The spine is a complex and functionally significant segment of the human body. Providing the mechanical linkage between the upper and lower extremities, the spine enables motion in all three planes, yet still functions as a bony protector of the delicate spinal cord. To many researchers and clinicians, the lumbar region of the spine is of particular interest because low back pain is a major medical and socioeconomic problem in modern times.

STRUCTURE OF THE SPINE

Vertebral Column

The spine consists of a curved stack of 33 vertebrae divided structurally into five regions (Figure 9-1). Proceeding from superior to inferior, there are 7 cervical vertebrae, 12 thoracic vertebrae, 5 lumbar vertebrae, 5 fused sacral vertebrae, and 4 small, fused coccygeal vertebrae. There may be one extra vertebra or one less, particularly in the lumbar region.

Because of structural differences and the ribs, varying amounts of movement are permitted between adjacent vertebrae in the cervical, thoracic, and lumbar portions of the spine. Within these regions, two adjacent

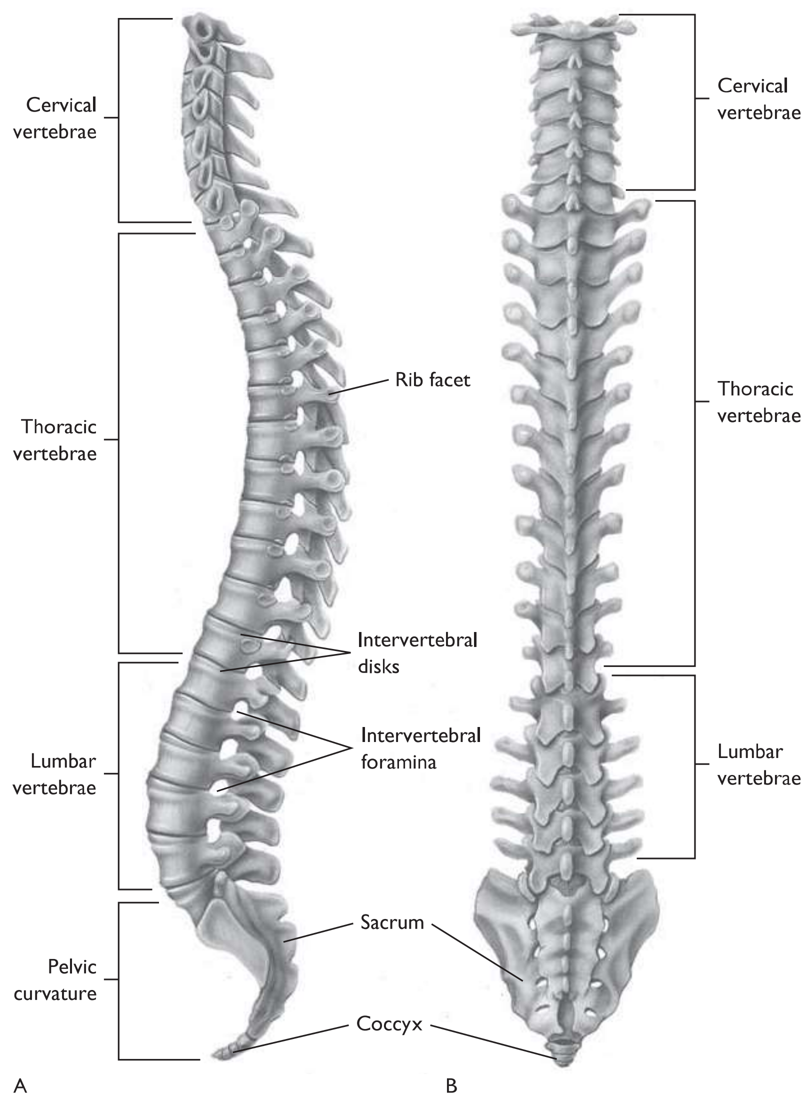


FIGURE 9-1

A. Left lateral and **B.** posterior views of the major regions of the spine. From Shier, Butler, and Lewis, *Hole's Human Anatomy and Physiology,* © 1996. Reprinted by permission of The McGraw-Hill Companies, Inc.

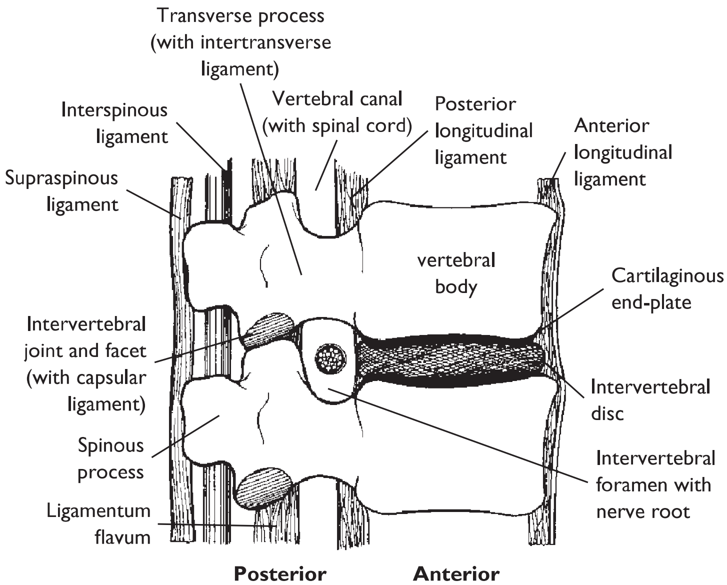


FIGURE 9-2

The motion segment, composed of two adjacent vertebrae and the associated soft tissues, is the functional unit of the spine.

vertebrae and the soft tissues between them are known as a motion segment. The motion segment is considered the functional unit of the spine (Figure 9-2).

motion segment
two adjacent vertebrae and the associated soft tissues; the functional unit of the spine

Each motion segment contains three joints. The vertebral bodies separated by the intervertebral discs form a symphysis type of amphiarthrosis. The right and left facet joints between the superior and inferior articular processes are diarthroses of the gliding type that are lined with articular cartilage.

- *The spine may be viewed as a triangular stack of articulations, with symphysis joints between vertebral bodies on the anterior side and two gliding diarthrodial facet joints on the posterior side.*

Vertebrae

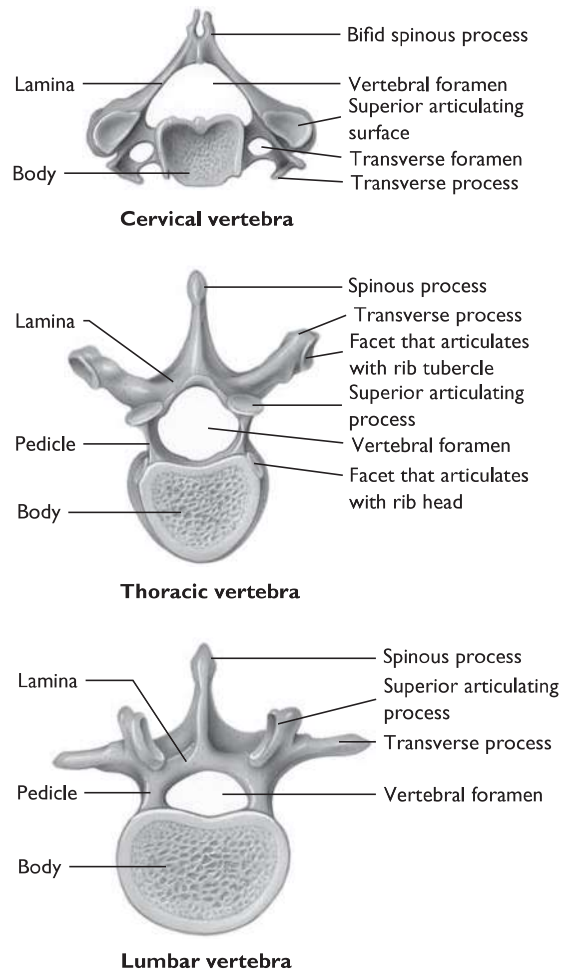
A typical vertebra consists of a body, a hollow ring known as the *neural arch,* and several bony processes (Figure 9-3). The vertebral bodies serve as the primary weight-bearing components of the spine. The neural arches and posterior sides of the bodies and intervertebral discs form a protective passageway for the spinal cord and associated blood vessels known as the vertebral canal. From the exterior surface of each neural arch, several bony processes protrude. The spinous and transverse processes serve as outriggers to improve the mechanical advantage of the attached muscles.

The first two cervical vertebrae are specialized in shape and function. The first cervical vertebra, known as the *atlas,* provides a reciprocally shaped receptacle for the condyles of the occiput of the skull. The atlanto-occipital joint is extremely stable, with flexion/extension of about 14–15° permitted, but with virtually no motion occurring in any other plane (17). A large range of axial rotation is provided at the next joint between the atlas and the second cervical vertebrae, the axis. Motion at the atlantoaxial joint averages around 75° of rotation, 14° of extension, and 24° of lateral flexion (17).

- *Although all vertebrae have the same basic shape, there is a progressive superior-inferior increase in the size of the vertebral bodies and a progression in the size and orientation of the articular processes.*
- *The orientation of the facet joints determines the movement capabilities of the motion segment.*

There is a progressive increase in vertebral size from the cervical region down through the lumbar region (Figure 9-3). The lumbar vertebrae, in particular, are larger and thicker than the vertebrae in the superior regions of the spine. This serves a functional purpose, since when the body is in an upright position each vertebra must support the weight of not only the arms and head but all the trunk positioned above it. The increased surface area of the lumbar vertebrae reduces the amount of stress

FIGURE 9-3



Superior views of the typical vertebrae. From Shier, Butler, and Lewis, *Hole's Human Anatomy and Physiology,* © 1996. Reprinted by permission of The McGraw-Hill Companies, Inc.

to which these vertebrae would otherwise be subjected. The weight-bearing surface area of the intervertebral disc also increases with the weight supported in all mammals (129).

The size and angulation of the vertebral processes vary throughout the spinal column (Figure 9-4). This changes the orientation of the facet joints, which limit range of motion in the different spinal regions. In addition to channeling the movement of the motion segment, the facet joints assist in load bearing. The facet joints and discs provide about 80% of the spine's ability to resist rotational torsion and shear, with half of this contribution from the facet joints (43, 61). The facet joints also sustain up to approximately 30% of the compressive loads on the spine, particularly when the spine is in hyperextension (Figure 9-5) (72). Contact forces are largest at the L5-S1 facet joints (77). Recent studies suggest that 15–40% of chronic low back pain emanates from the facet joints (11).

Intervertebral Discs

The articulations between adjacent vertebral bodies are symphysis joints with intervening fibrocartilaginous discs that act as cushions. Healthy intervertebral discs in an adult account for approximately one-fourth of the height of the spine. When the trunk is erect, the differences in the anterior and posterior thicknesses of the discs produce the lumbar, thoracic, and cervical curves of the spine.

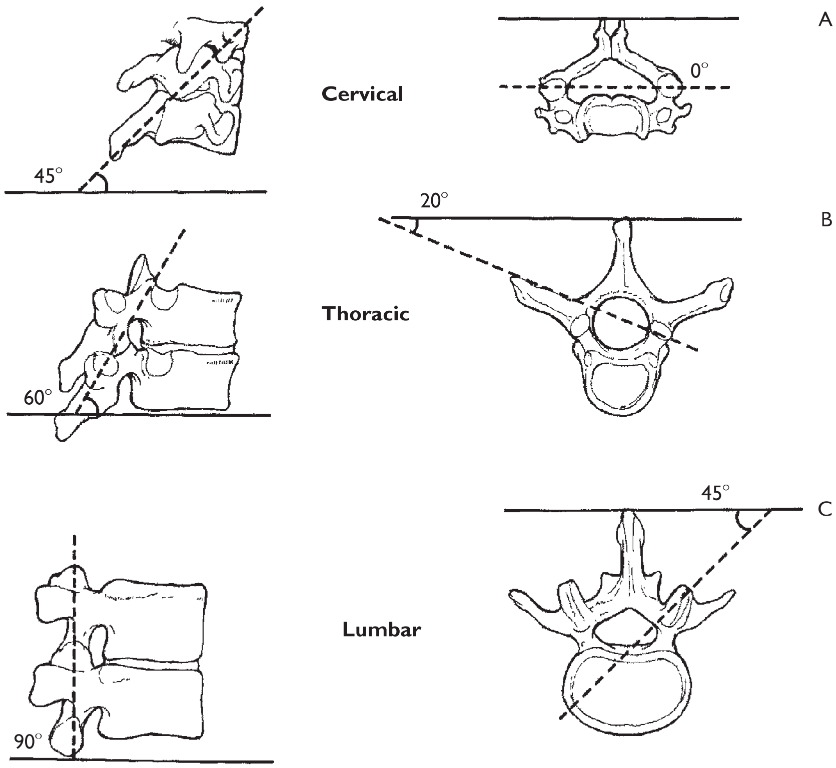


FIGURE 9-4

Approximate orientations of the facet joints. **A.** Lower cervical spine, with facets oriented 45° to the transverse plane and parallel to the frontal plane. **B.** Thoracic spine, with facets oriented 60° to the transverse plane and 20° to the frontal plane. **C.** Lumbar spine, with facets oriented 90° to the transverse plane and 45° to the frontal plane.

