CHAPTER 3

Vertebral Column and Epaxial Region of the Body Wall

EMBRYONIC ORIGIN OF VERTEBRAE

We have already learned that the sclerotome cells from two adjacent somites migrate toward the developing spinal cord, surround it, and differentiate into a vertebra. That part of an embryonic vertebra ventral to the spinal cord is called the **centrum** (see Fig. 2-3). As each centrum forms, it envelops and destroys the notochord (a mesodermal rod lying ventral to the neural tube and playing an important role in its induction). Between adjacent centra, notochordal tissue persists as part of the intervertebral disc. Attached to each vertebral centrum is an arch of skeletal tissue that surrounds the developing spinal cord and its coverings (see Fig. 2-3). This is called the **neural arch**, and the space occupied by the spinal cord is called the **vertebral foramen** (Fig. 3-1). At birth the centrum and neural arch are largely ossified, but cartilage still persists between the base of the neural arch and the centrum on each side. In early childhood this so-called **neurocentral synchondrosis** is bridged by bone to form the osseous vertebra. What we call the **body** of a vertebra (see Fig. 3-1) comprises its centrum and the bases of its neural arch.

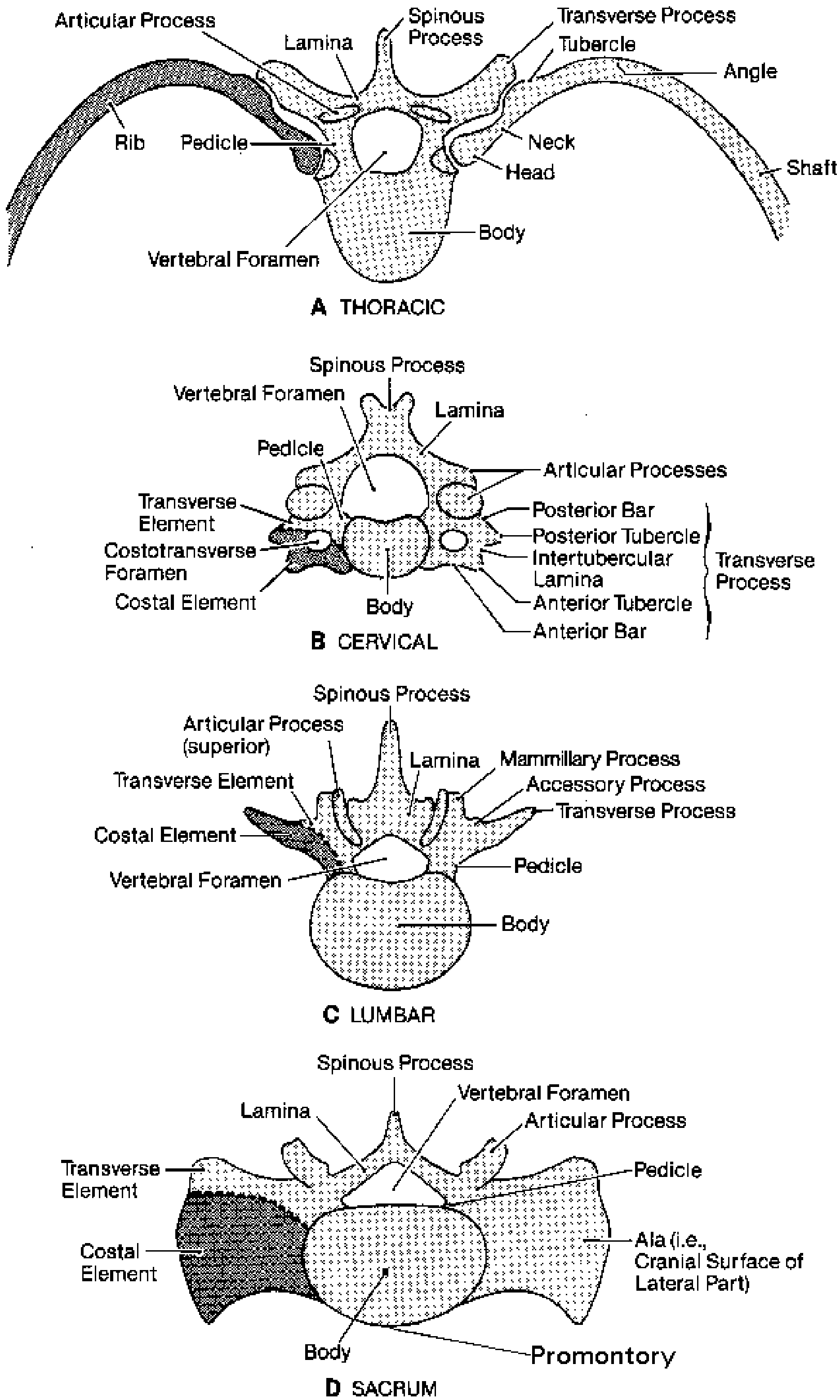

Figure 3–1. Superior views of vertebrae, their processes, and their elements. *A*, Thoracic vertebra and ribs. *B*, Cervical vertebra. *C*, Lumbar vertebra. *D*, Sacrum.

The remainder of the neural arch is called the **vertebral arch** (see Fig. 3-1). Up to the time of puberty, the osseous vertebral body is covered on both its superior and inferior surfaces by a plate of cartilage. After puberty, the margin of each cartilaginous plate ossifies to form the ring-like superior and inferior epiphyses of the vertebral body. These epiphyses fuse with the rest of the body sometime in one's early twenties.

The second cervical vertebra is highly modified from the others. Part of the tissue that should have become the centrum of C1 instead fuses to the upper surface of the centrum of C2, forming a process called the **dens** (Latin for "tooth") or **odontoid** (Greek for "tooth-like") **process** (Fig. 3-2). The first cervical vertebra obviously must be different than a typical cervical vertebra by virtue of the fact that most of its centrum has been given to C2. All that remains of the C1 centrum is an anterior arch with a prominent anterior tubercle (Fig. 3-3). On the inner surface of the anterior arch there will develop an articular facet for the dens of C2.

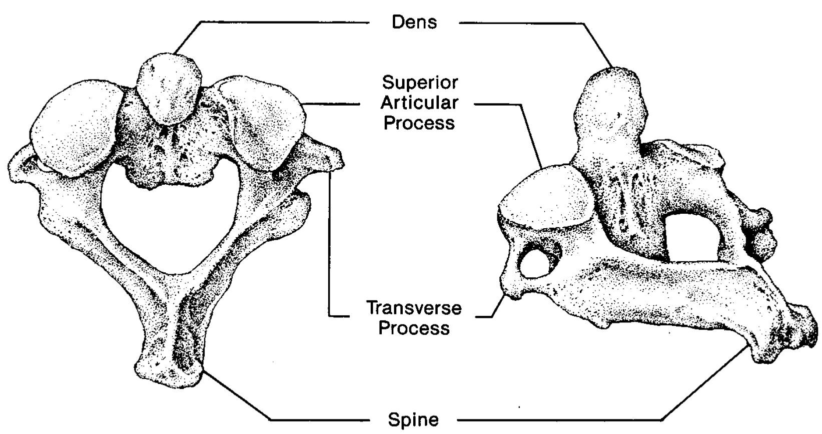

Figure 3–2. Superior view (*at left*) and oblique view (*at right*) of the axis (2nd cervical vertebra).

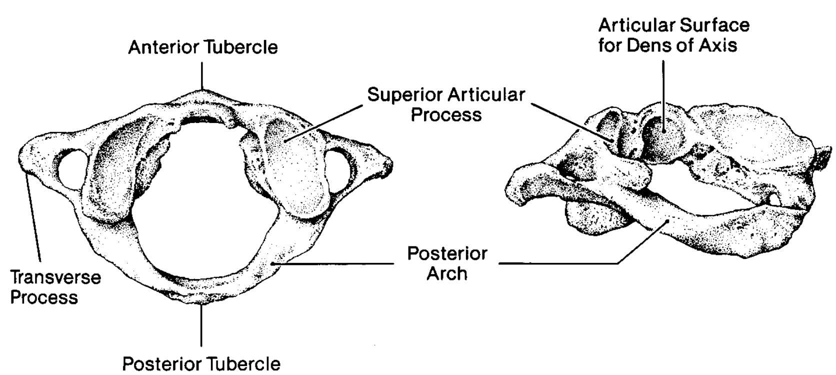

Figure 3–3. Superior view (*at left*) and oblique view (*at right*) of the atlas (1st cervical vertebra).

