 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.[5] 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 vertebral canal contents are well protected by the surrounding vertebrae and spinal ligaments. Space-occupying masses within the vertebral canal (e.g., abscess or neoplasia) cause displacement or compression of the vertebral canal contents. Clinical conditions affecting the spinal cord can cause varying combinations of ataxia and paresis depending on the level affected.

SPINOUS PROCESSES

The spinous processes project dorsally from the vertebral arch and vary in size, shape, and orientation in different vertebrae and vertebral regions (see Fig 1). The spinous processes function as a series of levers for the muscle and ligamentous attachments that provide support and movement to the vertebral column. Spinal extension and rotation are produced by contraction of the 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 vertebral region are angled caudally and elongated in the region of T2 to T12 to form the withers. The first palpable spinous process in the withers is T2 or T3. The apex of the withers is formed by the spinous processes of T4 and T5. The summits of the cranial thoracic spinous processes (T2–T9) have secondary ossification centers and are expanded for muscular, nuchal, and supraspinous ligamentous attachments.[9, 14] The summits of the S2 to S5 spinous processes are expanded and sometimes bifid and covered with fibrocartilaginous caps. Anatomically, the summits of the S2 to 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.

The angulation of the thoracolumbar spinous processes changes, theoretically, in response to attached soft tissue interactions. The T1 to T15 spinous processes are angled dorsocaudally, change at the anticlinal vertebra (T16) to an upright position, and are angled dorsocranially from T17 to L6. The anticlinal vertebra occurs at a site of changing spinous process orientation from a dorsocaudal direction to dorsocranial direction, suggesting a regional difference in the orientation of muscular and ligamentous forces acting on the vertebral column. The cranial thoracic vertebral region must resist forces produced by the head, neck, and forelimbs, whereas the caudal thoracic and lumbosacral vertebral 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 compared with the adjacent interspinous spaces.[7, 28, 30] The lumbosacral spinous process divergence allows an increased range of motion without the risk of spinous process impingement. Most horses with six lumbar vertebrae were found to have additional divergent spinous processes at the L5 to L6 interspinous space which produced an isolated L6 spinous process spaced equally between the L5 and S1 spinous processes.[12] Variations in the lumbosacral interspinous spaces may primarily affect muscular and ligamentous insertions and secondarily produce changes in vertebral or pelvic biomechanics, overall performance, or potential morbidity.[17, 30]

Spinous process overlap without any evidence of osseous impingement has been noted in horses.[13] It is thought that localized vertebral process overlap or malalignment may be related to asymmetrical ligamentous or musculotendinous forces that induce osseous remodeling and subsequent vertebral process deviation. In humans, isolated spinous process deviation is a common finding and can be related to vertebral rotation (i.e., scoliosis) or developmental asymmetries in the neural arch, but rarely is it associated with spinous process fracture or malposition of the entire vertebra.[5, 33] Fractures of the spinous process of the withers are often due to the horse flipping over backwards and landing on the highest point of its back. Conservative care is usually recommended and proper saddle fit is difficult. Impinged spinous processes (i.e., kissing spines) are characterized by spinous processes that closely appose each other and subsequently induce soft tissue inflammation and osseous proliferation. The final stage of spinous process impingement produces a nonpainful osseous union of the involved spinous processes.

ARTICULAR PROCESSES

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 (i.e., zygapophyseal joints). The size, shape, and orientation of the articular processes and articular surfaces vary in the different vertebral regions.[9, 20] In the cervical vertebral region, the articular surfaces lie at 45° to horizontal (i.e., tangential orientation to vertebral arch) and allow large ranges of motion along three axes of rotation. The articular surfaces in the thoracic vertebral region lie horizontally (i.e., dorsal plane), with the cranial articular surfaces facing dorsally and the caudal articular surfaces facing ventrally. Vertebral motion in the thoracic vertebral region is limited mostly to rotation and lateral flexion. The second thoracic vertebra (T2) is a site of abrupt transition of articular surface orientation from 45° to horizontal. A second and more subtle transition occurs at T16, where articular surface orientation changes from horizontal to vertical. The lumbar vertebral region has articular surfaces that predominantly lie vertically (i.e., sagittal plane), where the cranial articular surfaces are dorsally concave and the caudal articular surfaces are ventrally convex. Vertebral motion in the lumbosacral vertebral region is limited mostly to dorsoventral flexion. In the sacrum, the fused articular processes form the intermediate sacral crest.