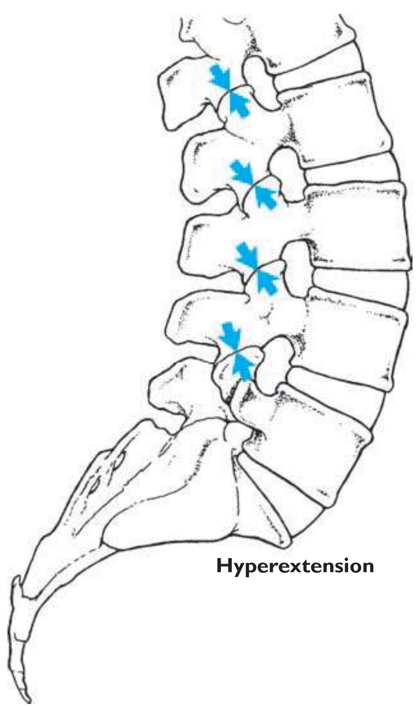


FIGURE 9-5

Hyperextension of the lumbar spine creates compression at the facet joints.

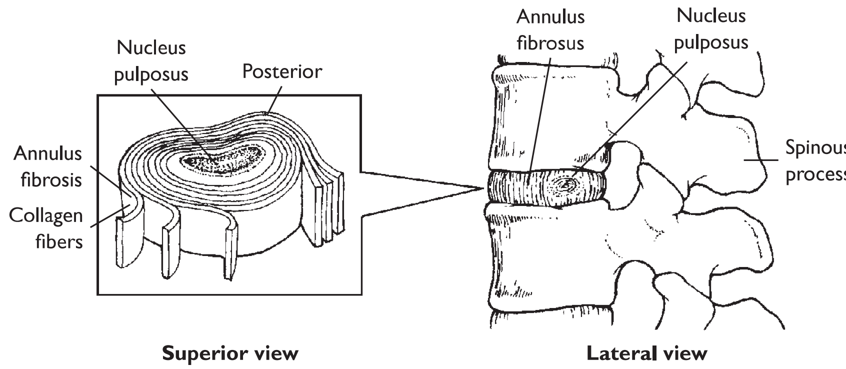


FIGURE 9-6

In the intervertebral disc, the annulus fibrosus, made up of laminar layers of criss-crossed collagen fibers, surrounds the nucleus pulposus.

annulus fibrosus
thick, fibrocartilaginous ring that forms the exterior of the intervertebral disc

nucleus pulposus
colloidal gel with a high fluid content, located inside the annulus fibrosus of the intervertebral disc

The intervertebral disc incorporates two functional structures: A thick outer ring composed of fibrous cartilage called the annulus fibrosus, or annulus, surrounds a central gelatinous material known as the nucleus pulposus, or nucleus (Figure 9-6). The annulus consists of about 90 concentric bands of collagenous tissue that are bonded together. The collagen fibers of the annulus crisscross vertically at about 30° angles to each other, making the structure more sensitive to rotational strain than to compression, tension, and shear (43). These fibers, which are crucial for the mechanical functioning of the disc, display changes in organization and orientation with loading of the disc, as well as with disc degeneration (64, 90). The nucleus of a young, healthy disc is approximately 90% water, with the remainder being collagen and proteoglycans, specialized materials that chemically attract water (98). The extremely high fluid content of the nucleus makes it resistant to compression.

Mechanically, the annulus acts as a coiled spring whose tension holds the vertebral bodies together against the resistance of the nucleus pulposus, and the nucleus pulposus acts like a ball bearing composed of an incompressible gel (Figure 9-7) (74). During flexion and extension, the vertebral bodies roll over the nucleus while the facet joints guide the movements. As shown in Figure 9-8, spinal flexion, extension, and lateral flexion produce compressive stress on one side of the discs and tensile stress on the other, whereas spinal rotation creates shear stress in the

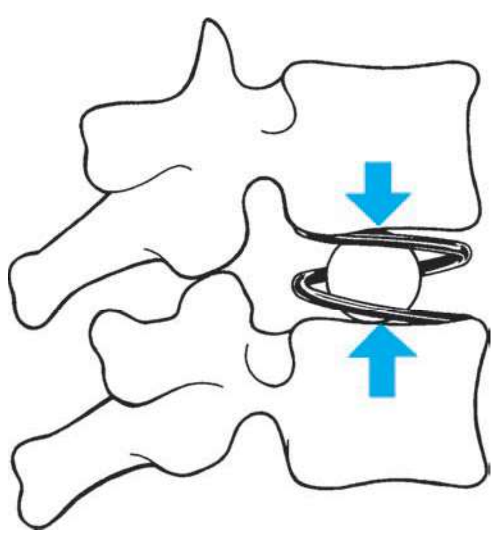


FIGURE 9-7

Mechanically, the annulus fibrosus behaves as a coiled spring, holding the vertebral bodies together, whereas the nucleus pulposus acts like a ball bearing that the vertebrae roll over during flexion/extension and lateral bending.

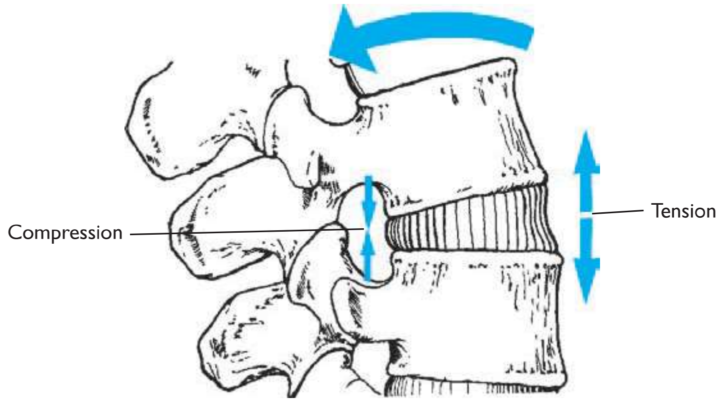


FIGURE 9-8

When the spine bends, a tensile load is created on one side of the discs, and a compressive load is created on the other.

discs (Figure 9-9) (72). Stress on the discs is significantly higher with flexion as compared to rotation, with bending stress approximately 450 times greater than the twisting stress from the same angle of bending or twisting of the annulus fibers (26). During daily activities, compression is the most common form of loading on the spine.

When a disc is loaded in compression, it tends to simultaneously lose water and absorb sodium and potassium until its internal electrolyte concentration is sufficient to prevent further water loss (70). When this chemical equilibrium is achieved, internal disc pressure is equal to the external pressure (8). Continued loading over a period of several hours results in a further slight decrease in disc hydration (1). For this reason, the spine undergoes a height decrease of up to nearly 2 cm over the course of a day, with approximately 54% of this loss occurring during the first 30 minutes after an individual gets up in the morning (101).

Once pressure on the discs is relieved, the discs quickly reabsorb water, and disc volumes and heights are increased (70). Astronauts experience a temporary increase in spine height of approximately 5 cm while free from the influence of gravity (88). On earth, disc height and volume are typically greatest when a person first arises in the morning. Because increased disc volume also translates to increased spinal stiffness, there appears to be a heightened risk of disc injury early in the morning (38). Measurements of spinal shrinkage following activities performed for one hour immediately after rising in the morning yielded average values of −7.4 mm for standing, −5.0 mm for sitting, −7.9 mm for walking, −3.7 mm for cycling, and +0.4 mm for lying down (121). Body positions that allow rehydration and height increase in the discs are spinal hyperextension in the prone position and trunk flexion in the supine position (93).

The intervertebral discs have a blood supply up to about the age of 8 years, but after that the discs must rely on a mechanically based means

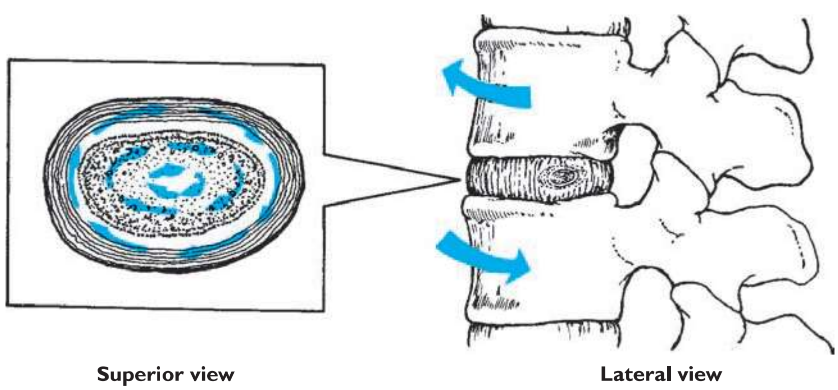


FIGURE 9-9

Spinal rotation creates shear stress within the discs, with the greatest shear around the periphery of the annulus.

●*It is important not to maintain any one body position for too long, since the intervertebral discs rely on body movement to pump nutrients in and waste products out.*

for maintaining a healthy nutritional status. Intermittent changes in posture and body position alter internal disc pressure, causing a *pumping action* in the disc. The influx and outflux of water transports nutrients in and flushes out metabolic waste products, basically fulfilling the same function that the circulatory system provides for vascularized structures within the body. Maintaining even an extremely comfortable fixed body position over a long period curtails this pumping action and can negatively affect disc health. Research has shown that there is a zone of optimal loading frequency and magnitude that promotes disc health (125).

Injury and aging irreversibly reduce the water-absorbing capacity of the discs, with a concomitant decrease in shock-absorbing capability. Magnetic resonance imaging (MRI) studies show degenerative changes to be the most common at L5-S1, the disc subjected to the most mechanical stress by virtue of its position (104). However, the fluid content of all discs begins to diminish around the second decade of life (8). A typical geriatric disc has a fluid content that is reduced by approximately 35% (128). As this normal degenerative change occurs, abnormal movements occur between adjacent vertebral bodies, and more of the compressive, tensile, and shear loads on the spine must be assumed by other structures—particularly the facets and joint capsules. Results include reduced height of the spinal column, often accompanied by degenerative changes in the spinal structures that are forced to assume the loads of the discs. Postural alterations may also occur. The normal lordotic curve of the lumbar region may be reduced as an individual attempts to relieve compression on the facet joints by maintaining a posture of spinal flexion (128). Factors such as habitual smoking and exposure to vibration can negatively affect disc nutrition, while regular exercise can improve it (98).

●*Although most of the load sustained by the spine is borne by the symphysis joints, the facet joints may play a role, particularly when the spine is in hyperextension and when disc degeneration has occurred.*

Ligaments

●*The enlarged cervical portion of the supraspinous ligament is the ligamentum nuchae, or ligament of the neck.*

A number of ligaments support the spine, contributing to the stability of the motion segments (Figure 9-10). The powerful anterior longitudinal ligament and the weaker posterior longitudinal ligament connect the vertebral bodies in the cervical, thoracic, and lumbar regions. The supraspinous

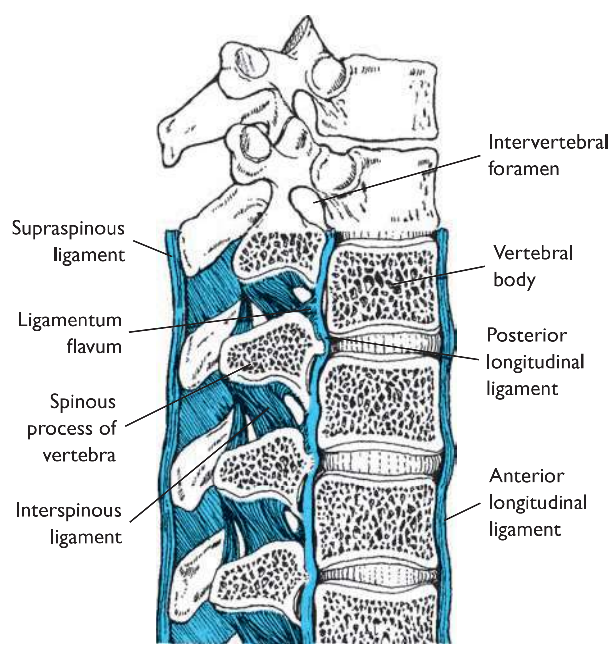


FIGURE 9-10

The major ligaments of the spine. (The intertransverse ligament is not visible in this medial section through the spine.)