Because the globe of the skull sits on top of the first cervical vertebra, the latter reminds one of the mythological character Atlas supporting the earth. Hence, C1 is called the **atlas** vertebra. Because the dens of C2 acts as an axis around which C1 rotates, C2 is called the **axis** vertebra.

ADULT VERTEBRAL COLUMN

The **vertebral column** is that structure formed by the entire series of vertebrae (Fig. 3-4). The series of vertebral foramina constitutes the **vertebral canal**. Within the vertebral canal lie the spinal cord and its coverings. Obviously, one function of the vertebral arches is to protect the spinal cord.

The series of vertebral bodies form a pressure-bearing rod that gives rigidity to the trunk. Yet one does not want a completely rigid trunk such as would occur if the bodies of adjacent vertebrae were fused together. Thus, between the bodies of adjacent vertebrae there develops a most clever connective tissue apparatus that both allows intervertebral motion and can sustain high compressive loads. This **intervertebral disc** consists of a central gelatinous core--the **nucleus pulposus** (derived from notochord)--encircled by concentric layers of a densely fibrous connective tissue said to form an **anulus fibrosus** (Fig. 3-5). When any two vertebral bodies are pushed toward each other, they compress the nucleus pulposus. The spread of this gelatinous substance is restrained by the anulus fibrosus. It is obvious that if the anulus fibrosus should ever weaken, the nucleus pulposus may press against the weakened area, either flattening it into a thin sheet and pushing it out beyond the margins of the neighboring intact fibers (so-called **disc prolapse**), or actually rupturing through the anulus (so-called **disc herniation)**. We shall consider the most likely sites of such "slipped" discs and their clinical consequences further on.

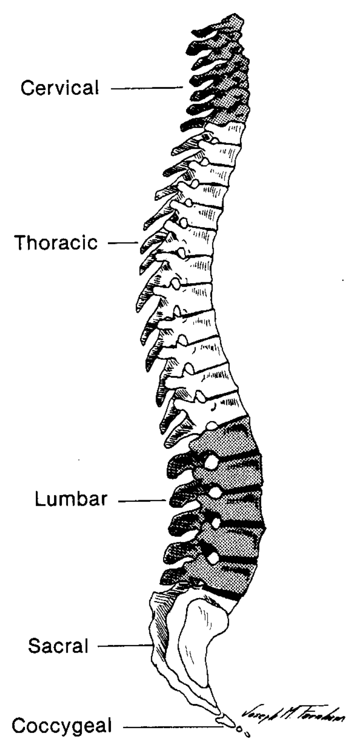

Figure 3–4. Lateral view of articulated vertebral column. (From Norkin and Levangie.[36]) [7]

At birth the entire vertebral column has a gentle curve that is concave on its ventral surface (Fig. 3-6). A ventrally concave curve is called a **kyphosis** but is quite normal at birth. In the thoracic region the kyphosis of the newborn persists throughout life due to the greater height of the thoracic vertebral bodies

[7] Here, and in all future figures that say "From Norkin and Levangie [36]", the complete reference is Norkin CC, Levangie PK. 1983. Joint Structure and Function: A Comprehensive Analysis. FA Davis, Philadelphia.

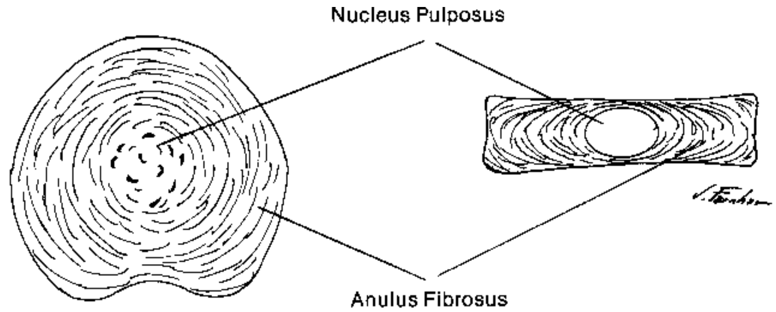

Figure 3-5. Superior view (*at left*) and coronal section (*at right*) of a typical intervertebral disc. (From Norkin and Levangie.[36])

posteriorly. The sacral kyphosis of the newborn also persists into adulthood because it is fixed by fusion of the sacral vertebrae. The ventral concavity of the male sacrum is usually distributed fairly evenly from one end of the bone to the other. In females, the superior end of the sacrum is nearly straight and the kyphosis is marked in the region of S4 and S5. It seems that the straightness of the upper end of the female sacrum causes the bone to be directed more posteriorly, and thus to impinge less on the birth canal.

The kyphoses of the newborn cervical and lumbar regions are soon lost. As the child begins to lift its head, and becoming accentuated when the child starts to sit erect, the intervertebral discs of the cervical region become thicker on their anterior margins and cause the cervical portion of the vertebral column to develop a gentle curve that is concave on its *posterior* surface (see Fig. 3-6). A posterior concavity is called a **lordosis**; thus, a cervical lordosis is a normal product of development. It can be eliminated by flexion of the neck. As the child begins to sit erect, and becoming accentuated as it starts to walk, the lumbar vertebrae and intervertebral discs become thickened at their anterior margins inducing a lumbar lordosis (see Fig. 3-6). As in the neck, flexion of the lumbar column temporarily eliminates the lordosis.

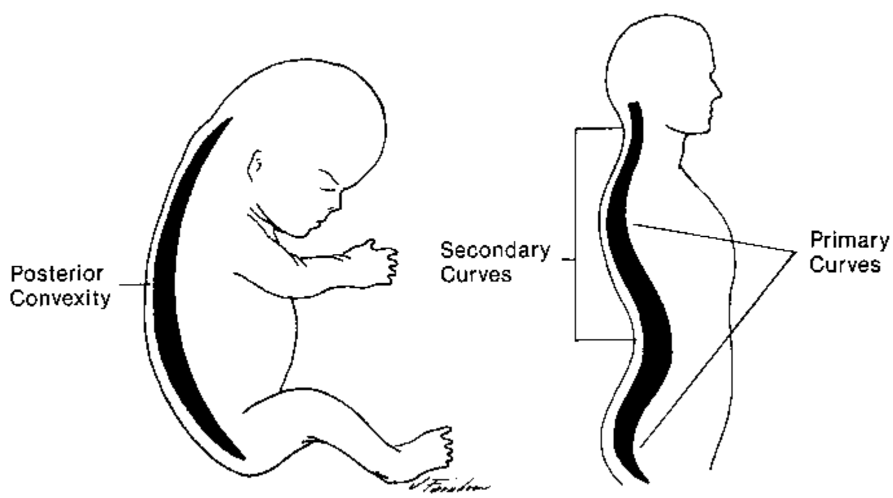

Figure 3-6. Lateral views of neonatal and adult vertebral columns illustrating the change from a single kyphosis at birth to a state in which two lordoses (cervical and lumbar) are interspersed with two kyphoses (thoracic and sacral). (From Norkin and Levangie.[36])

MOVEMENTS OF THE VERTEBRAL COLUMN

The series of vertebral bodies, intervertebral discs, and vertebral arches form a mobile rod that also protects the spinal cord. Yet two other requirements for a useful vertebral column must be met: (1) One should be able voluntarily to produce motion of the column, and (2) there must be mechanisms to restrict excessive movements of any one vertebra upon another. Voluntary motion is achieved by having muscles attach to the vertebral arch and to lever-like processes that extend from it. Prevention of undesirable intervertebral motion is achieved primarily by the development of articular processes (zygapophyses) and intervertebral ligaments.

Lever-Like Processes of Vertebrae (see Fig. 3-1)

Five lever-like processes are formed on a typical vertebra. One, the **spinous process** (**spine**), passes dorsally from the midline of the vertebral arch. Two additional processes, one on the right and one on the left, pass laterally from the sides of the vertebral arch. These are called **transverse processes**. The formation of transverse processes permits us to distinguish two portions of the vertebral arch. The region that runs from the body to the transverse process is called the **pedicle**; that which runs from the transverse process to the spine is called the **lamina**. The ventral and dorsal roots of each spinal nerve, ensheathed in a single dural covering (see further on), pass out of the vertebral canal between the pedicles of adjacent vertebrae (Fig. 3-7). This "interpedicle" space is called the **intervertebral foramen**. Its anterior border is formed by the lower part of a vertebral body and its subjacent disc (see Fig. 3-7). The dorsal root ganglion is located within the intervertebral foramen, thus between the pedicles of adjacent vertebrae (except for sacral nerves whose dorsal root ganglia are within the vertebral canal).