Apart from the normal transitional changes between vertebral regions, 83% of Thoroughbred racehorses in a necropsy survey had obvious asymmetries in the individual articular processes, with an average of two vertebral segments affected per specimen.[12] Most articular process shape and orientation asymmetries seem 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 morphological abnormality in cases of torticollis, scoliosis, and lordosis in horses.[3, 21–23, 32] Several authors suggest that congenital articular process hypoplasia is caused by malpositioning or in utero postural restrictions.[21, 22, 32] Articular process abnormalities may induce asymmetries in vertebral mobility with subsequent joint instability, muscle shortening, and bone modeling.[22]

The zygapophyseal joint capsule has a dense outer fibrous layer, a 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 zygapophyseal 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 neurological functions of the zygapophyseal joints.[2, 10] Multilevel spinal innervation of the zygapophyseal joints may contribute to nonlocalized pain patterns.[5] Synovial folds (menisci) are synovial-lined extensions of the joint capsule commonly found in the equine cervical zygapophyseal joints. In humans, the synovial folds contain adipose, nociceptors, and blood vessels and may be a source of pain if chemically or mechanically irritated.[5]

The articular processes function in the support and movement of the vertebral arch. The amplitude and direction of segmental vertebral motion are related to the size, shape, and orientation of the articular surfaces and to the functional status of the articulations.[8, 17, 28, 30] As is the case with any synovial articulation, loss of motion or aberrant joint physiology can be a primary source of pain.[5] Regional and overall spinal motion is due to the cumulative effects of small amounts of segmental vertebral motion. Clinical conditions affecting the articular processes include degenerative joint disease and ankylosis.[13]

TRANSVERSE PROCESSES

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 and to induce rotation and lateral flexion.[5] The transverse processes in the cranial thoracic vertebral region are large but gradually diminish in size in the caudal thoracic vertebral region. In the thoracic region, the transverse processes contain articular surfaces that contribute to the costotransverse articulations. The lumbar vertebral region has elongated horizontally flattened transverse processes that provide attachment sites for the large dorsal paraspinal muscles and ventral psoas muscles. It has been reported that rhinoceroses and all species of the genus *Equus* (i.e., domestic horses, wild horses and asses, and prehistorical horses) have intertransverse synovial articulations between the transverse processes of the last two or three lumbar vertebrae and at the lumbosacral junction.[28, 30] The overall size and width of the intertransverse joints are largest at the lumbosacral joint and decrease in size cranially. Biomechanically, the intertransverse joints aid in the transfer of propulsive forces from the hind limbs to the vertebral column and provide resistance to lateral bending and axial rotation of the spine. Intertransverse joints are not present at birth but develop soon afterwards.[28] The number of intertransverse joints seems to depend on the length (i.e., number of vertebrae) of the lumbar vertebral region, where a reduced number of lumbar vertebrae have fewer intertransverse joints. Most of the lumbar intertransverse joints occur in pairs, although asymmetrical distributions of intertransverse joints have been reported.[12, 28] Unilateral or bilateral intertransverse joint ankylosis is also common but is probably not a significant cause of back pain in horses.[26, 30, 31] Within the sacrum, the fused transverse processes form the lateral sacral crest.

SACROILIAC JOINT

The pelvis articulates with the vertebral column at bilateral sacroiliac articulations. 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.[6] In humans, the sacroiliac joint is richly innervated with both nociceptors and proprioceptors that function in the recognition of pain, movement, and joint position.[5] The sacroiliac joint is supported by three bilateral sets of strong sacroiliac ligaments that act to support the weight of the caudal vertebral column. The dorsal sacroiliac ligaments, consisting of dorsal and lateral portions, 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 consists 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 articulations is enhanced by the sacrosciatic ligaments.