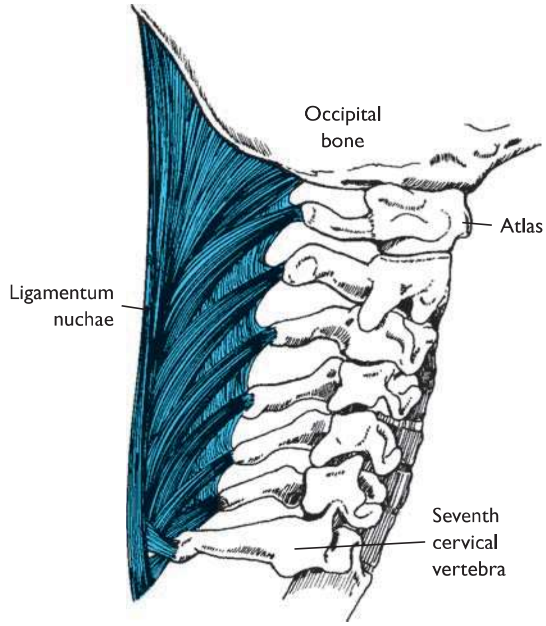


FIGURE 9-11

The supraspinous ligament is well developed in the cervical region, where it is referred to as the *ligamentum nuchae.*

ligament attaches to the spinous processes throughout the length of the spine. This ligament is prominently enlarged in the cervical region, where it is referred to as the *ligamentum nuchae,* or *ligament of the neck* (Figure 9-11). Adjacent vertebrae have additional connections between spinous processes, transverse processes, and laminae, supplied respectively by the interspinous ligaments, the intertransverse ligaments, and the ligamenta flava.

Another major ligament, the ligamentum flavum, connects the laminae of adjacent vertebrae. Although most spinal ligaments are composed primarily of collagen fibers that stretch only minimally, the ligamentum flavum contains a high proportion of elastic fibers, which lengthen when stretched during spinal flexion and shorten during spinal extension. The ligamentum flavum is in tension even when the spine is in anatomical position, enhancing spinal stability. This tension creates a slight, constant compression in the intervertebral discs, referred to as prestress.

ligamentum flavum
yellow ligament that connects the laminae of adjacent vertebrae; distinguished by its elasticity

prestress
stress on the spine created by tension in the resting ligaments

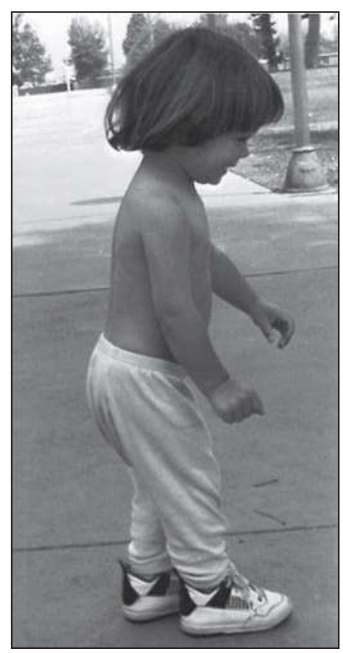
primary spinal curves
curves that are present at birth

secondary spinal curves
curves that do not develop until the weight of the body begins to be supported in sitting and standing positions

Spinal Curves

As viewed in the sagittal plane, the spine contains four normal curves. The thoracic and sacral curves, which are concave anteriorly, are present at birth and are referred to as primary curves. The lumbar and cervical curves, which are concave posteriorly, develop from supporting the body in an upright position after young children begin to sit up and stand. Since these curves are not present at birth, they are known as the secondary spinal curves. Although the cervical and thoracic curves change little during the growth years, the curvature of the lumbar spine increases approximately 10% between the ages of 7 and 17 (124). Spinal curvature (posture) is influenced by heredity, pathological conditions, an individual's mental state, and the forces to which the spine is habitually subjected. Mechanically, the curves enable the spine to absorb more shock without injury than if the spine were straight.

As discussed in Chapter 4, bones are constantly modeled or shaped in response to the magnitudes and directions of the forces acting on them. Similarly, the four spinal curves can become distorted when the spine is habitually subjected to asymmetrical forces.



Note the relatively flat spine of this 3-year-old. The lumbar curve does not reach full development until approximately age 17.

lordosis
extreme lumbar curvature

Exaggeration of the lumbar curve, or lordosis, is often associated with weakened abdominal muscles and anterior pelvic tilt (Figure 9-12). Causes of lordosis include congenital spinal deformity, weakness of the abdominal muscles, poor postural habits, and overtraining in sports requiring repeated lumbar hyperextension, such as gymnastics, figure skating, javelin throwing, and swimming the butterfly stroke. Because lordosis places added compressive stress on the posterior elements of the spine, some have hypothesized that excessive lordosis is a risk factor for low back pain development. Limited range of motion in hip extension is associated with exaggerated lumbar lordosis (45). Obesity causes reduced range of motion of the entire spine and pelvis, and obese individuals resultingly display increased anterior pelvic tilt and an associated increased lumbar lordosis (123). Similarly, increased anterior pelvic tilt and increased lordosis are greater during running than during walking (45).

kyphosis
extreme thoracic curvature

Another abnormality in spinal curvature is kyphosis (exaggerated thoracic curvature) (Figure 9-12). The incidence of kyphosis has been estimated to be as high as 8% in the general population, with equal distribution across genders (2). Kyphosis can result from a congenital abnormality, a pathology such as osteoporosis, or Scheuermann's disease, in which one or more wedge-shaped vertebrae develop because of abnormal epiphyseal plate behavior. Scheuermann's disease typically develops in individuals between the ages of 10 and 16 years, which is the period of most rapid growth of the thoracic spine (35). Both genetic and biomechanical factors are believed to play a role (7). The condition has been called *swimmer's back* because it is frequently seen in adolescents who have trained heavily with the butterfly stroke (119). Scheuermann's disease is not limited to swimmers, however, with research showing a strong association between incidence of this pathology and cumulative training time in any sport (130). Treatment for mild cases may consist of exercises to strengthen the posterior thoracic muscles, although bracing or surgical corrections are used in more severe cases. Kyphosis also often develops in elderly women with osteoporosis, as discussed in Chapter 4. Both the thoracic vertebrae and the intervertebral discs in the region develop a characteristic wedge shape (110).

scoliosis
lateral spinal curvature

Lateral deviation or deviations in spinal curvature are referred to as scoliosis (Figure 9-12). The lateral deformity is coupled with rotational deformity of the involved vertebrae, with the condition ranging from mild

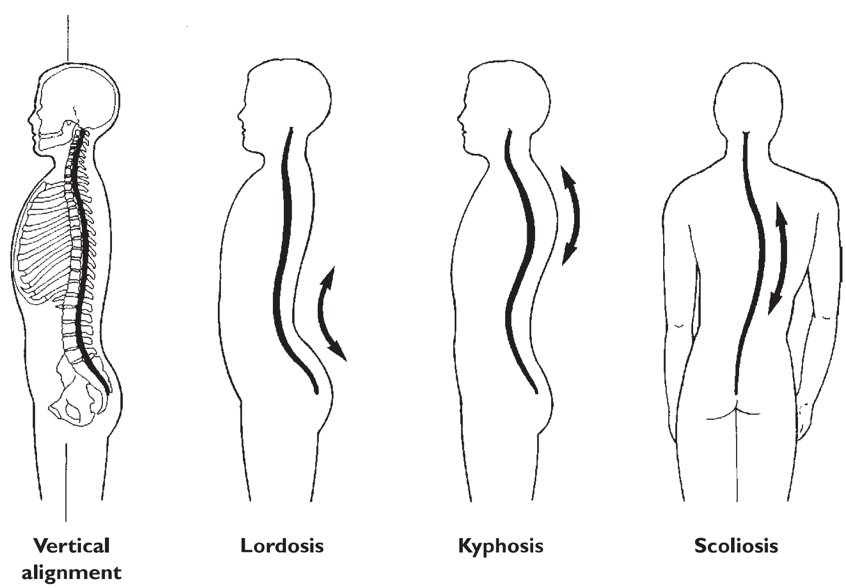


FIGURE 9-12

Abnormal spinal curvatures.

to severe. Scoliosis may appear as either a C- or an S-curve involving the thoracic spine, the lumbar spine, or both.

A distinction is made between structural and nonstructural scoliosis. Structural scoliosis involves inflexible curvature that persists even with lateral bending of the spine. Nonstructural scoliotic curves are flexible and are corrected with lateral bending.

Scoliosis results from a variety of causes. Congenital abnormalities and selected cancers can contribute to the development of structural scoliosis. Nonstructural scoliosis may occur secondary to a leg length discrepancy or local inflammation. Small lateral deviations in spinal curvature are relatively common and may result from a habit such as carrying books or a heavy purse on one side of the body every day. Approximately 70–90% of all scoliosis, however, is termed *idiopathic,* which means that the cause is unknown (133). Idiopathic scoliosis is most commonly diagnosed in children between the ages of 10 and 13 years, but can be seen at any age. It is present in 2–4% of children between 10 and 16 years of age and is more common in females (100). Low bone mineral density is typically associated with idiopathic scoliosis and may play a causative role in its development (28).

Symptoms associated with scoliosis vary with the severity of the condition. Mild cases may be nonsymptomatic and may self-correct with time. A growing body of evidence supports the effectiveness of appropriate stretching and strengthening exercises for resolving the symptoms and appearance of mild to moderate scoliosis (133). Severe scoliosis, however, which is characterized by extreme lateral deviation and localized rotation of the spine, can be painful and deforming, and is treated with bracing and/or surgery. As is the case with kyphosis, both the vertebrae and the intervertebral discs in the affected region(s) assume a wedge shape (114).

MOVEMENTS OF THE SPINE

As a unit, the spine allows motion in all three planes of movement, as well as circumduction. Because the motion allowed between any two adjacent vertebrae is small, however, spinal movements always involve a number of motion segments. The range of motion (ROM) allowed at each motion segment is governed by anatomical constraints that vary through the cervical, thoracic, and lumbar regions of the spine.

• *The movement capabilities of the spine as a unit are those of a ball-and-socket joint, with movement in all three planes, as well as circumduction, allowed.*

Female gymnasts undergo extreme lumbar hyperextension during many commonly performed skills.
Photo courtesy of Royalty-Free/CORBIS.

Flexion, Extension, and Hyperextension

The ROM for flexion/extension of the motion segments is considerable in the cervical and lumbar regions, with representative values as high as 17° at the C5-C6 vertebral joint and 20° at L5-S1. In the thoracic spine, however, due to the orientation of the facets, the ROM increases from only approximately 4° at T1-T2 to approximately 10° at T11-T12 (127).

It is important not to confuse spinal flexion with hip flexion or anterior pelvic tilt, although all three motions occur during an activity such as touching the toes (Figure 9-13). Hip flexion consists of anteriorly directed sagittal plane rotation of the femur with respect to the pelvic girdle (or vice versa), and anterior pelvic tilt is anteriorly directed movement of the anterior superior iliac spine with respect to the pubic symphysis, as discussed in Chapter 8. Just as anterior pelvic tilt facilitates hip flexion, it also promotes spinal flexion.

Extension of the spine backward past anatomical position is termed *hyperextension*. The ROM for spinal hyperextension is considerable in the cervical and lumbar regions. Lumbar hyperextension is required in the execution of many sport skills, including several swimming strokes, the high jump and pole vault, and numerous gymnastic skills. For example, during the execution of a back handspring, the curvature normally present in the lower lumbar region may increase twentyfold (53).

Lateral Flexion and Rotation

Frontal plane movement of the spine away from anatomical position is termed *lateral flexion*. The largest ROM for lateral flexion occurs in the cervical region, with approximately 9–10° of motion allowed at C4-C5. Somewhat less lateral flexion is allowed in the thoracic region, where the ROM between adjacent vertebrae is about 6°, except in the lower segments, where lateral flexion capability may be as high as approximately 8–9°. Lateral flexion in the lumbar spine is also on the order of 6°, except at L5-S1, where it is reduced to only about 3° (127).

Spinal rotation in the transverse plane is again freest in the cervical region of the spine, with up to 12° of motion allowed at C1-C2. It is next freest in the thoracic region, where approximately 9° of rotation is permitted among the upper motion segments. From T7-T8 downward, the range of rotational capability progressively decreases, with only about 2° of motion allowed in the lumbar spine due to the interlocking of the articular

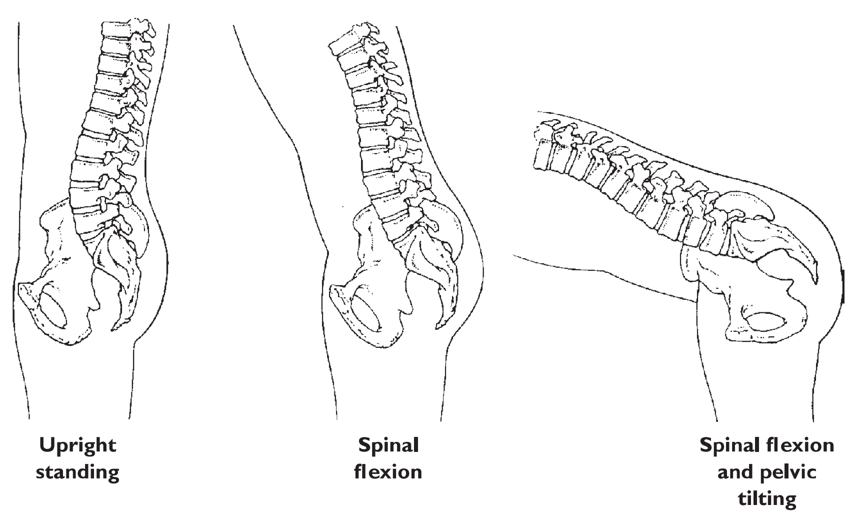


FIGURE 9-13

When the trunk is flexed, the first 50–60° of motion occurs in the lumbar spine, with additional motion resulting from anterior pelvic tilt.

processes there. At the lumbosacral joint, however, rotation on the order of 5° is allowed (127). Since the structure of the spine causes lateral flexion and rotation to be coupled, rotation is accompanied by slight lateral flexion to the same side, although this motion is not observable with the naked eye.