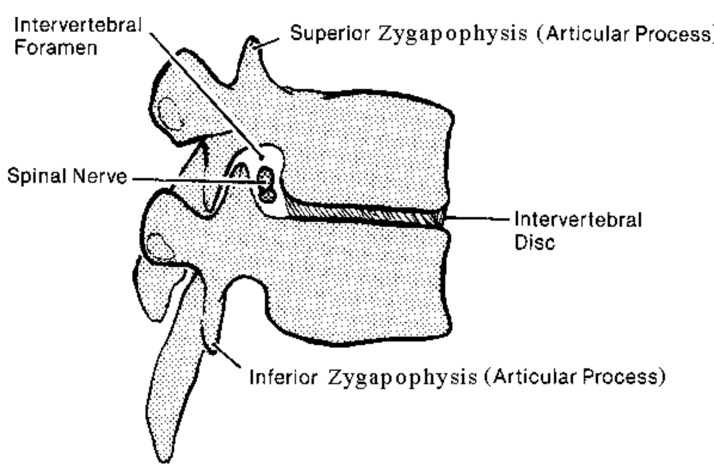

Figure 3–7. Lateral view of two articulated thoracic vertebrae illustrating the position of the spinal nerve within the intervertebral foramen.

Every vertebra has two additional lever-like processes. These are the **costal processes**. On each side, sclerotome cells migrate laterally from the base of the embryonic neural arch to form a costal process (see Fig. 2-3). In the chest this migration is extensive, carrying such cells far beyond the tip of the developing transverse process and all the way around to the front of the embryo. These long thoracic costal processes develop a separate ossification center and become ribs (see Fig. 3-1*A*). A joint forms between a thoracic costal process and the base of the neural arch from which it grew. Since, after birth, the bases of the neural arch become incorporated into the vertebral body, this joint will lie between the rib and the vertebral body. The part of the rib that articulates with the vertebral body is called its **head**;

the joint is called the **capitular joint** of the rib[8]. A second joint forms between the costal process and tip of the transverse process of the vertebra. This is the **costotransverse joint**. The bump on the rib that articulates with the transverse processes is called the **tubercle**. Between the head and tubercle of a rib is its **neck**. Beyond the tubercle is the **shaft**. The space between the neck of a rib and the transverse process of its corresponding vertebra is occupied by a ligament.

Specializations of Costal, Transverse, and Spinous Processes in Cervical Vertebrae (see Fig. 3-1)

The extraordinary development of a costal process into a rib is normally limited to the chest. In the cervical region a costal process never grows much beyond the tip of the transverse process (see Fig. 3-1*B*). Furthermore, capitular and costotransverse joints do not form. In other words, the head of such a cervical "rib" is fused to the body of the vertebra, and the "tubercle" of such a cervical "rib" is fused to the tip of the transverse process. The gap between the neck of this cervical costal process and the transverse process persists as a **costotransverse foramen** (see Fig. 3-1*B*).

Because the costal and transverse processes of a cervical vertebra are joined, most texts refer to the ensemble as a **cervical transverse process with costal and transverse elements**. The costotransverse foramen may be referred to simply as the **transverse foramen**. The tubercle of the costal element is called the **posterior tubercle** of the transverse process. The head of the costal element comprises the **anterior bar** and **anterior tubercle** of a cervical transverse process. The neck of the costal element is called the **intertubercular lamina** (or sometimes, incorrectly, the costotransverse bar). The transverse element of a cervical vertebra is represented only by the posterior bar of its transverse process.

The relationships of soft tissue structures to the costal element of the cervical vertebra are the same as the relationships of soft tissue structures to a rib. Thus, as the ventral ramus of a thoracic spinal nerve passes between the necks of adjacent ribs to get to the ventrolateral body wall, the ventral ramus of a cervical nerve passes between adjacent intertubercular laminae. The dorsal ramus of a thoracic nerve passes between adjacent transverse processes of thoracic vertebrae to enter the back; the dorsal ramus of a cervical nerve passes between the posterior bars of adjacent cervical transverse processes. The muscles that attach to costal elements of cervical vertebrae are serially homologous to those that attach to ribs.

The lever-like processes of the first and last cervical vertebrae are sufficiently different from the others to deserve special mention. Because no powerful back muscles reach as high as C1, its spine is abortive and exists only as the so-called **posterior tubercle** of the atlas (not at all homologous to the posterior tubercles of cervical transverse processes). Whereas most cervical vertebrae have short bifid spines, the 7th cervical vertebra has an unusually long and nonbifid spine. When the neck is flexed, this spine bulges out the skin at the nape of the neck. For this reason C7 is called the **vertebra prominens**.

> If it is necessary to identify the spine of a specific thoracic vertebra on a patient, the patient should be asked to bend the neck forward so that the examiner may count downward from the easily recognizable spine of C7. Counting upward to identify higher cervical spines is difficult, since the 6th cervical spine may or may not be palpable, and the higher ones are not.

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[8] Actually, the capitular joint of any rib from the 2nd through the 10th involves only the upper edge of its corresponding vertebra and "spreads out" to include the lower edge of the vertebra above. The joint space is then broken into two cavities by a ligament that runs from the middle of the rib head to the intervertebral disc.

The anterior tubercles of the transverse processes of C7, C2, and C1 are poorly developed because they receive few muscular attachments. In fact, that of C1 is so tiny a bump that the transverse process of the atlas is not considered to have two tubercles. The entire tip of the atlas transverse process is composed of an enlarged "posterior tubercle" that extends further laterally than do the posterior tubercles of the lower cervical vertebrae. As mentioned previously, the terms "anterior tubercle" and "posterior tubercle," when applied to the atlas, refer to bumps projecting from the middle of the anterior and posterior arches, respectively.

Specializations of the Bodies of Cervical Vertebrae 3 - 7

Projecting superiorly from the upper surfaces of cervical vertebral bodies 3 - 7 are lateral lips that “grasp” the next higher vertebral body and actually form joints with it. These are called **unciform** processes and joints, but I don’t know what significance they have.

Specializations of Costal and Transverse Processes in Lumbar Vertebrae

The transverse process of a lumbar vertebra is also a compound structure formed of transverse and costal elements, with the latter predominating (see Fig. 3-1*C*). A lumbar costal element is completely fused to both the pedicle of the vertebral arch and to the projecting, but small, transverse element. Thus, no costotransverse foramen exists. The tip of the transverse element is represented by a little bump that is called the **accessory process**.

Specializations of Sacral Vertebrae

In the sacral region as in the lumbar region, fusion of the costal element to the pedicle and transverse element is complete (see Fig. 3-1*D*). Furthermore, the body and laminae of one sacral vertebra are fused to those of the adjacent sacral vertebrae. Clearly, this has occurred so as to provide a rigid structure for transmitting weight to the pelvis and for giving a solid origin to important back muscles. It is instructive to remember that sacral pedicles cannot fuse, otherwise the intervertebral foramen passing the spinal nerve would be occluded.

The laminae of the 4th and 5th sacral vertebra are abortive in development. Obviously, when laminae fail to form, so must spines. Thus, there is formed a gap in the dorsum of the sacrum at its lower end. The gap is called the **sacral hiatus**. The sacral hiatus is subcutaneous, and there was a time when it was used to gain access to the sacral vertebral canal for the purpose of producing anesthesia of the lower sacral nerves (see below).

The sacral spines that do exist (1-3) are not fused; instead they form a series of short bumps called the **median sacral crest**. Although the tips of the transverse elements of sacral vertebra are fused (forming the **lateral sacral crest**), a hole persists between the shafts of adjacent sacral transverse elements to allow passage of the dorsal rami of spinal nerves. Each such gap is called a **dorsal sacral foramen**. Similarly, a gap persists between the "necks" of adjacent sacral costal elements to allow passage of ventral rami of sacral nerves. These gaps are the **ventral sacral foramina**.

On each side of the sacrum, the lateral surfaces of the fused costal elements of S1-S3 form an L-shaped region for articulation with the os coxae (see Chapter 10). This is called the **auricular surface** because of its supposed resemblance to an ear. The costal elements of S1 are often referred to as the **alae** of the sacrum, since they look like wings when the superior aspect of the bone is viewed. The anterosuperior margin of the body of S1 is called the **promontory**, because it is the most forward-projecting part of the bone.

Mechanisms for Restricting Undesirable Vertebral Motion

The job of preventing excessive movement between vertebrae is accomplished by two general mechanisms: (1) the development of articular processes between adjacent vertebral arches and (2) the development of ligaments between adjacent vertebral bodies, vertebral arches, and lever-like processes. In the thoracic region of the vertebral column, these mechanisms are further aided by overlapping of the obliquely disposed spinous processes (see Fig. 4-17), which limits extension, and by the pronounced development of the costal processes (i.e., ribs), which have a very restrictive effect on all movements. In the sacral region, the two general mechanisms of movement restriction are superseded by fusion of the vertebrae.