The sacroiliac ligaments support the weight of the caudal vertebral column as it attaches to the ilial wing. Dynamically, the sacroiliac joints aid in locomotion via transfer of hind limb propulsive forces to the vertebral column.[20] Clinical conditions affecting the sacroiliac joint include either unilateral tuber sacrale height asymmetry or bilateral tuber sacrale prominence (i.e., hunter's bump). Evidence of sacroiliac joint degenerative joint disease is common, although its clinical significance remains uncertain.[13, 29] Sacroiliac joint luxation is a rare condition characterized by gross anatomical separation of the sacral and ilial articular surfaces.

SPINAL LIGAMENTS

A series of long and short spinal ligaments contributes to vertebral column stability. Three separate longitudinal spinal ligaments span the length of the vertebral column and provide regional vertebral stability. The nuchal ligament in the cervical vertebral region continues as the supraspinous ligament in the thoracolumbar vertebral region and joins the tips of the associated spinous processes. The dorsal longitudinal ligament connects the dorsal vertebral bodies within the vertebral canal and acts to reinforce the intervertebral disk. The ventral longitudinal ligament attaches to the ventral vertebral bodies and 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 vertebral 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 (see Fig. 1). In humans, ligamentous disruption has been noted in the midportion of the interspinous ligaments, where bone-ligament-bone attachments are present.[1] The most ventral fibers of the interspinous ligaments fuse with the ligamentum flavum ventrally. The ligamenta flava span the space between adjacent vertebral laminae. A high elastin-to-collagen ratio (70%–80% elastin) ensures that the ligamentum flavum does not bulge into the dorsal vertebral canal during maximal spinal extension.[2] The elastin also contributes to the stabilizing function and potential energy storage of the vertebral column. Specialized costovertebral and costotransverse ligaments provide additional stability to the thoracic vertebral region and ribs. The intertransverse ligaments connect adjacent transverse processes in the lumbar vertebral region and limit lateral flexion. The intervertebral disk can be considered to be a specialized connective tissue structure that connects adjacent vertebral bodies. Clinical conditions affecting the spinal ligaments include mild, moderate, or severe grades of sprains. Severe injuries are characterized by complete ligamentous disruption and joint laxity (i.e., joint luxation).

INTRINSIC SPINAL MUSCLES

Muscles that attach only to the axial skeleton are considered to be intrinsic spinal muscles. The spinal musculature can be categorized into epaxial or hypaxial muscle groups based on the location of the muscles compared with that of the transverse processes of the vertebral column. The epaxial muscles lie dorsal to transverse processes, are segmentally innervated by dorsal branches of spinal nerves, and produce spinal extension and lateral flexion. Hypaxial muscles lie ventral to transverse processes, are segmentally innervated by ventral branches of spinal nerves, and produce spinal flexion and lateral flexion.

The thoracolumbar epaxial fascia and musculature are discussed, proceeding from the superficial to deep layers. The thoracolumbar fascia is an aponeurosis that serves as an attachment site for many spinal and proximal limb muscles. The thoracolumbar fascia is strong and attaches to the thoracolumbar spinous processes and the cranial edge of the ilial wing. The first muscular layer includes two thin muscles: the serratus dorsalis cranialis and the serratus dorsalis caudalis. These muscles assist in respiration and have superficial and deep fascial layers that encase the iliocostalis muscle group. The second layer of muscles is the largest group of epaxial muscles and is organized into three parallel columns. These include (laterally to medially) the iliocostalis, longissimus, and spinalis muscle groups (Fig. 2). The iliocostalis muscles are a thin muscle group that attaches to the angle of the ribs and the tips of the lumbar transverse processes. The longissimus muscles are by far the largest and longest group of back muscles. These muscles primarily attach to the dorsal spinous and transverse processes of the thoracolumbar vertebral region and the wing of the ilium and help to support the weight of the saddle and rider. The spinalis muscles cover the lateral aspects of spinous processes of the withers and may be compromised