Studies of activities of daily living have quantified ROMs in the cervical and lumbar regions of the spine. Among these activities, backing up a car was found to require the most motion in the cervical region, with approximately 32% of sagittal, 26% of lateral, and 92% of rotational motion capability involved (13). Similarly, the task requiring the greatest lumbar motion was picking up an object from the floor (14). ROM in the cervical spine has been found to decrease linearly with increasing age, with a loss in passive range of motion of about 0.5 degrees per year (103).

MUSCLES OF THE SPINE

The muscles of the neck and trunk are named in pairs, with one on the left and the other on the right side of the body. These muscles can cause lateral flexion and/or rotation of the trunk when they act unilaterally, and trunk flexion or extension when acting bilaterally. The primary functions of the major muscles of the spine are summarized in Table 9-1.

Anterior Aspect

The major anterior muscle groups of the cervical region are the prevertebral muscles, including the rectus capitis anterior, rectus capitis lateralis, longus capitis, and longus colli, and the eight pairs of hyoid muscles (Figures 9-14 and 9-15). Bilateral tension development by these muscles results in flexion of the head, although the main function of the hyoid muscles appears to be to move the hyoid bone during the act of swallowing. Unilateral tension development in the prevertebrals contributes to lateral flexion of the head toward the contracting muscles or to rotation of the head away from the contracting muscles, depending on which other muscles are functioning as neutralizers.

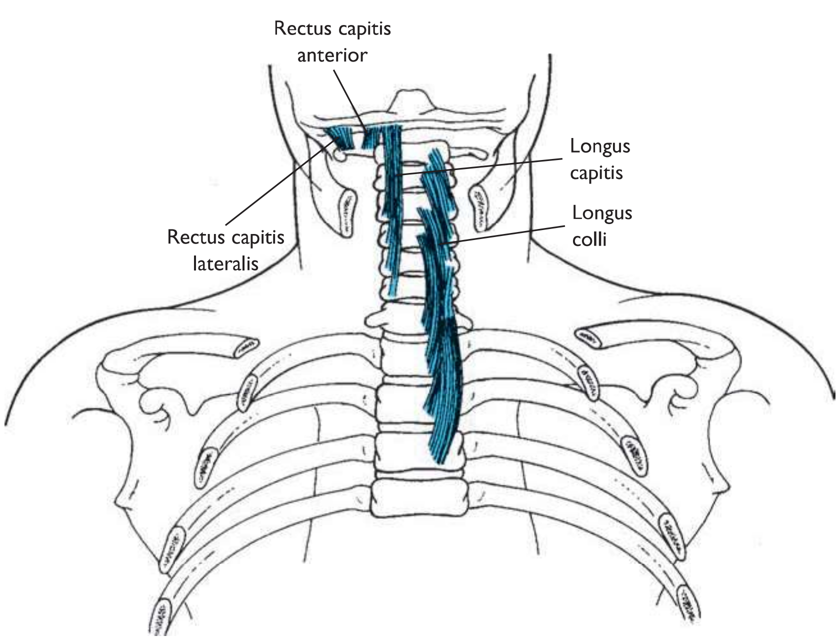


FIGURE 9-14

Anterior muscles of the cervical region.

TABLE 9-1

Muscles of the Spine

MUSCLE	PROXIMAL ATTACHMENT	DISTAL ATTACHMENT	PRIMARY ACTION(S) ABOUT THE HIP	INNERVATION
Prevertebral muscles (rectus capitis anterior, rectus capitis lateralis, longus capitis, longus coli)	Anterior aspect of occipital bone and cervical vertebrae	Anterior surfaces of cervical and first three thoracic vertebrae	Flexion, lateral flexion, rotation to opposite side	Cervical nerves (C_1–C_6)
Rectus abdominis	Costal cartilage of ribs 5–7	Pubic crest	Flexion, lateral flexion	Intercostal nerves (T_6–T_{12})
External oblique	External surface of lower eight ribs	Linea alba and anterior iliac crest	Flexion, lateral flexion, rotation to opposite side	Intercostal nerves (T_7 –T_{12})
Internal oblique	Linea alba and lower four ribs	Inguinal ligament, iliac crest, lumbodorsal fascia	Flexion, lateral flexion, rotation to same side	Intercostal nerves (T_7–T_{12}, L_1)
Splenius (capitis and cervicis)	Mastoid process of temporal bone, transverse processes of first three cervical vertebrae	Lower half of ligamentum nuchae, spinous processes of seventh cervical and upper six thoracic vertebrae	Extension, lateral flexion, rotation to same side	Middle and lower cervical nerves (C_4–C_8)
Suboccipitals (obliquus capitus superior and inferior, rectus capitis posterior major and minor)	Occipital bone, transverse process of first cervical vertebra	Posterior surfaces of first two cervical vertebrae	Extension, lateral flexion, rotation to same side	Suboccipital nerve (C_1)
Erector spinae (spinalis, longissimus, iliocostalis)	Lower part of ligamentum nuchae, posterior cervical, thoracic, and lumbar spine, lower nine ribs, iliac crest, posterior sacrum	Mastoid process of temporal bone, posterior cervical, thoracic, and lumbar spine, twelve ribs	Extension, lateral flexion, rotation to opposite side	Spinal nerves (T_1–T_{12})
Semispinalis (capitis, cervicis, thoracis)	Occipital bone, spinous processes of thoracic vertebrae 2–4	Transverse presses of thoracic and seventh cervical vertebrae	Extension, lateral flexion, rotation to opposite side	Cervical and thoracic spinal nerves (C_1–T_{12})
Deep spinal muscles (multifidi, rotatores, interspinales, intertransversarii, levatores costarum)	Posterior processes of all vertebrae, posterior sacrum	Spinous and transverse processes and laminae of vertebrae below those of proximal attachment	Extension, lateral flexion, rotation to opposite side	Spinal and intercostal nerves (T_1–T_{12})
Sternocleidomastoid	Mastoid process of temporal bone	Superior sternum, inner third of clavicle	Flexion of neck, extension of head, lateral flexion, rotation to opposite side	Accessory nerve and C_2 spinal nerve
Levator scapulae	Transverse processes of first four cervical vertebrae	Vertebral border of scapula	Lateral flexion	Spinal nerves (C_3–C_4), dorsal scapular nerve (C_3–C_5)
Scaleni (scalenus anterior, medius, posterior)	Transverse processes of cervical vertebrae	Upper two ribs	Flexion, lateral flexion	Cervical nerves (C_3–C_7)
Quadratus lumborum	Last rib, transverse processes of first four lumbar vertebrae	Iliolumbar ligament, adjacent iliac crest	Lateral flexion	Spinal nerves (T_{12}–L_4)
Psoas major	Sides of twelfth thoracic and all lumbar vertebrae	Lesser trochanter of the femur	Flexion	Femoral nerve (L_1–L_3)

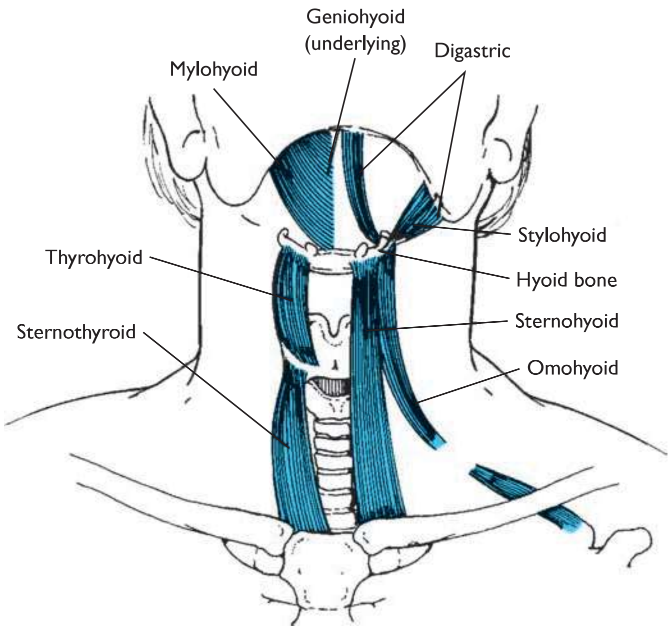


FIGURE 9-15

The hyoid muscles.

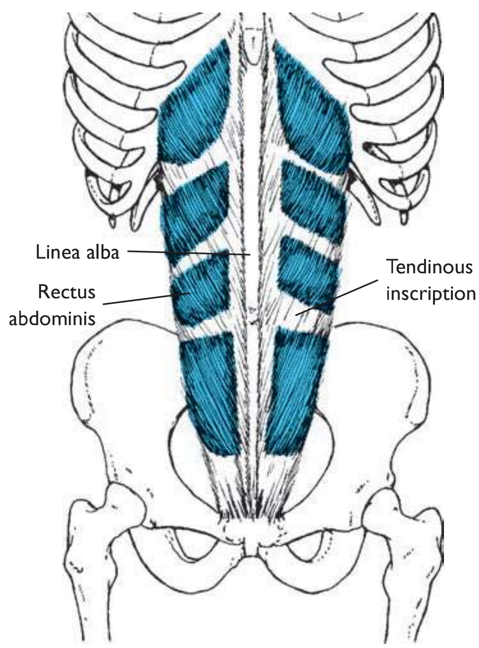
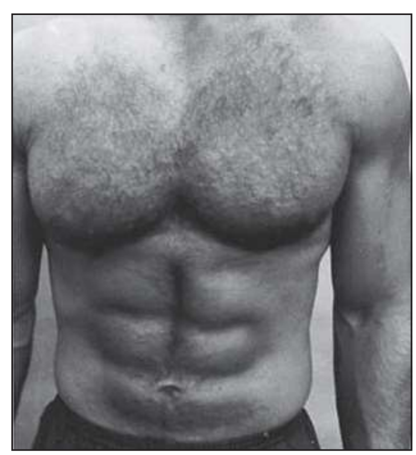


FIGURE 9-16

The rectus abdominis.



The rectus abdominis is a prominent abdominal muscle.

The main abdominal muscles are the rectus abdominis, the external obliques, and the internal obliques (Figures 9-16, 9-17, and 9-18). Functioning bilaterally, these muscles are the major spinal flexors and also reduce anterior pelvic tilt. Unilateral tension development by the muscles produces lateral flexion of the spine toward the tensed muscles. Tension development in the internal obliques causes rotation of the spine toward the same side. Tension development by the external obliques results in rotation toward the opposite side. If the spine is fixed, the internal obliques produce pelvic rotation toward the opposite side, with the external obliques producing rotation of the pelvis toward the same side. These muscles also form the major part of the abdominal wall, which protects the internal organs of the abdomen.

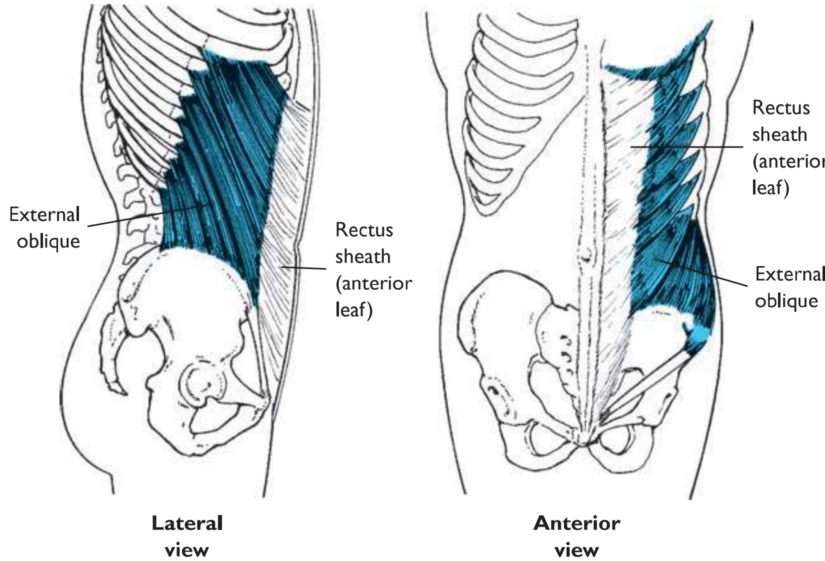


FIGURE 9-17

The external obliques.