Articular Processes (Zygapophyses) and Interarticular (Zygapophyseal, Facet[9]) Joints

Vertebrae send **superior articular processes** (**superior zygapophyses**) upward from their vertebral arches and **inferior articular processes** (**inferior zygapophyses**) downward from their vertebral arches (see Fig. 3-7). The superior zygapophyses emanate from the arch at the junction of its laminae and pedicles. The origin of an inferior zygapophysis is from the lamina-pedicle junction in the cervical vertebrae, but from the lamina for thoracic and lumbar vertebrae. Excluding those of the sacrum, the superior articular processes of any one vertebra form true synovial **interarticular (zygapophyseal) joints** with the inferior articular processes of the next higher vertebra. The spinal nerve, passing through the "interpedicle space," runs just in front of the zygapophyseal joint (see Fig. 3-7). Arthritis of this joint may result in bony spicules that press upon the nerve.

In the sacral region, the articular processes of adjacent vertebrae are fused, forming a series of bumps on the back of the bone between the median sacral crest (spines) and the lateral sacral crest (tips of transverse elements). This series of bumps is said to constitute an **intermediate sacral crest**. The lower portions of the two intermediate sacral crests form the borders of the sacral hiatus and are called **sacral cornua**.

The presence of zygapophyseal joints actually serves to restrict certain motions between vertebrae. Exactly which motions are restricted depends on the planes of the joint surfaces. For example, in the lumbar region, joints between articular processes lie in a sagittal plane. This permits a considerable amount of flexion/extension and even lateral flexion, but rotation between lumbar vertebrae is virtually prohibited. In the cervical region, the joints between articular processes lie halfway between a coronal and transverse plane (i.e., face posterosuperiorly). Such an orientation allows a moderate amount of movement in all directions, with flexion/extension and lateral flexion being somewhat freer than rotation. The planes of the joints between articular processes of thoracic vertebrae are almost coincident with a coronal plane and really pose very little hindrance to movement, especially rotation and lateral flexion. However, the attachment of thoracic vertebrae to ribs and the overlapping of the thoracic spines restrict movement between thoracic vertebrae to such a great extent that the freedom offered by the zygapophyseal joint orientation is more or less irrelevant.

The superior zygapophysis of C2 and the inferior zygapophysis of C1 differ from those of all lower vertebrae in that they come from the site where the costal element meets the base of the neural arch (see Figs. 3-2 and 3-3), rather than from the vertebral arch further posteriorly. This change in location causes the second cervical spinal nerve to pass posterior to the zygapophyseal joint between C1 and C2, rather than anterior to it, as occurs for lower nerves. The planes of the zygapophyseal joints between C1 and C2 are also entirely different from the planes of lower cervical zygapophyseal joints. Each atlanto-axial joint lies almost in a transverse plane (but a little lower laterally than medially) and permits extensive rotation between the atlas and axis.

The superior articular processes of C1 are shallow cup-shaped structures (see Fig. 3-3) that receive the bulbous condyles of the occipital bone. They too are located at the junctions of the costal elements and the neural arch. Thus, the first cervical nerves pass posterior to the atlanto-occipital joints. The cup-shaped articulation of C1 with the skull allows a fair amount of flexion and extension, and some lateral flexion. Rotation between the skull and the atlas is effectively prohibited by the socket-like

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[9] Orthopaedists call these “facet” joints, pronouncing the word “facet” with the accent on the second syllable.

conformation of the paired atlanto-occipital joints. The atlanto-axial joints (between C1 and C2) are specialized to permit the rotation that is absent between C1 and the skull.

The superior zygapophysis, inferior zygapophysis and transverse process of the atlas are often said to form its **lateral mass**. Thus, the atlas has two lateral masses joined by **anterior** and **posterior arches**.

Intervertebral Ligaments (Fig. 3-8)

The ligaments between adjacent vertebrae have the same effect on limiting motion regardless of the region of the column in which they occur. These ligaments can be grouped according to whether they limit (1) excessive flexion, (2) excessive extension, or (3) excessive lateral flexion.

Excessive flexion of the vertebral column (particularly in the lumbar region) is the greatest danger to its integrity. **The following ligaments prevent excessive flexion**:

1. **Supraspinous ligaments** that run between the tips of spines. In the neck, the supraspinous ligaments are highly specialized to form the powerful **ligamentum nuchae** that passes superiorly from the tip of the 7th cervical spine, fanning out in the median sagittal plane as it ascends. This fanning carries the attachment of the ligamentum nuchae to the tips of all the other, shorter, cervical spines and to a median sagittal crest and protuberance (the external occipital crest and protuberance) on the occipital bone posterior to the foramen magnum.

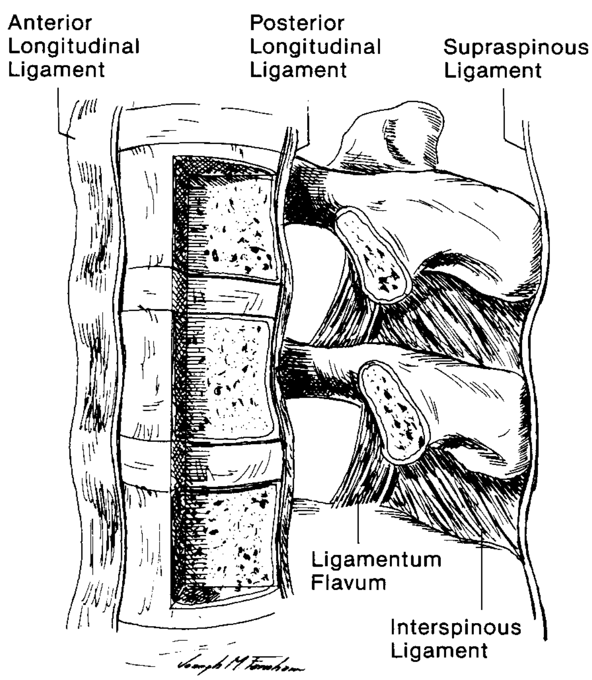

Figure 3-8. Partial sagittal section through articulated vertebrae illustrating the four ligaments (supraspinous, interspinous, flava, and posterior longitudinal) that limit excessive flexion of the vertebral column and the one ligament (anterior longitudinal) that limits excessive extension. (From Norkin and Levangie.[36])

2. **Interspinous ligaments** that run between the inferior edge of one spine and the superior edge of the next lower spine.

3. The *extremely important* **ligamenta flava**, which are powerful fibroelastic sheets running from the inner surface of a lamina near its inferior edge to the superior edge of the next lower lamina.

Ligamenta flava are named for the yellow color imparted by their high content of elastic tissue, but it would have been better if they were called interlaminar ligaments. They come in pairs, a right and a left, but meet one another in the midline causing some people to recognize only a single ligamentum flavum. Laterally, the ligamentum flavum runs into the capsule of the zygapophyseal joint.

4. The **posterior longitudinal ligament** that runs from the skull all the way down to the sacrum along the posterior surfaces of the vertebral bodies. The ligament attaches to the vertebral bodies and, as it passes each intervertebral disc, is connected by fibrous tissue to the anulus fibrosus (Fig. 3-9). It reinforces the back of the anuli fibrosus except at the site marked X in Figure 3-9. This is the most frequent site for herniation of the nucleus pulposus. The uppermost fibers of the posterior longitudinal ligament (i.e., between C2 and the skull) are said to constitute the **tectorial membrane**.

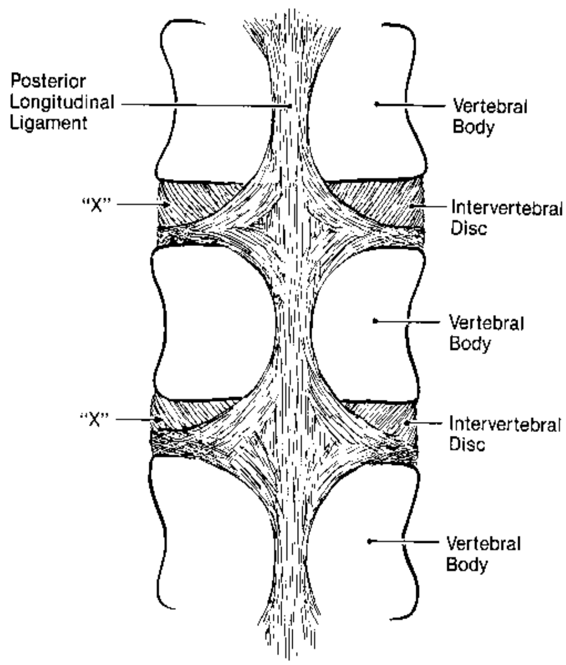

Figure 3-9. Posterior view of vertebral bodies, intervertebral discs, and posterior longitudinal ligament. Note how the disc is reinforced by the ligament except superolaterally (at site X) where, as a consequence, herniations of the nucleus pulposus are most common.