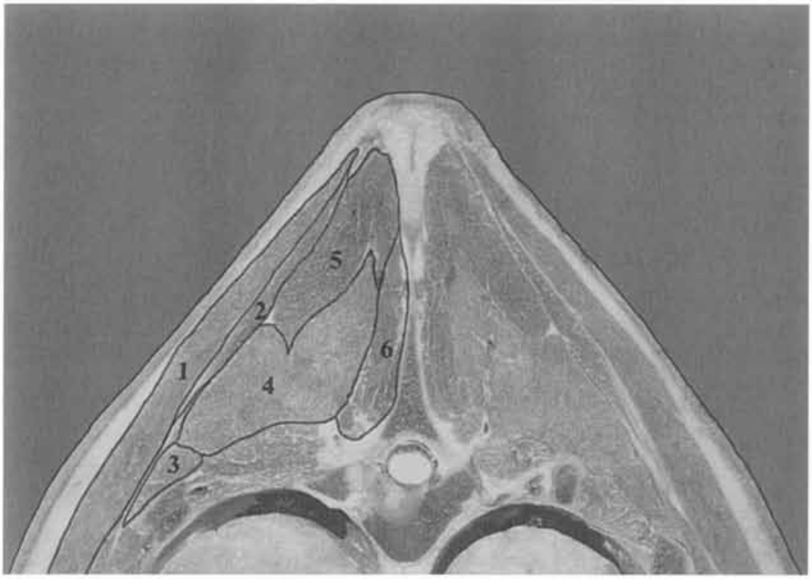

Figure 2. Transverse section at the T8 vertebral region. Outline of the muscles represented are: *1)* latissimus dorsi; *2)* rhomboideus thoracis; *3)* iliocostalis; *4)* longissimus; *5)* spinalis; and *6)* multifidi.

by a narrow saddle. The third layer, the transversospinalis muscle group, is the deepest and most medial muscle group (Fig. 3). The transversospinalis muscle group is largely composed of multifidi muscles in the thoracolumbar vertebral region. The multifidi muscle group is a series of short musculotendinous units that originate from transverse, articular, and mamillary processes and insert on adjacent spinous processes. These short muscles span two to four vertebrae and are segmentally innervated by dorsal spinal branches.

The epaxial muscles produce spinal extension when activated bilaterally and lateral flexion and rotation when activated unilaterally. Superficial muscle groups usually span one or more vertebral regions, whereas deep spinal muscles usually only span a few vertebrae.[20] The spinal musculature is important for movement, posture, and flexibility. The superficial spinal muscles are usually more dynamic (higher percentage of type II muscle fibers) and play a role during regional vertebral motion, energy storage, and force redistribution during locomotion.[20] Deep short spinal muscles have more of a static function (higher percentage of type 1 muscle fibers) and are active in segmental stabilization, proprioception, and posture. A clinical condition of the spinal musculature includes muscle strain due to overexertion or trauma.

EXTRINSIC SPINAL MUSCLES

Muscles that have attachments on the proximal limbs and the axial skeleton can be considered to be extrinsic spinal muscles (or extrinsic limb muscles). The general function of the extrinsic spinal muscles is to induce the proximal limb

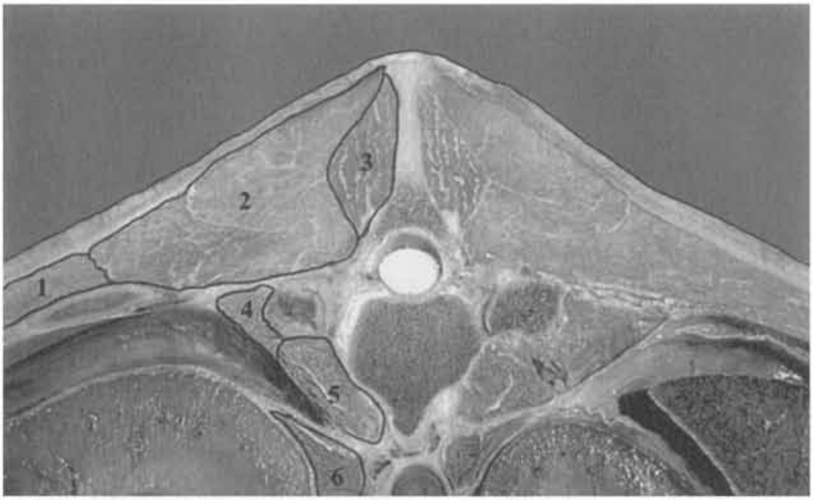

Figure 3. Transverse section at the T18 vertebral region. Outline of the muscles represented are: *1)* iliocostalis; *2)* longissimus; *3)* multifidi; *4)* psoas major; *5)* psoas minor; and *6)* crus of the diaphragm.