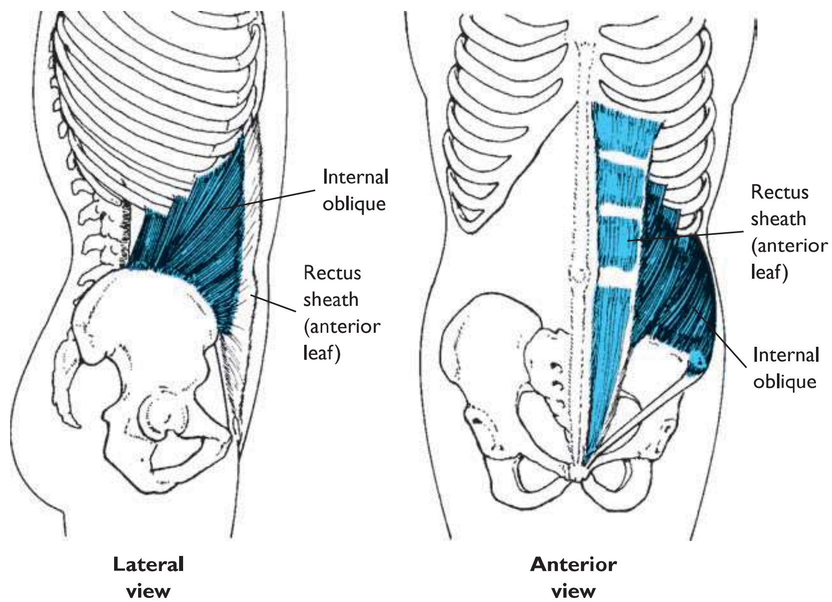
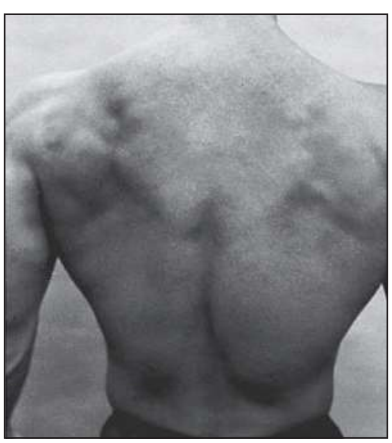


FIGURE 9-18

The internal obliques.



The superficial muscles of the posterior trunk.

Posterior Aspect

The splenius capitis and splenius cervicis are the primary cervical extensors (Figure 9-19) (89). Bilateral tension development in the four suboccipitals—the rectus capitis posterior major and minor and the obliquus capitis superior and inferior—assist (Figure 9-20). When these posterior cervical muscles develop tension on one side only, they laterally flex or rotate the head toward the side of the contracting muscles.

The posterior thoracic and lumbar region muscle groups are the massive erector spinae (sacrospinalis), the semispinalis, and the deep spinal muscles. As shown in Figure 9-21, the erector spinae group includes the spinalis, longissimus, and iliocostalis muscles. The semispinalis, with its capitis, cervicis, and thoracis branches, is shown in Figure 9-22. The deep spinal muscles, including the multifidi, rotatores, interspinales, intertransversarii,

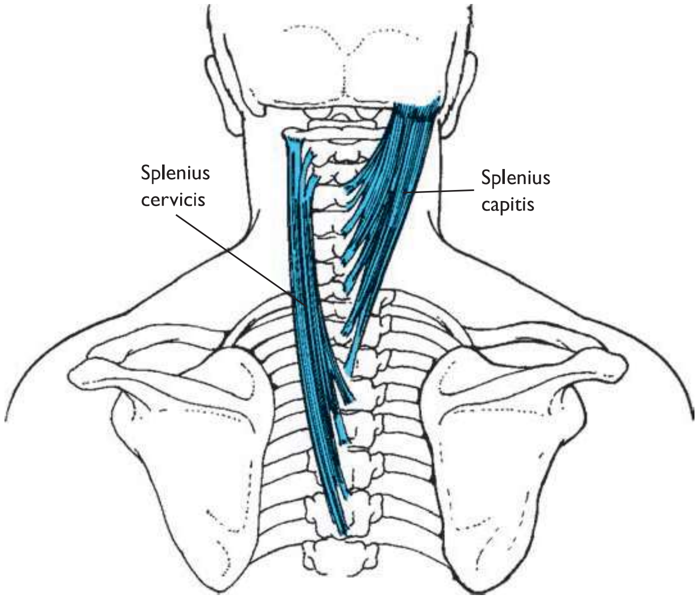


FIGURE 9-19

The major cervical extensors.

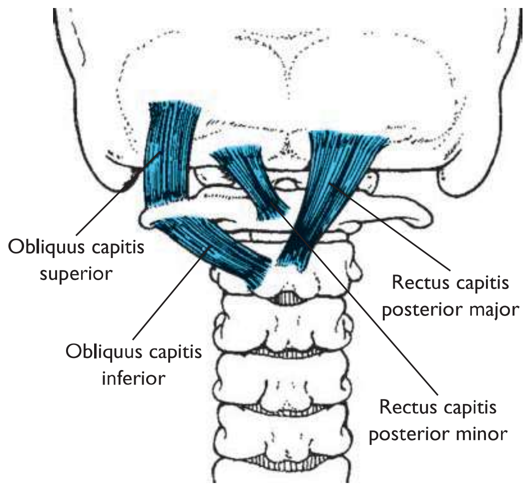


FIGURE 9-20

The suboccipital muscles.

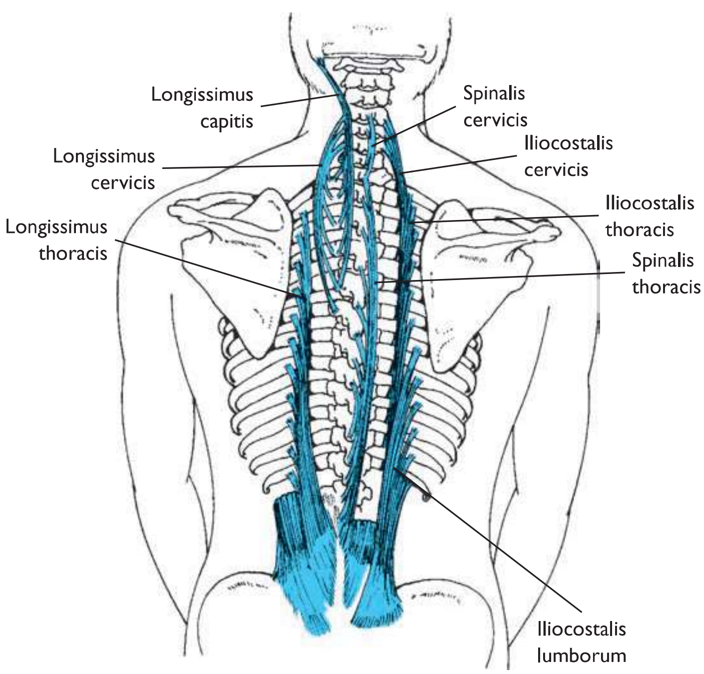
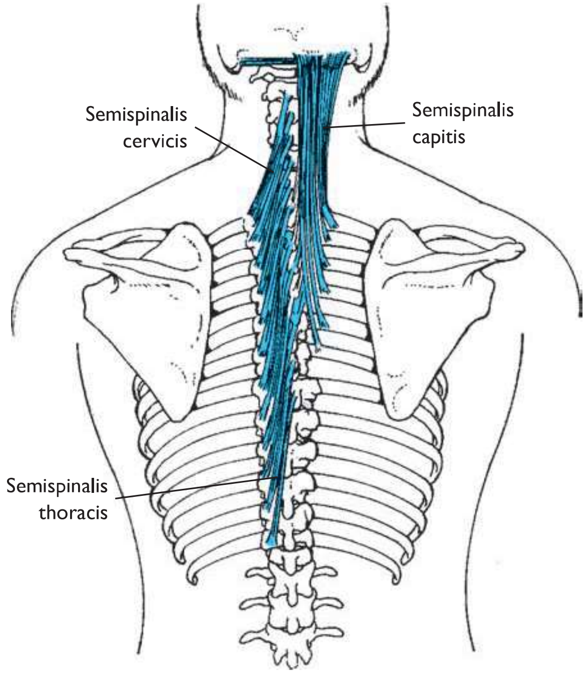


FIGURE 9-21

The erector spinae group.

FIGURE 9-22

The semispinalis group.



•The prominent erector spinae muscle group—the major extensor and hyperextensor of the trunk—is the muscle group of the trunk most often strained.

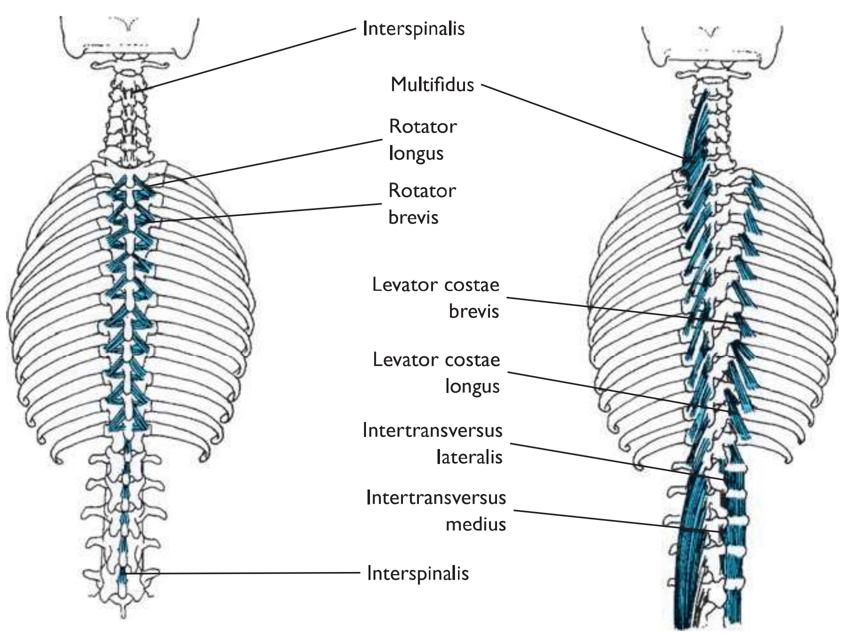
and levatores costarum, are represented in Figure 9-23. The muscles of the erector spinae group are the major extensors and hyperextensors of the trunk. All posterior trunk muscles contribute to extension and hyperextension when contracting bilaterally and to lateral flexion when contracting unilaterally.

Lateral Aspect

Muscles on the lateral aspect of the neck include the prominent sternocleidomastoid, the levator scapulae, and the scalenus anterior, posterior,

FIGURE 9-23

The deep spinal muscles.



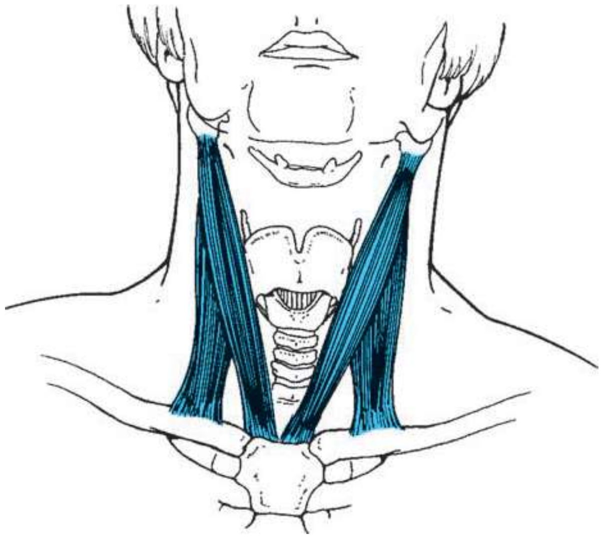


FIGURE 9-24

The sternocleidomastoid.

and medius (Figures 9-24, 9-25, and 9-26). Bilateral tension development in the sternocleidomastoid may result in either flexion of the neck or extension of the head, with unilateral contraction producing lateral flexion to the same side or rotation to the opposite side. The levator scapulae can also contribute to lateral flexion of the neck when contracting unilaterally with the scapula stabilized. The three scalenes assist with flexion and lateral flexion of the neck, depending on whether tension development is bilateral or unilateral.

•Many muscles of the neck and trunk cause lateral flexion when contracting unilaterally but either flexion or extension when contracting bilaterally.

In the lumbar region, the quadratus lumborum and psoas major are large, laterally oriented muscles (Figures 9-27 and 9-28). These muscles function bilaterally to flex and unilaterally to laterally flex the lumbar spine.