The ligaments that limit excessive flexion of the vertebral column play a significant role when a person bends the trunk forward while keeping the knees straight, as if to touch the toes. Interestingly, at the end of such a movement the muscles that extend the vertebral column cease firing. Thus, while in the toe-touch posture, the lumbar region of the vertebral column is prevented from collapsing into hyperflexion (under the weight of the upper trunk) solely by tension within the dorsal ligaments of the spine. Furthermore, as one attempts to raise the trunk from the toe-touch position to the normal erect posture, the dorsal ligaments of the spine are subjected to an even greater stress because the effort is initiated by muscles that extend the hip, while the back muscles delay onset of their activity until the movement is well underway. Given these facts, it should be obvious that if one tries to lift a heavy object off the ground after bending forward with the knees held straight, very great stress is placed on the dorsal spinal ligaments at the beginning of the lift. Thus, we have the explanation for the commonly given advice that one should only attempt to lift heavy objects off the ground from a position with the knees bent and the back held straight. In this case, spinal muscles are continuously active, and risk of injury to the dorsal spinal ligaments is avoided.

Only one ligament **prevents excessive extension** of the vertebral column. This is the powerful **anterior longitudinal ligament** that starts at the base of the skull and runs down the front of the vertebral bodies, getting wider as it descends.

It is the anterior longitudinal ligament that will be injured during hyperextension of the vertebral column caused by external forces. Such injuries are most common in the cervical region during what is called whiplash of the neck, produced by a force that drives the trunk forward while the head lags behind. Once the anterior longitudinal ligament in the cervical region has been strained, the clinician must devise a method for preventing further stress on this structure. Such a method is a neck collar that is higher in the back than in the front, because a collar of this shape will force the cervical vertebral column into flexion and keep it there.

The anterior longitudinal ligament reinforces the ventral surfaces of the anuli fibrosus of intervertebral discs. As a result, anterior herniation of the nucleus pulposus is rare.

Excessive lateral flexion of the vertebral column is limited by ligamenta flava and the capsules of the zygapophyseal joints. The only ligaments that have limitation of lateral flexion as their chief function are small **intertransverse ligaments** that pass between the transverse processes of adjacent thoracic vertebrae. These ligaments are replaced by intertransverse muscles in the cervical region, where lateral flexion must be freer and also under muscular control. Intertransverse muscles also are found in the lumbar part of the vertebral column, although here the large muscles of the abdominal wall are far more effective in controlling lateral flexion than are the tiny intertransverse muscles.

The Iliolumbar Ligament--a Special Structure for Stabilizing the Lumbosacral Joint

Because the superior surface of the first sacral body does not face directly upward but, rather, is tilted to point partly forward (Fig. 3-10), there is a tendency in the erect position for the body of the 5th lumbar vertebra to slide anteroinferiorly off the sacrum. Normally this is prevented by the shapes of the joints between the inferior zygapophyses of L5 and the superior zygapophyses of the sacrum, as well as by the various ligaments connecting their bodies and arches. However, it seems that one more ligament is helpful. Thus, on each side, running from the anterior surface and tip of the 5th lumbar transverse process outward and backward to the inner lip of the iliac crest in front of the linea limitans is the strong **iliolumbar ligament** (see Chapter 10 for definitions of the relevant iliac structures, and see fig. 10-19 for an illustration of the ligament). This band between the 5th lumbar vertebra and the iliac crest may be joined by fibers coming from the transverse process of L4. It also may send some fibers that fan out to an attachment on the linea limitans itself.

It would seem that of all the factors preventing antero-inferior slippage of L5, the shapes of the L5/S1 zygapophyseal joints are the most important. This is revealed by cases in which trauma to the 5th lumbar vertebrae causes both laminae to be fractured

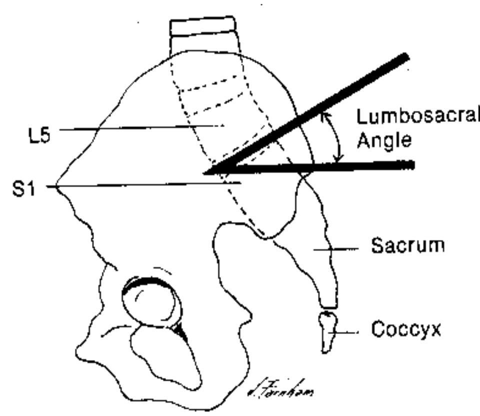

Figure 3-10. Lateral view of the lower lumbar vertebrae and sacrum illustrating that the superior surface of the first sacral body faces anterosuperiorly, resulting in a tendency for the fifth lumbar vertebra to slide downward and forward off the sacrum. (From Norkin and Levangie.[36])

between the superior and inferior zygapophyses. Clinicians call this region of a lumbar lamina the "**pars interarticularis**." Bilateral defects in the partes interarticulares is called **spondylolysis** (Fig. 3-11). A common consequence of L5 spondylolysis is a gradual yielding of the intact ligamentous structures that connect the body and transverse processes of the vertebra to the ilia and sacrum. This permits the body of L5 to slide downward and forward, a condition known as **spondylolisthesis** (see Fig. 3-11). Because the laminae and inferior zygapophyses do not change position, there is no compression of the contents of the vertebral canal, and symptoms of spondylolisthesis are generally confined to the pain of ligamentous injury and/or muscle spasm.

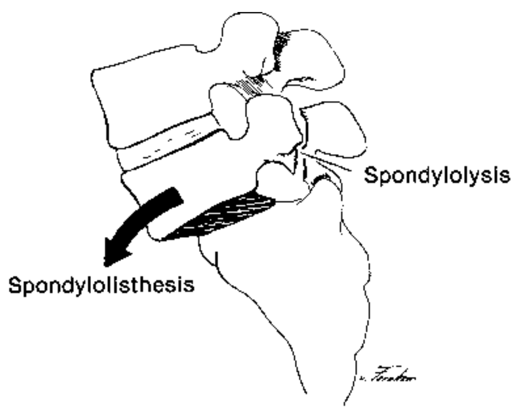

Figure 3-11. Lateral view of the lower lumbar vertebrae and the sacrum illustrating bilateral spondylolysis (i.e., fracture of partes interarticulares of lumbar laminae) and spondylolisthesis (i.e., anteroinferior displacement of the intact lumbar body, pedicles, and superior articular processes).
Modified from Norkin & Levangie[36]

Special Ligaments of the Atlanto-axial and Atlanto-occipital Joints

The skull and atlas rotate as a unit around the dens of the axis. In order to prevent this rotation from proceeding to a point that threatens dislocation of the atlanto-axial interarticular joints, there exist powerful **alar** ligaments that run from the dens, near its tip, laterally to the inner surfaces of the occipital condyles. The left alar ligament becomes taut when a person turns the head too far to the right; the right ligament prevents excessive rotation of the head to the left. A tiny ligament of no particular functional significance runs from the apex of the dens to the inner surface of the occipital bone just above the anterior rim of the foramen magnum. This is the **apical dental ligament**.

In order to prevent dislocation of the dens from its articulation with the anterior arch of the atlas, a powerful **transverse ligament of the atlas** runs from the inner surface of its right lateral mass to the inner surface of its left lateral mass, passing behind the dens (see Fig. 3-12). Two smaller ligaments

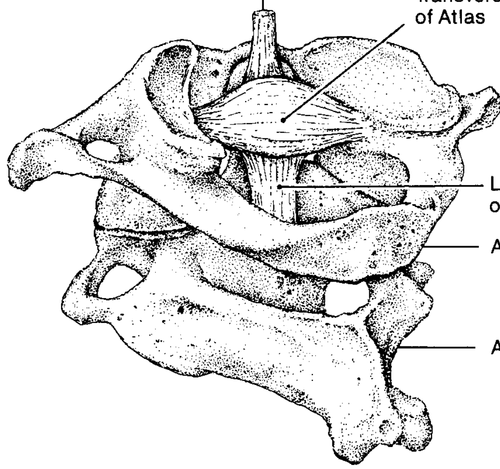

Figure 3-12. Oblique posterior view of articulated atlas and axis showing the powerful transverse ligament that holds the dens of the axis against the anterior arch of the atlas. Stabilizing upper and lower bands join the transverse ligament of the atlas to form the so-called cruciate ligament.

stabilize the vertical position of this transverse ligament. One runs from the middle of the transverse ligament to the inner surface of the occipital bone a bit above the anterior rim of the foramen magnum; the other runs from the middle of the transverse ligament down to the body of the axis. Because these two vertical bands and the transverse ligament make a cross-shaped structure, the three ligaments are often gathered together under the name **cruciate ligament of the atlas**, with transverse, upper, and lower bands. The cruciate ligament of the atlas lies just anterior to the tectorial membrane. Its upper band is sandwiched between the tectorial membrane and apical dental ligament.