motions required in locomotion or to assist vertebral mobility depending on whether the vertebral column or limbs are held stationary relative to each other. The shoulder girdle muscles can be categorized into dorsal and ventral muscle groups.[4] The dorsal muscles of the shoulder girdle act to suspend the forelimbs from the neck and trunk. The dorsal shoulder muscles include the brachiocephalicus, omotransversarius, trapezius, rhomboideus, cutaneous trunci, and latissimus dorsi. The ventral muscles of the shoulder girdle function in suspending the neck and trunk from the forelimbs. The ventral shoulder muscles include the subclavius, superficial pectoral, deep pectoral, and serratus ventralis.

The pelvic girdle muscles are best characterized as cranial-caudal and lateral-medial muscle groups.[4] The cranial muscles of the pelvic girdle function in hind limb protraction and hip flexion. Muscles in this group include the sartorius, iliopsoas, tensor fascia lata, and rectus femoris. The caudal muscles of the pelvic girdle produce hind limb retraction and hip extension. Muscles in this group include the biceps femoris, semitendinosus, and semimembranosus. The lateral muscles of the pelvic girdle mostly cause hind limb abduction and include the superficial, middle, and deep gluteal muscles (Fig. 4). The medial muscles of the pelvic girdle produce hind limb adduction and include the gracilis, pectineus, and adductor muscles.

The hypaxial or sublumbar muscles include the psoas minor, psoas major, and iliacus. The psoas minor and psoas major originate on the ventral vertebral column (T16–L6) and insert on the pelvic inlet and lesser trochanter of the femur, respectively. Together, the psoas major and iliacus form the iliopsoas, the largest flexor of the coxofemoral joint (see Fig. 4). If the rear limb is stabilized, the iliopsoas muscle induces flexion of the low back and pelvic flexion about the sacroiliac articulations. Clinical conditions affecting the extrinsic spinal muscles may produce a shortened cranial or caudal swing phase to the gait depending on the muscle groups affected and the type of muscular pathology present.

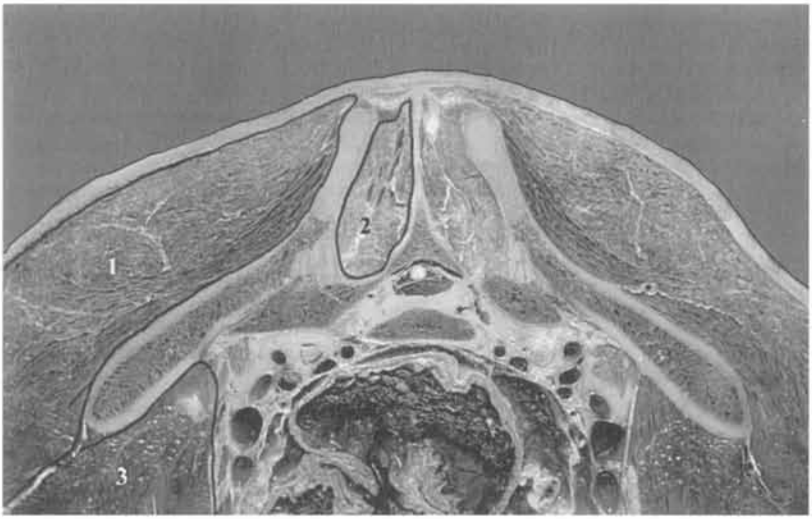

Figure 4. Transverse section at the lumbosacral and sacroiliac articulations. Outline of the muscles represented are: *1)* gluteus medius; *2)* sacrocaudalis dorsalis; and *3)* iliopsoas (psoas major and iliacus). The tuber sacrale and interosseous and ventral sacroiliac ligaments are also shown.

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