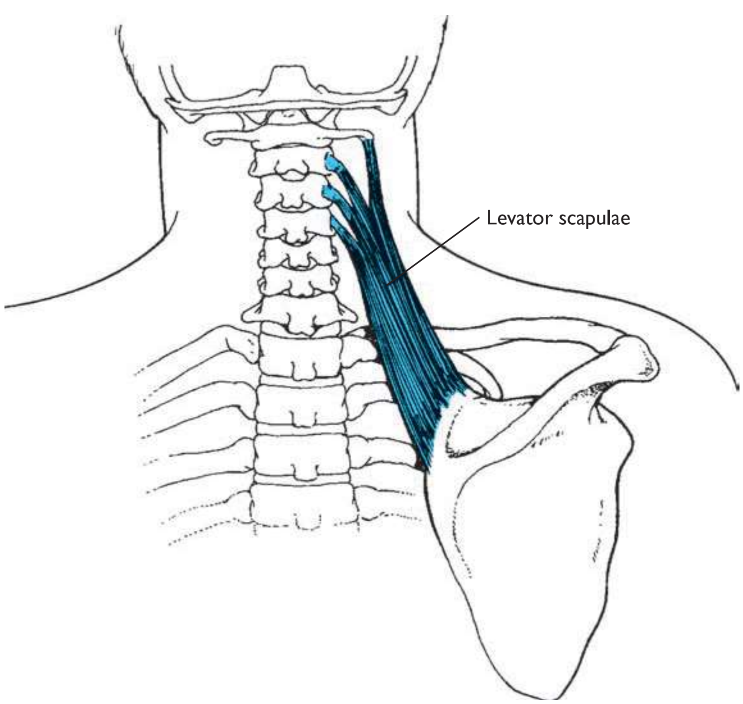


FIGURE 9-25

The levator scapulae.

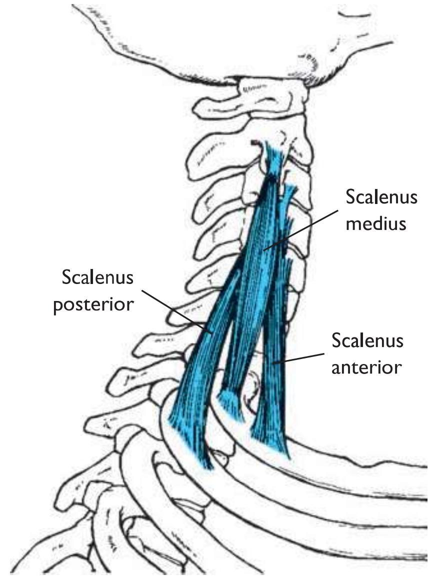


FIGURE 9-26

The scaleni muscles.

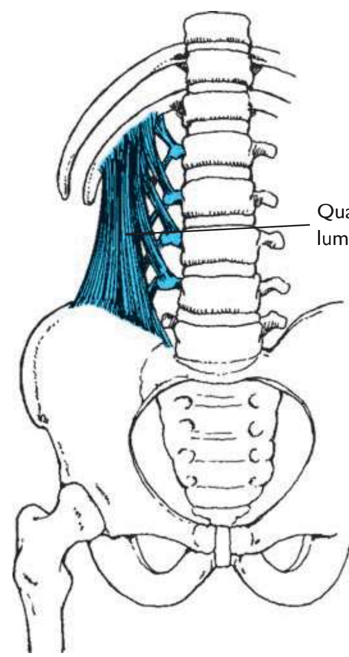


FIGURE 9-27

The quadratus lumborum.

LOADS ON THE SPINE

Forces acting on the spine include body weight, tension in the spinal ligaments, tension in the surrounding muscles, intraabdominal pressure, and any applied external loads. When the body is in an upright position, the major form of loading on the spine is axial. In this position, body weight, the weight of any load held in the hands, and tension in the surrounding ligaments and muscles all contribute to spinal compression.

During erect standing, the total-body center of gravity is anterior to the spinal column, placing the spine under a constant forward-bending moment (Figure 9-29). To maintain body position, this torque must be counteracted by tension in the back extensor muscles. As the trunk or the arms are flexed, the increasing moment arms of these body segments

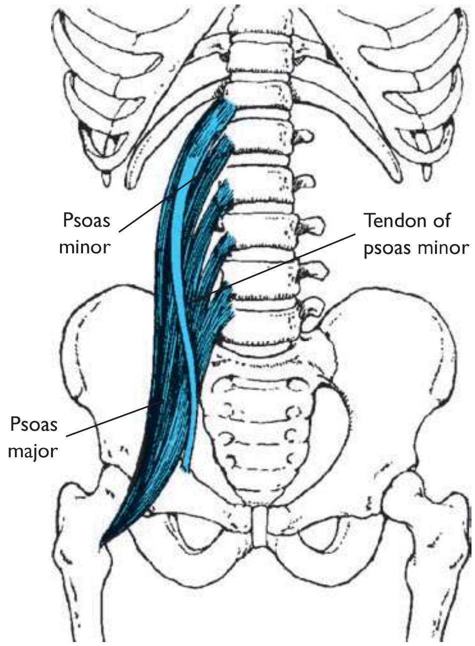


FIGURE 9-28

The psoas muscle.

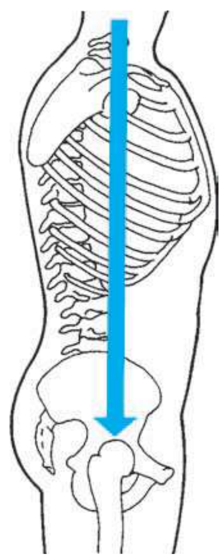


FIGURE 9-29

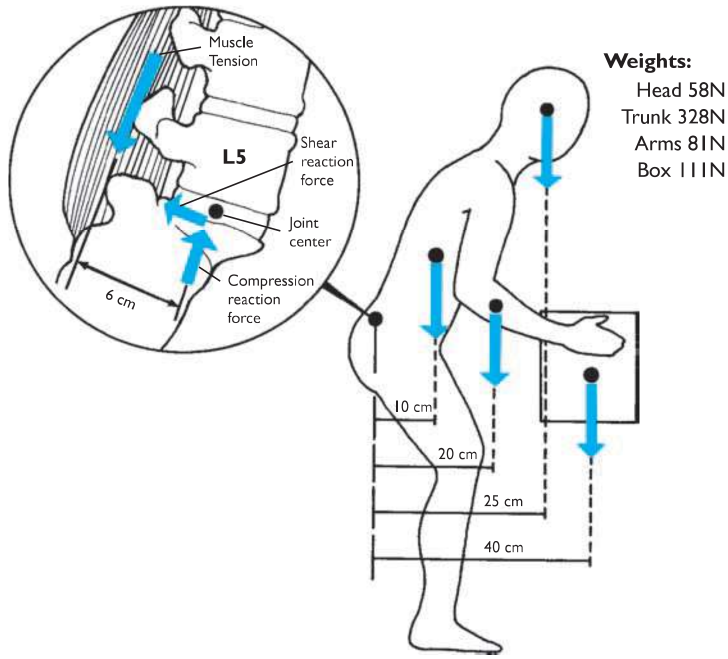
Because the line of gravity for the head, trunk, and upper extremity passes anterior to the vertebral column, a forward torque acts on the spine.

contribute to increasing flexor torque and increasing compensatory tension in the back extensor muscles (Figure 9-30). Because the spinal muscles have extremely small moment arms with respect to the vertebral joints, they must generate large forces to counteract the torques produced about the spine by the weights of body segments and external loads (see Sample Problem 9.1). Consequently, the major force acting on the spine is usually that derived from muscle activity (105). In comparison to the load present during upright standing, compression on the lumbar spine increases with sitting, increases more with spinal flexion, and increases still further with a slouched sitting position (Figure 9-31). During sitting, the pelvis rotates backward and the normal lumbar lordosis tends to flatten, resulting in increased loading on the intervertebral discs (126). A slumped sitting posture increases disc loading even more (126). Ergonomically designed chairs that provide lumbar support and enable slight forward tilting of

• *Because the spinal muscles have small moment arms, they must generate large forces to counteract the flexion torques produced by the weight of body segments and external loads.*

FIGURE 9-30

The back muscles, with a moment arm of approximately 6 cm, must counter the torque produced by the weights of body segments plus any external load. This illustrates why it is advisable to lift and carry heavy objects close to the trunk.



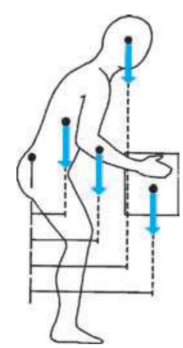
Torque at L5,S1 vertebral joint created by body segments and load:
T = (328 N)(10 cm) + (81 N)(20 cm) + (58 N)(25 cm) + (111 N)(40 cm)
= 10,790 Ncm

SAMPLE PROBLEM 9.1

How much tension must be developed by the erector spinae with a moment arm of 6 cm from the L5-S1 joint center to maintain the body in a lifting position with segment moment arms as specified? (Segment weights are approximated for a 600 N (135 lb) person.)

Known

SEGMENT	WT	MOMENT ARM
head	50 N	22 m
trunk	280 N	12 cm
arms	65 N	25 cm
box	100 N	42 cm
F_m		6 cm



Solution

When the body is in a static position, the sum of the torques acting at any point is zero. At L5-S1:

$$\Sigma T_{L5,S1} = 0$$
$$0 = (F_m)(6 \text{ cm}) - [(50 \text{ N})(22 \text{ cm}) + (280 \text{ N})(12 \text{ cm}) + (65 \text{ N})(25 \text{ cm}) + (100 \text{ N})(42 \text{ cm})]$$
$$0 = (F_m)(6 \text{ cm}) - 10{,}285 \text{ Ncm}$$
$$\boxed{F_m = 1714 \text{ N}}$$

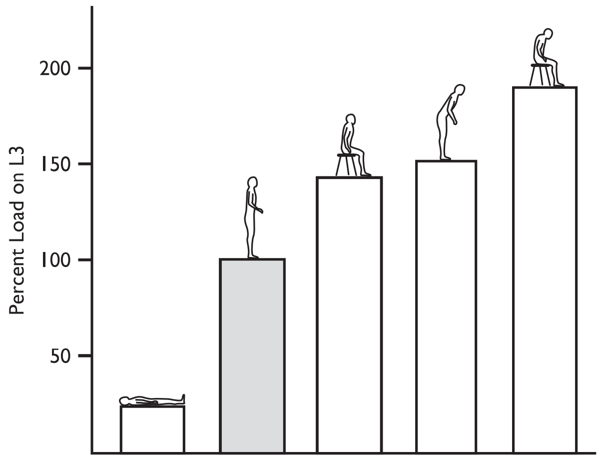


FIGURE 9-31

The load on the third lumbar disc during upright standing (100%) is markedly reduced in a supine position, but increases for each of the other positions shown.
Adapted from Nachemson A: Towards a better understanding of back pain: a review of the mechanics of the lumbar disc, Rheumatol Rehabil, 14:129, 1975.

the seat such that more weight is supported by the thighs have been shown to reduce the load on the spine (76).

Pressure within the intervertebral discs changes significantly with body position and loading, but is relatively consistent through the different regions of the spine (97). During static loading, the discs deform over time, transferring more of the load to the facet joints (30). After 30 minutes of dynamic repetitive spinal flexion, such as might occur with a lifting task, the general stiffness of the spine is decreased, and deformation of the discs in combination with elongation of the spinal ligaments results in altered loading patterns that may predispose the individual to low back pain (95).

During erect standing, body weight also loads the spine in shear. This is particularly true in the lumbar spine, where shear creates a tendency for vertebrae to displace anteriorly with respect to adjacent inferior vertebrae (Figure 9-32). Because very few of the fibers of the major spinal extensors lie parallel to the spine, as tension in these muscles increases, both compression and shear on the vertebral joints and facet joints increase (73). Fortunately, however, the shear component produced by muscle tension in the lumbar region is directed posteriorly, so that it partially counteracts the anteriorly directed shear produced by body weight (99). Shear is

• *Body weight produces shear as well as compression on the lumbar spine.*

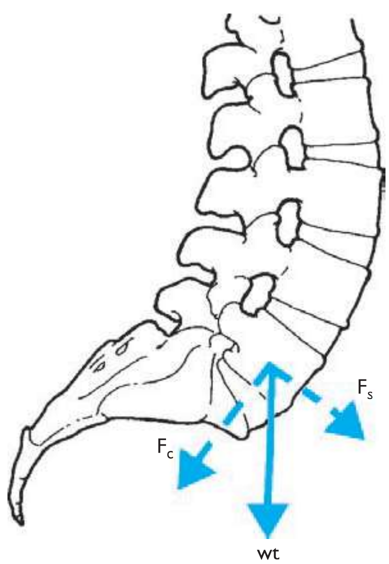


FIGURE 9-32

Body weight during upright standing produces shear (F_s) as well as compression (F_c) components on the lumbar spine. (Note that the vector sum of F_s and F_c is wt.)

a dominant force on the spine during flexion as well as during activities requiring backward lean of the trunk, such as rappelling and trapezing during sailing (54). Although the relative significance of compression and shear on the spine is poorly understood, excessive shear stress is believed to contribute to disc herniation.