The arches of the atlas are connected by fibrous sheets to the inferior surface of the occipital bone. One such sheet forms the **anterior atlanto-occipital membrane**; the other is called the **posterior atlanto-occipital membrane**.

COCCYX

The human coccyx is composed of four rudimentary vertebrae. The first consists of a body and some bumps that seem to be pedicles, transverse processes, and superior zygapophyses. The rudimentary superior zygapophyses are called **coccygeal cornua**. Coccygeal vertebrae 2-4 are even less well-developed, each being little more than a nubbin of bone representing a vertebral body. The are usually fused to one another.

An abortive intervertebral disc is interposed between the bodies of S5 and Co1; the sacral cornua are connected to the coccygeal cornua by ligaments. The bodies of Co1 and Co2 are initially joined by fibrous tissue but usually fuse in middle age. Later in life, Co1 and the sacrum may fuse.

THE SPINAL MENINGES AND THEIR RELATIONSHIP TO SPINAL NERVES (see Fig. 3-13)

As it forms within the vertebral canal, the spinal cord becomes surrounded by three connective tissue sleeves. The innermost sleeve, actually adherent to the external surface of the cord itself, is called the **pia mater**. Outside the pia, and separated from it by cerebrospinal fluid, is a sleeve of very delicate membrane called the **arachnoid**. This is held by surface tension to the inside of a thick fibrous sleeve

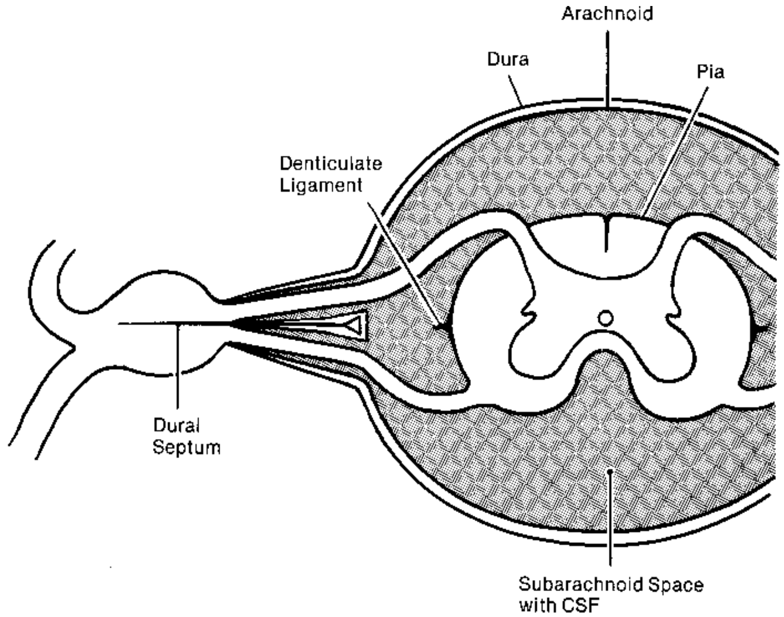

Figure 3-13. Transverse section of the spinal cord and a spinal nerve illustrating relationships of these structures to the three meningeal layers of the CNS.

called the **dura**. The dura is separated from the surrounding vertebrae by fat and a plexus of veins--the **internal vertebral plexus**. The space occupied by this fat and venous plexus is called the **epidural space**.

When the dorsal and ventral rootlets leave the spinal cord, they carry with them a connective tissue sleeve derived from pia mater. This is the epineurium of the rootlets. The rootlets then travel within the subarachnoid space, bathed by cerebrospinal fluid, toward the arachnoid membrane. Just before the site where the rootlets of a spinal nerve would contact the arachnoid, the dorsal ones join to form the single dorsal root, and the ventral ones join to form the single ventral root. The dorsal and ventral roots then contact the arachnoid separately. Neither root pierces this membrane. Instead, each pushes out a little sleeve of arachnoid and apposed dura. The dural sleeve of the dorsal root fuses to the dural sleeve of the ventral root so that, on dissection, one seems to find a single nerve bundle surrounded by a tough connective tissue sheath. However, within this apparent single bundle are the two roots with their own arachnoid and dural envelopes. In fact, there is still cerebrospinal fluid (CSF) deep to the arachnoid, between it and the true epineurium of the roots. This apparently single bundle is not the spinal nerve *sensu stricto*, there being no interweaving of motor and sensory fibers. In the adult, this "false" spinal nerve is several millimeters long. It extends laterally from the margin of the spinal dura toward the dorsal root ganglion. For most spinal nerves, the ganglion lies relatively far away from the margin of the spinal dura, usually in the intervertebral foramen. Upon reaching the ganglion, the arachnoid membrane fuses to the epineurium of the roots, obliterating the extensions of the subarachnoid space that exist beyond the margins of the spinal dura. Still, at the level of the dorsal root ganglion, the dorsal and ventral roots do not interweave; they remain separated by a dural septum. It is only at the distal edge of the ganglion that the dural septum between the dorsal and ventral roots disappears and the “true” spinal nerve, with interweaving of motor and sensory fibers, begins. As stated earlier, this true spinal nerve is short, dividing almost immediately into dorsal and ventral rami.

The Denticulate Ligament

On both the right and left edges of the spinal cord, running its length from the foramen magnum down to the beginning of the 1st lumbar segment, the pia is prolonged a millimeter or two laterally to form a flat fibrous band (see Fig. 3-13). At the site opposite the junction of the brainstem with the 1st cervical spinal cord segment, and then at sites opposite the junctions between each of the first 21 spinal cord segments, this pial band is prolonged laterally an additional millimeter or so to form projections that resemble the teeth of a saw. The apex of each "tooth" sends a very slender cord out to attach to the inner surface of the spinal dura. On each side, the longitudinal pial band with its 21 tooth-like projections attached to dura is called a **denticulate ligament**. It is presumed that the two denticulate ligaments prevent side-to-side motion of the spinal cord within the subarachnoid space. In dissection, a denticulate ligament can serve as a guide to differentiate dorsal rootlets of spinal nerves, which exit the cord posterior to the ligament, from ventral rootlets, which exit the cord anterior to it.

The Changing Relationship Between the Vertebral Column, Meninges, and Spinal Cord During Development and Growth

During embryonic life the spinal cord, the pia which adheres to it, the sleeve of arachnoid membrane, and the dural sleeve are all the same length as the vertebral column (Fig. 3-14*A*). At the caudal tip of the spinal cord the pia, arachnoid, and dura meet one another and are attached to the bodies of the lower coccygeal vertebrae. As the individual vertebrae grow in length causing the vertebral column to become longer, the linear growth of the spinal cord lags behind. Thus, at birth, the spinal cord (with all its contained white and gray matter) extends no further caudally than the 3rd lumbar vertebra. The differential growth between spinal cord and vertebral column continues throughout childhood. **In the adult, the caudal end of the spinal cord lies at a level opposite the disc between the 1st and 2nd lumbar vertebrae**. Inferior to the caudal tip of the spinal cord, a thin bundle of glistening pia continues down to its primordial attachment on the coccyx. This bundle is called the **filum terminale** (see Fig. 3-14*B*). The narrowed region of the spinal cord just superior to the filum terminale is called the **conus medullaris**. Although the spinal cord has "shortened" relative to the vertebral column, no spinal segments are lost. It is simply that the lower spinal cord segments no longer lie adjacent to the lower vertebrae (Fig. 3-14*B*).

The linear growth of the dura and arachnoid does a better job of keeping up with the vertebral column than does that of the spinal cord. **The caudal end of the sac formed by the dura and arachnoid lies opposite the level of the 2nd sacral vertebra in the adult**. Inferior to S2, the dura and arachnoid continue only as a thin covering around the filum terminale down to the coccyx. The resulting trilaminar cord is called the **filum of the spinal dura**. **Thus, from L1/L2 down to S2 there is an extensive subarachoid space unoccupied by the spinal cord. From S2 down to the coccyx, there is an extensive epidural space within the vertebral canal** (see Fig. 3-14*B*).