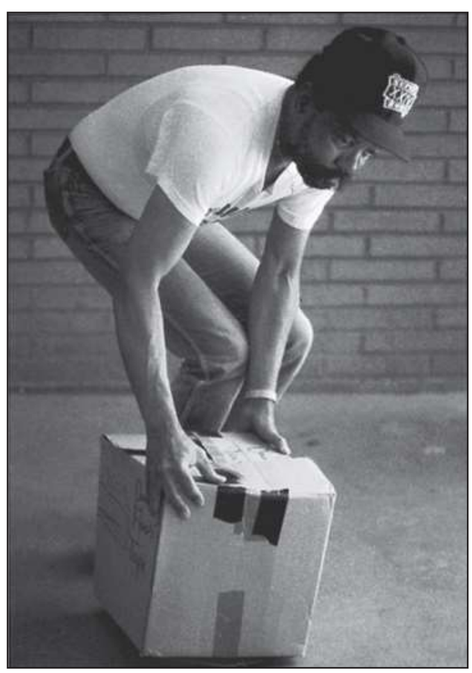
Tension in the trunk extensors increases with spinal flexion until the spine approaches full flexion, when it abruptly disappears. This has been shown to occur at 57% of maximum hip flexion and at 84% of maximum vertebral flexion (51). At this point, the posterior spinal ligaments completely support the flexion torque. The quiescence of the spinal extensors at full flexion is known as the flexion relaxation phenomenon. Unfortunately, when the spine is in full flexion, tension in the interspinous ligament contributes significantly to anterior shear force and increases facet joint loading (79). During repeated trunk flexion and extension movements over time, the flexion relaxation period is lengthened, which reduces lumbar stability and may predispose the individual to low back pain (91).

flexion relaxation phenomenon
condition in which, when the spine is in full flexion, the spinal extensor muscles relax and the flexion torque is supported by the spinal ligaments

• *Lateral flexion and rotation create much larger spinal loads than do flexion and extension.*

When the spine undergoes lateral flexion and axial twisting, a more complex pattern of trunk muscle activation is required than for flexion and extension. Researchers estimate that, whereas 50 Nm of extension torque places 800 N of compression on the L4-L5 vertebral joint, 50 Nm of lateral flexion and axial twisting torques respectively generate 1400 N and 2500 N of compression on the joint (81). Information derived from biomechanical modeling of the spine suggests that tension in antagonist trunk muscles produces a significant part of these increased loads (79). Asymmetrical frontal plane loading of the trunk also increases both compressive and shear loads on the spine because of the added lateral bending moment (39, 82).

Another factor affecting spinal loading is body movement speed. It has been shown that executing a lift in a rapid, jerking fashion dramatically increases compression and shear forces on the spine, as well as tension in the paraspinal muscles (52). This is one of the reasons that resistance-training exercises should always be performed in a slow, controlled fashion.



Lifting while twisting should be avoided because it places about three times more stress on the back than lifting in the sagittal plane.

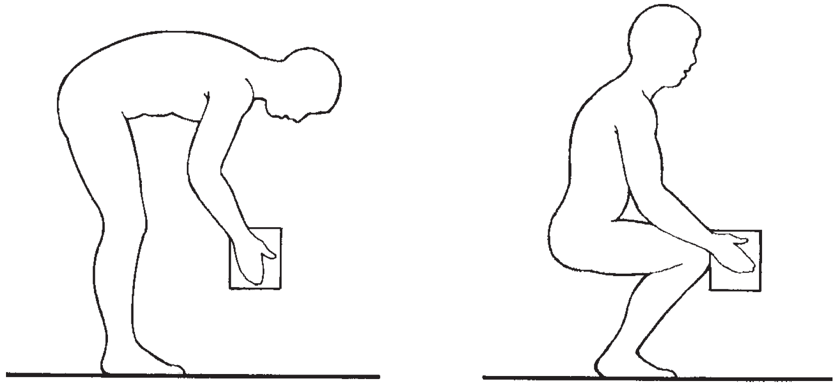
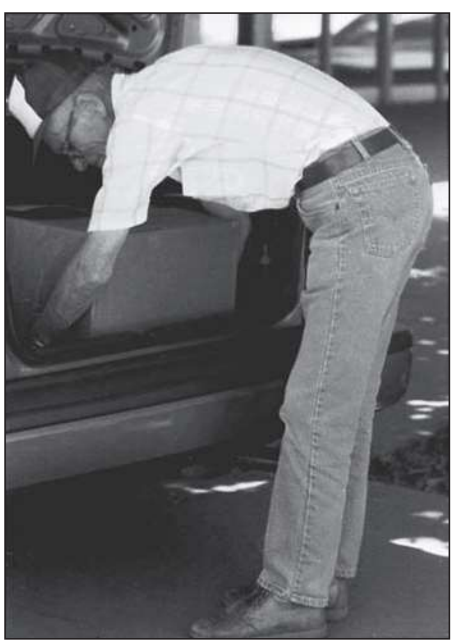


FIGURE 9-33

It is advisable to maintain normal lumbar curvature rather than allowing the lumbar spine to flex when lifting, as discussed in the text.

Maximizing the smoothness of the motion pattern of the external load acts to minimize the peaks in the compressive force on the lumbosacral joint (60). However, when lifting moderate loads that are awkwardly positioned, skilled workers may be able to reduce spinal loading by initially jerking the load in close to the body and then transferring momentum from the rotating trunk to the load (see Chapter 14) (81).

The old adage to lift with the legs and not with the back refers to the advisability of minimizing trunk flexion and thereby minimizing the torque generated on the spine by body weight. However, either the physical constraints of the lifting task or the added physiological cost of leg-lifting as compared to back-lifting (49) often make this advice impractical. Research suggests that a more important focus of attention for people performing lifts may be maintaining the normal lumbar curve, rather than either increasing lumbar lordosis or allowing the lumbar spine to flex (Figure 9-33) (79). Maintaining a normal or slightly flattened lumbar curve enables the active lumbar extensor muscles to partially offset the anterior shear produced by body weight (as discussed), and uniformly loads the lumbar discs rather than placing a tensile load on the posterior annulus of these discs (106). A lordotic lumbar posture, alternatively, increases loading of the posterior annulus and facet joints, while full lumbar flexion changes the line of action of the lumbar extensor muscles, such that they cannot



Many activities of daily living are stressful to the low back. The constraints of the automobile trunk make it difficult to lift with the spine erect.

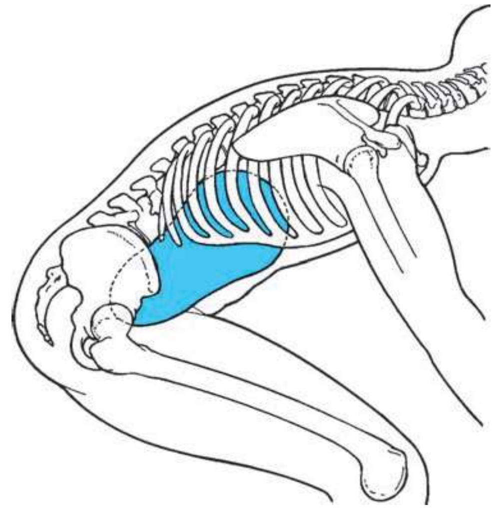


FIGURE 9-34

Intraabdominal pressure, which often increases during lifting, contributes to the stiffness of the lumbar spine to help prevent buckling.

intraabdominal pressure
pressure inside the abdominal cavity; believed to help stiffen the lumbar spine against buckling

effectively counteract anterior shear (36, 80). Anterior shear load on the lumbar spine has been associated with increased risk of back injury (80).

A factor once believed to alleviate compression on the lumbar spine is intraabdominal pressure. Researchers hypothesized that intraabdominal pressure works like a balloon inside the abdominal cavity to support the adjacent lumbar spine by creating a tensile force that partially offsets the compressive load (10) (Figure 9-34). This was corroborated by the observation that intraabdominal pressure increases just prior to the lifting of a heavy load (52). More recently, however, scientists have discovered that pressure in the lumbar discs actually increases when intraabdominal pressure increases (84). It now appears that increased intraabdominal pressure may help to stiffen the trunk to prevent the spine from buckling under compressive loads (31). When an unstable load is assumed, there is also increased coactivation of antagonistic trunk muscles to contribute to spinal stiffening (122). Research has shown that increases in intraabdominal pressure generate proportional increases in trunk extensor moment (58). This is of value in performing a task such as lifting, because the spinal extensor muscles must generate sufficient extensor moment to overcome the flexion moment generated by the forward lean of the trunk, as well as by the load in front of the body being lifted.

Carrying a loaded book bag or backpack loads the spine, with heavier loads resulting in postural adjustments including forward trunk and head lean and reduced lumbar lordosis. Research shows that placing the load low within the backpack and limiting the load to no more than 15% body weight minimizes these postural adaptations (19, 33).

COMMON INJURIES OF THE BACK AND NECK

Low Back Pain

Low back pain is an extremely prevalent problem, with up to 85% of people experiencing low back pain at some time during their lives and more than half of the population having had back pain (5). That is, at any given time, approximately 35% of people have not yet had back pain, but will have it in the future. Low back pain is second only to the common cold in causing absences from the workplace, and back injuries are the most frequent and the most expensive of all worker's compensation claims in the

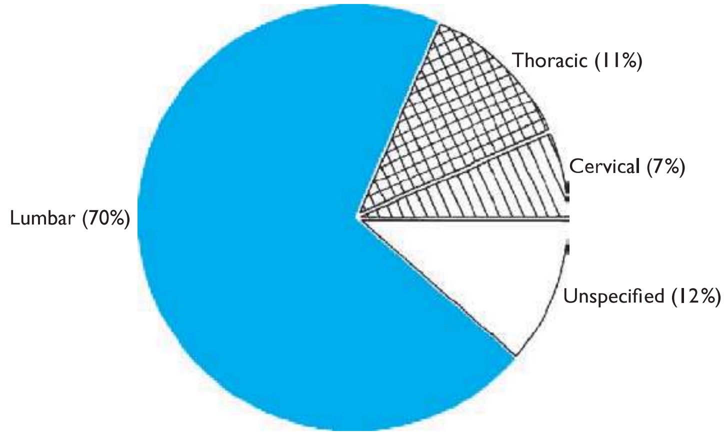


FIGURE 9-35

The majority of back injuries that result in lost work time involve the lumbar region.

United States (29, 86). Moreover, the incidence of low back pain in the United States has been steadily increasing for more than the past decade (46). This is likely a direct result of the increasing incidence of overweight and obesity, which is significantly associated with low back pain in both men and women and at all ages (56, 57). Most back injuries also involve the lumbar or low back region (Figure 9-35).

Although psychological and social components are a factor in some low back pain cases, mechanical stress typically plays a significant causal role in the development of low back pain (47). Perhaps because of their predominance in occupations involving the handling of heavy materials, men experience low back pain about four times more frequently than do women (71). However, some female-dominated groups, such as nurses' aides, register higher rates of low back injury than do male workers in general (111).

The incidence of low back pain in children is nearly 30% (40). This incidence increases with age and by age 16 approaches that found in adults, with back pain more common in boys than in girls (22). In contrast to the situation for adults, however, low back pain in children is associated with increased physical activity and stronger back flexor muscles (87). The main causes of low back pain in children are believed to be musculotendinous strains and ligamentous sprains (87).

Not surprisingly, athletes have a much higher incidence of low back pain than do nonathletes, with over 9% of college athletes in different sports receiving treatment for low back pain (55, 79, 85). In some sports, such as gymnastics, as many as 85% of the participants experience low back pain (116, 117).

High incidences of low back pain have been found in workers who sit for prolonged periods and in those unable to sit at all during the work day (75). High-risk occupations for the development of low back pain, in order of frequency, include laborers, truck drivers, garbage collectors, warehouse workers, mechanics, nursing aides, materials handlers, lumber workers, practical nurses, and construction laborers (110). Cigarette smokers have an increased incidence of low back pain compared to nonsmokers, possibly due to the contributions of habitual smoking to disc degeneration (44). Accidental low back pain is often associated with working in an unnatural posture, with sudden and unexpected motions, and with working single-handed (3, 131). Work involving dynamic motion in multiple planes is also associated with significantly increased risk for developing low back pain (34).

As discussed in Chapter 3, loading patterns that injure biological tissues may involve one or a few repetitions of a large load or numerous repetitions of a small load. Repeated loading, such as that which occurs in industrial work, in exercise performance, and in jobs such as truck driving that involve vibration, can all produce low back pain.

A factor recently implicated in our evolving understanding of low back injuries is the relative stability of the spine. In the absence of contraction of the surrounding musculature, buckling of the lumbar spine occurs under compressive loads as small as 4 N (41). Although bone structure, intervertebral discs, and ligaments all contribute to spinal stability, it is the surrounding muscles that have been shown to be the primary contributors to spinal stability (41). Recent research suggests that coactivation of spinal agonists and antagonists serves to increase the stiffness of the motion segments and enhance spinal stability (48, 50). Only relatively modest levels of coactivation of the paraspinal and abdominal wall muscles are needed to provide adequate spinal stability for daily living tasks, however (32). Accordingly, McGill advocates training the trunk muscles for endurance rather than for strength as a prophylactic for low back injury (78). Fatigue of the spinal extensor muscles with concomitantly reduced force output has been shown to increase the bending moment on the lumbar spine and also to reduce the ability of these muscles to protect the spine (36, 37).

Although injuries and some known pathologies may cause low back pain, 60% of low back pain is idiopathic, or of unknown origin. The risk factors for chronic disability due to low back pain include involvement of the spinal nerve roots, substantial functional disability, widespread pain, and previous injury with an extended absence from work (120). However, most low back pain is self-limiting, with 75% of cases resolving within three weeks and a recovery rate of over 90% within two months, whether treatment occurs or not (25).

Despite this fact, clinicians often recommend abdominal exercises as both a prophylactic and a treatment for low back pain. The general rationale for such prescriptions is that weak abdominal muscles may not contribute sufficiently to spinal stability. However, sit-up-type exercises, even when performed with the knees in flexion, generate compressive loads on the lumbar spine of well over 3000 N (78). According to one clinical report, the use of sit-up exercises appears to have actually contributed to low back pain development among a group of 29 exercisers (83). Partial curl-up exercises have also been advocated as providing strong abdominal muscle challenge, with minimal spinal compression (9).

Soft-Tissue Injuries

Contusions, muscle strains, and ligament sprains collectively compose the most common injury of the back, accounting for up to 97% of all back pain in the general population (4). These types of injuries typically result from either sustaining a blow or overloading the muscles, particularly those of the lumbar region. Painful spasms and knotlike contractions of the back muscles may also develop as a sympathetic response to spinal injuries, and may actually be only symptoms of the underlying problem. Researchers believe that a biochemical mechanism is responsible for these sympathetic muscle spasms (21), which act as a protective mechanism to immobilize the injured area (102).

Acute Fractures

Differences in the causative forces determine the type of vertebral fracture incurred. Transverse or spinous process fractures may result from extremely forceful contraction of the attached muscles or from the sustenance of a hard blow to the back of the spine, which may occur during participation in contact sports such as football, rugby, soccer, basketball, hockey, and lacrosse (102). The most common cause of cervical fractures is indirect trauma involving force applied to the head or trunk rather than to the cervical region itself (23). The most common mechanism for catastrophic cervical injuries is an axial force to the top of the head with the neck in slight flexion (118). Fractures of the cervical vertebrae frequently result from impacts to the head when people dive into shallow water or engage in gymnastics or trampolining activities without appropriate supervision (108, 109). In wrestling, there are three common cervical injury scenarios: (a) The wrestler's arms are in a hold, and he is unable to prevent himself from landing on his head; (b) the wrestler attempts to roll, but is landed on by his opponent's full weight, causing a hyperflexion injury of the neck; and (c) the wrestler lands on the top of his head and sustains an axial compression force (15, 16).

Large compressive loads (such as those encountered in the sport of weight lifting or in the handling of heavy materials) can cause fractures of the vertebral end plates. High levels of impact force may result in anterior compression fractures of the vertebral bodies. This type of injury is generally associated with vehicular accidents, although it can also result from contact with the boards in ice hockey, head-on blocks or tackles in football, collisions between baseball catchers and base runners, or impacts during tobogganing, snowmobiling, and hot air ballooning. When a snowmobile drops 4 ft, the forces generated far exceed the level known to cause a compression fracture (67).

Because one function of the spine is to protect the spinal cord, acute spinal fractures are extremely serious, with possible outcomes including paralysis and death. Unfortunately, increased participation in leisure activities is associated with an increased prevalence of spinal injuries (107). Whenever a spinal fracture is a possibility, only trained personnel should move the victim. Spinal stress injuries can also result from repeated sustenance of relatively modest forces, such as heading the ball in soccer. Degenerative changes in the cervical spine of soccer players have been shown to occur 10–20 years earlier than in the general population, with changes more pronounced among those with more years of playing time (132).

Fractures of the ribs are generally caused by blows received during accidents or participation in contact sports. Rib fractures are extremely painful because pressure is exerted on the ribs with each inhalation. Damage to the underlying soft tissues is a potentially serious complication with this type of injury.

Stress Fractures

The most common type of vertebral fracture is a stress fracture of the pars interarticularis, the region between the superior and inferior articular facets, which is the weakest portion of the neural arch (Figure 9-36). A fracture of the pars is termed spondylolysis, with the severity ranging from hairline fracture to complete separation of bone. Although some pars defects may be congenital, they are also known to be caused by mechanical stress. One mechanism of injury appears to involve repeated axial loading of the lumbar spine when it is hyperextended. The prevalence of lumbar spondylolysis in the general population is 11.5%, with approximately three times as many males as females affected (65).

spondylolysis
presence of a fracture in the pars interarticularis of the vertebral neural arch

A bilateral separation in the pars interarticularis, called spondylolisthesis, results in the anterior displacement of a vertebra with respect to the vertebra below it (Figure 9-36). The most common site of this injury is the lumbosacral joint, with 90% of the slips occurring at this level. Spondylolisthesis is often initially diagnosed in children between the ages of

spondylolisthesis
complete bilateral fracture of the pars interarticularis, resulting in the anterior slippage of the vertebra

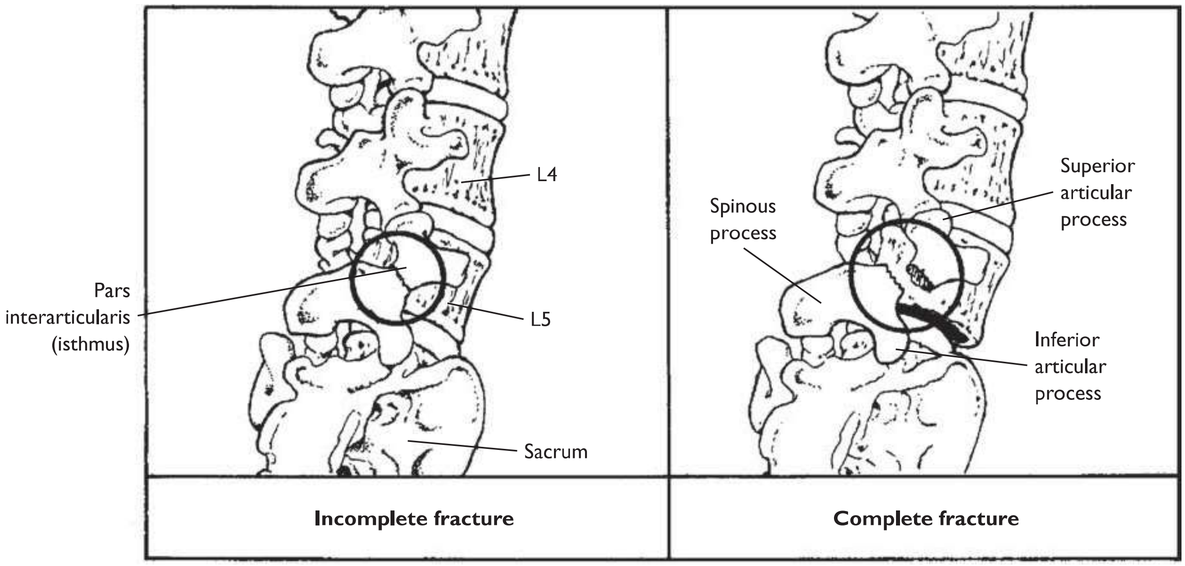


FIGURE 9-36 Stress fractures of the pars interarticularis may occur unilaterally or bilaterally and may or may not result in complete separation.

10 and 15 years, and is more commonly seen in boys. Risk factors for spondylolysis and spondylolisthesis in children include genetics, the growth spurt, repetitive stresses, and participation in sports for more than 15 hours per week (40). The prevalence of spondylolysthesis increases from the fifth through the eighth decades of life and affects approximately three times as many females as males (65).

Unlike most stress fractures, spondylolysis and spondylolisthesis do not typically heal with time, but tend to persist, particularly when there is no interruption in sport participation. Individuals whose sports or positions require repeated hyperextension of the lumbar spine are prime candidates for stress-related spondylolysis. Those particularly susceptible to this pathology include female gymnasts, interior football linemen, and weight lifters, with increased incidences also found among volleyball players, pole-vaulters, wrestlers, figure skaters, dancers, and rowers (92). Degenerative spondylolisthesis is also a common condition of the aging spine, although the causative factors for this condition are unknown (12). A high incidence of spondylolysis has been found in human remains from circa A.D. 1200 to 1500, a period characterized by the use of stone pillars for the construction of houses (6).

•*Stress-related fractures of the pars interarticularis, the weakest section of the neural arch, are unusually common among participants in sports involving repeated hyperextension of the lumbar spine.*

Disc Herniations

The source of approximately 1–5% of back pain is a herniated disc, which consists of the protrusion of part of the nucleus pulposus from the annulus. Disc herniations may be either traumatic or stress related, but only occur in discs that show signs of previous degeneration (62). The most common sites of protrusions are between the fifth and sixth and the sixth and seventh cervical vertebrae, and between the fourth and fifth lumbar vertebrae and the fifth lumbar vertebra and the first sacral vertebra (68, 69). Most occur on the posterior or posterior-lateral aspect of the disc (8).

•*The term* slipped disc *is often used to refer to a herniated or prolapsed disc. It is a misnomer, because the discs as intact units do not slip around.*

Although the disc itself is not innervated and therefore is incapable of generating a sensation of pain, sensory nerves do supply the anterior and posterior longitudinal ligaments, the vertebral bodies, and the articular cartilage of the facet joints (24). If the herniation presses on one or more of these structures, on the spinal cord, or on a spinal nerve, pain or numbness may result.

Disc herniations do not cause a significant decrease in intervertebral space height, and so cannot be effectively detected through X-rays. The average decrease in the height of a disc that has undergone a herniation is less than that reported in normal daily disc height variation (59). Most lumbar disc herniations are treated conservatively, meaning without surgery. Many individuals have disc herniations without being aware of it, since there are no symptoms. For those who do present with symptoms of pain or minor neural deficits, treatment includes medications, physical therapy, and sometimes lumbar injection (63). More serious cases that fail to respond to conservative treatment options are treated with surgical interventions, often lumbar discectomy.

Whiplash Injuries

Whiplash injury to the cervical region is relatively common, with a reported incidence of 4 per 1000 individuals (42). Such injuries typically occur during automobile collisions, with the neck undergoing sudden acceleration and deceleration. Shear force and extension moment at the junction between the cervical and thoracic spines are the underlying mechanism causing neck motion and potential injury (113). Research suggests that the cervical vertebrae go through a sequence of abnormal motion, although there are different variations to the pattern depending on the direction and speed of the impact, as well as possibly the gender of the individual (20, 66). Generally, however, the cervical spine assumes an S-shape, with the upper segments in flexion and the lower segments in extension (27). The cervical muscles contract rapidly in such situations, with potential for forced eccentric tension development (20). Both upper and lower cervical injuries are possible (94). Symptoms of whiplash injury include neck pain; muscle pain; pain or numbness radiating from the neck to the shoulders, arms, or hands; and, in 50–60% of cases, accompanying headache (18, 96, 115). Women appear to be at greater risk for whiplash injury than men due to less stiffness of the cervical structures (112).

SUMMARY

The spine is composed of 33 vertebrae that are divided structurally into five regions: cervical, thoracic, lumbar, sacral, and coccygeal. Although most vertebrae adhere to a characteristic shape, there is a progression in vertebral size and in the orientation of the articular facets throughout the spinal column.

Within the cervical, thoracic, and lumbar regions, each pair of adjacent vertebrae with the intervening soft tissues is called a motion segment. Three joints interconnect the vertebrae of each motion segment. The intervertebral discs function as shock absorbers at the weight-bearing vertebral joints. The right and left pairs of superior and inferior facet joints significantly influence the movement capabilities of the motion segments at different levels of the spine.

The muscles of the neck and trunk are named in pairs, with one on the left and the other on the right side of the body. These muscles can cause lateral flexion and/or rotation of the trunk when they act unilaterally, and trunk flexion or extension when acting bilaterally.

Forces acting on the spine include body weight, tension in the spinal ligaments, tension in the surrounding muscles, intraabdominal pressure,