In the embryo, the spinal nerve rootlets pass directly laterally through the subarachnoid space to contact the arachnoid, pushing sleeves of arachnoid and overlying dura directly laterally through the intervertebral foramen and out the vertebral canal. However, in the adult, because of the previous differential growth of the spinal cord and arachnoid/dura, many of the lower spinal rootlets find that their sites of contact with the arachnoid now lie quite a bit below the origin of these rootlets from the spinal cord. In other words, many of the lower spinal rootlets must descend in the subarachnoid space for some considerable distance before reaching the site where they contact the arachnoid/dura. When one looks at this mass of descending rootlets it looks like a horse's tail, and is thus called the **cauda equina** (see Fig. 3-14*B*).

Also, in the embryo the arachnoid/dura was coextensive with the vertebral column. The sheathed spinal nerves passed from the point of contact with the arachnoid/dura directly laterally out to the corresponding intervertebral foramen. In the adult, with the arachnoid/dura having shortened relative to the vertebral column, the sacral and coccygeal spinal nerves, with their dural covering, descend in the epidural space of the vertebral canal before reaching their corresponding intervertebral foramina (see Fig. 3-14B).

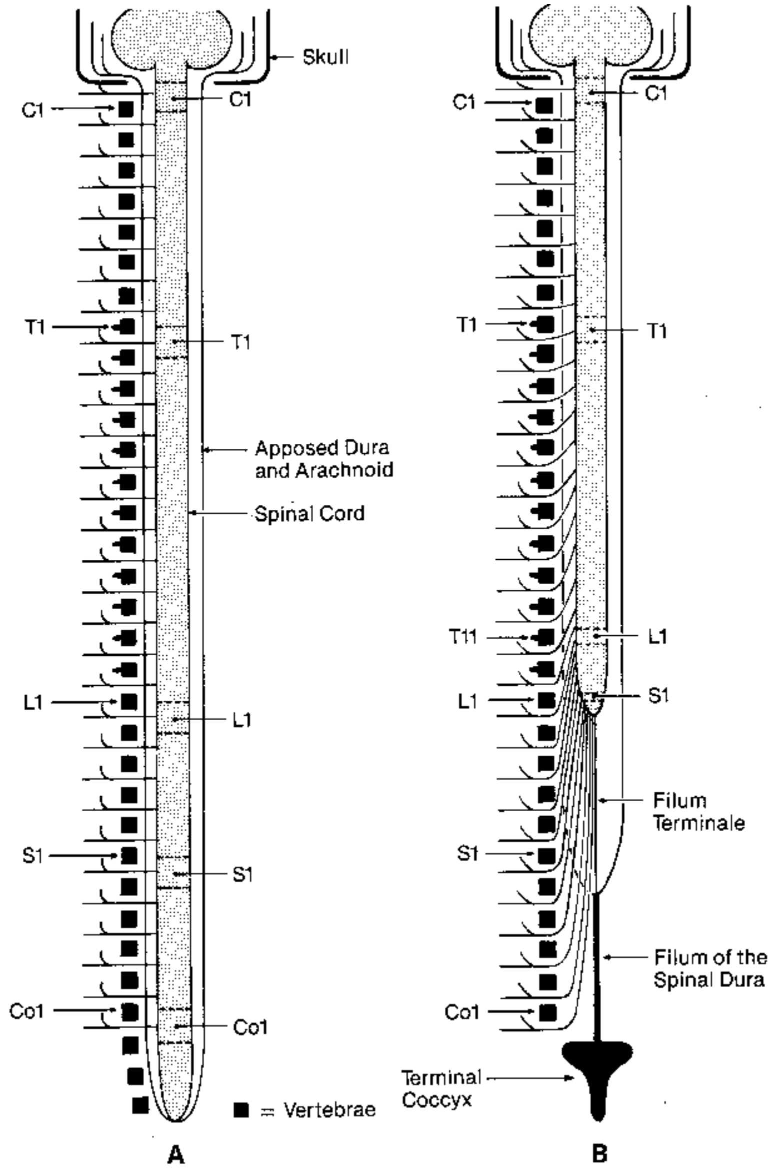

Figure 3–14. Schematic coronal sections of the spinal cord and spinal nerves at sequential stages in development. *A*, In the embryo the spinal cord and its meninges are the same length as is the vertebral column. The 1st cervical, 1st thoracic, 1st lumbar, 1st sacral, and 1st coccygeal segments of the embryonic spinal cord are labelled, as are the corresponding vertebrae. Each spinal nerve passes straight laterally to encounter the opposed layers of dura and arachnoid, and it then continues straight laterally out of the vertebral canal. *B*, In the adult the spinal cord is much shorter than is the vertebral column and the sleeve of dura/arachnoid is also somewhat shorter. The segments of the lower half of the spinal cord no longer lie near the vertebrae with which they were developmentally associated. Also, the sites where the lower spinal nerves contact the arachnoid/dura are now inferior to the sites of origin of these nerves from the spinal cord. A cauda equinae composed of spinal rootlets floating in CSF is formed before the L1/L2 intervertebral disc. The epidural space is extensive below the 2nd sacral vertebra.

CLINICAL CONSIDERATIONS

There are several important clinical consequences of the previously described disparity between lengths of the spinal cord, arachnoid/dura sac, and vertebral column.

Spinal Injuries

First, in order to predict the neurologic consequences of penetrating wounds to the back, one must know where the different spinal cord segments lie in relation to the vertebral column. There is a relatively simple guide to this information--only the digit 1 need be memorized:

The top of spinal cord segment **C1** lies opposite top of vertebra **C1**.
The top of spinal cord segment **T1** lies opposite top of vertebra **T1**.
The top of spinal cord segment **L1** lies opposite top of vertebra **T11**.
The top of spinal cord segment **S1** lies opposite top of vertebra **L1**.

It is obvious that the cervical cord is virtually unshortened relative to the vertebral column. The thoracic cord is shortened slightly. The lumbar segments of the cord run from the top of T11 to the top of L1 and are thus shortened considerably. The 5 sacral and 1 coccygeal segments of the cord (comprising the conus medullaris) span only the distance occupied by the body of L1.

An injury to the spinal cord not only leads to paralysis of the muscles supplied by the damaged region, it also leads to loss of cerebral control over muscles innervated by all the intact cord segments below the injury, and, of course, it prevents sensory information that enters such intact segments from reaching consciousness. Intraspinal reflexes below the injury are unaffected or, in the case of the stretch reflex of striated muscles, even accentuated.

An injury to the spinal cord above the L1 vertebra will remove descending influences on the sacral cord neurons controlling striated muscles that regulate urination and defecation. However, such an injury will not affect the intraspinal parasympathetic reflexes initiating these behaviors. Thus, the bladder contracts when it is full, generating high intravesical pressure. However, the striated muscle that normally is responsible for the voluntary control of urination, being deprived of descending neural influences, becomes spastic and cannot properly relax. Urination is incomplete and a suite of complications results. It may be necessary to cut the striated muscle, or its nerve, to enable complete emptying of the bladder. I do not know if a similar problem characterizes defecation or if it simply occurs automatically when visceral sensory neurons detect a full rectum.

A man who has suffered a spinal cord injury above the sacral levels of the cord can reflexly achieve an erection (a result of parasympathetic discharge from S3 and S4) upon sensory stimulation of the penis but cannot achieve erection when shown erotic pictures.

It should be obvious that injuries to the vertebral column below the L1/L2 intervertebral disc have an impact only in so far as spinal nerve rootlets are damaged.

Spinal Tap and Spinal Anesthesia

A second and very important consequence of relative spinal cord shortening is that the subarachnoid space between the L1/L2 disc and the 2nd sacral vertebra is filled with dorsal and ventral rootlets floating in a pool of cerebrospinal fluid. It is from this pool that one may readily withdraw cerebrospinal fluid (**spinal tap**) for diagnostic purposes, and it is a place where anesthetic may be injected into the CSF to deaden spinal nerves (**spinal anesthesia**). A needle inserted between spines of the lower lumbar vertebrae through the dura/arachnoid into the subarachnoid space cannot injure the spinal cord. Instead, it encounters rootlets floating in fluid. Just as one would find it difficult to impale a piece of cooked spaghetti floating in water, so it is unlikely that a needle inserted between lumbar spines into the subarachnoid space will impale a spinal rootlet.

In the adult, the preferred site of a spinal tap is between the 3rd and 4th, or 4th and 5th, lumbar spines. Insertion of a needle into the subarachnoid space at these levels is called a **lumbar puncture**. It is done is sufficiently low to avoid the spinal cord in virtually every individual (after all, there is some normal variation in how far down the spinal cord goes). Furthermore, there is an excellent surface landmark for identifying the 4th lumbar spine. It is on the same transverse plane as a line joining the most superior points on the iliac crests (see Chapter 10 for a description of the ilium). When one palpates the posterior midline of the back at the site where it is crossed by this **supracristal (intercristal) plane**, the 4th lumbar spine is felt. If the patient is asked to adopt a position with the lower back flexed, the space for passage of the needle is widened.

In cases where some mass is blocking cerebrospinal fluid flow to low lumbar regions, spinal taps may be done at higher levels along the vertebral column., but use of such sites entails great risk to the spinal cord. Many physicians believe that one should not perform a lumbar puncture if there are signs of increased intracranial pressure (e.g., edema of the optic disc--papilledema). In such circumstances a lumbar puncture may cause too rapid a drop in spinal fluid pressure resulting in a pressure differential between the fluid around the brain and that around the spinal cord. This pressure differential may then push the brainstem and cerebellar tonsils downward through the foramen magnum, causing death. When there are signs of increased intracranial pressure, one must either perform a lumbar puncture very carefully or, as an alternative, attempt to withdraw CSF from a site above the foramen magnum. There is a substantial pool of CSF between the inferior surface of the cerebellum and dorsal surface of the medulla. This pool is called the **cisterna magna**, and it can be approached by a needle inserted upward and forward between the posterior arch of the atlas and the occipital bone. Such a **cisternal puncture** should only be attempted by someone skilled in its practice, as the risk to the brainstem is substantial.

Lumbar Epidural Anesthesia

Spinal anesthesia is no longer the preferred method for abdominopelvic procedures in which general anesthesia is to be avoided. Instead, anesthetic is injected into the lumbar epidural space. This entails essentially no risk of undesired spread of anesthetic to the higher regions (as can occur if anesthetic is injected into the CSF), and it is compatible with insertion of a catheter that allows continuous administration of anesthetic. The use of lumbar epidural anesthesia has become very widespread in obstetrics.

The technique of lumbar epidural anesthesia is similar to that of lumbar puncture, with some important distinctions. A needle is inserted between the L3/L4 or (unlike a lumbar puncture) the L2/L3 vertebral spines. The trick in an epidural block is to pierce the ligamentum flavum but stop before you pierce the dura, thus ending up in the epidural space. This is often done by using the air-rebound technique. The needle is attached to a syringe filled with air. When you are superficial to the ligamentum flavum, any attempt to inject the air will meet with resistance and the plunger of the needle will rebound. When you have entered the epidural space, there is a negative pressure and the air will be sucked in. You then exchange the air-filled syringe for one with anesthetic, or pass a catheter through the needle. Depending on the volume of anesthetic injected, or the direction of the catheter, one can control how many spinal nerves are anesthetized.

Sacral Epidural Anesthesia (saddle block)

This is a method of anesthetizing sacral spinal nerves. It takes advantage of the fact that the spinal arachnoid/dura is shorter than the vertebral column. Thus, one may introduce anesthetic into the relatively wide epidural space of the sacral vertebral canal via a needle inserted through the sacral hiatus. Saddle block was designed primarily for anesthetizing the perineum during childbirth. It is no longer popular. One reason for its demise is because of the tendency of fecal matter to leak from the anus and contaminate the site of entry of the catheter. The other reason is the great success of lumbar epidural block for obstetrics.

An approach to the epidural space through the sacral hiatus is used by some physicians to inject anti-inflammatory drugs for the treatment of spinal nerve compression caused by arthritic changes in the lumbar intervertebral joints. The value of this treatment is not universally accepted.

Prolapsed or Herniated Intervertebral Disc (Slipped Disc)

Extrusion of the nucleus pulposus, whether it is covered by a thin layer of stretched anulus fibrosus (prolapse of the disc) or ruptures through the anulus (herniation of the disc), occurs most commonly in the low lumbar region. No doubt this is due to the very much greater stresses on the discs of this region. The second most frequent site is in the neck, usually as a consequence of some trauma. As stated above, a herniated nucleus pulposus will generally present to either the right or left of the posterior longitudinal ligament (site X in Fig. 3-9). If herniation occurs in the neck, the spinal cord may be subjected to pressure. However, in the more common case of a low lumbar slipped disc, the spinal cord has ended above the site of nuclear protrusion and only spinal nerve roots are in danger of compression.

Herniations of cervical discs affect the spinal nerve that exits at the corresponding intervertebral foramen. Thus, herniation of the C5/6 disc may compress the 6th cervical spinal nerve roots, or herniation of the C7/T1 disc may compress the 8th cervical spinal nerve roots. The situation is different for lumbar disc herniations. Because lumbar pedicles attach to the upper half of their vertebral body, lumbar intervertebral foramina are set high relative to the intervertebral disc. As a lumbar spinal nerve exits its intervertebral foramen, it is related more to the back surface of the vertebral body than to an intervertebral disc. For example, the 5th lumbar spinal nerve exits the L5/S1 intervertebral foramen along the posterior surface of the lower half of the L5 body, above and lateral to most herniations of the L5/S1 disc. A herniation of the L5/S1 disc is far more likely to compress the S1 spinal roots as they pass downward toward their exit from the next lower intervertebral foramen. The general rule is that a slipped lumbar disc leads to a compression neuropathy of the next lower spinal nerve.

The most commonly herniated lumbar intervertebral discs are L4/5 and L5/S1; thus the most commonly affected nerves are L5 and S1. For this reason it is important that you the know the rough distributions of these nerves. The pain resulting from L5 compression spreads from the outer aspect of the leg across the dorsum of the foot to its inner border (this is close to the distribution territory of the superficial peroneal nerve, which you will learn about in Chapter 10). The pain of S1 compression is down the calf to the outer border of the foot (more or less along the path of the sural nerve, again which you learn about in Chapter 10) and also most of the sole of the foot. The weakness associated with L5 compression is predominantly one of dorsiflexion of the foot and toes (most noticeable for the big toe). The weakness associated with S1 compression is predominantly one of plantarflexion. Compression of the L4 nerve roots is less common than of either L5 or S1. Sensory symptoms involve the knee and anteromedial lower leg. Weakness of the quadriceps is a prominent motor symptom. Pain localized to the back, without radiating along the distribution of a spinal nerve, is probably not due to a slipped disc, but rather to strained ligaments or muscles of the back.

MUSCLES SEEN IN THE BACK

Muscles derived from the epaxial portions of dermomyotomes are said to constitute the **intrinsic (or proper) muscles of the back**. As we could deduce, they are all innervated by dorsal rami of spinal nerves. These muscles are confined to strips on either side of the vertebral column, dorsal to the laminae, transverse, and costal elements of the vertebrae.

Oddly, when one takes off the skin and superficial fascia of the back, almost none of the proper back muscles can be seen. They are hidden from view by three muscles - latissimus dorsi, trapezius, and (to a lesser extent) sternocleidomastoid - derived from either hypaxial dermomyotome or cranial somite cells that have migrated onto the back. Deep to these muscles are yet other immigrant hypaxial muscles--the rhomboids and posterior serrati--that cover small regions of the intrinsic spinal musculature. Given their derivations, it is predictable that none of the immigrant muscles are innervated by dorsal rami of spinal nerves.

The Three Superficial Immigrant Muscles in the Back--Latissimus Dorsi, Trapezius, and Sternocleidomastoid

The latissimus dorsi is a hypaxial muscle of the upper limb and will be given more detailed consideration in Chapter 9. It has gained a broad aponeurotic origin from the posterior aspect of the iliac crest and the tips of vertebral spines all the way from the sacral to the mid-thoracic region. Its lower fibers pass almost vertically upward; its upper fibers pass more horizontally. Both converge on a tendon that inserts onto the proximal humeral shaft. The latissimus dorsi covers the lower half of the intrinsic back musculature.

The trapezius and sternocleidomastoid are muscles of complex developmental origins involving hypaxial dermomyotomes of the neck and cranial somites. They will be given detailed consideration in Chapter 7. The trapezius has migrated to gain an origin from all the thoracic spines (superficial to the latissimus dorsi where the two muscles overlap), the posterior edge of the ligamentum nuchae, and a bit of the medial part of the superior nuchal line of the occipital bone. Its fibers pass laterally, converging toward a more limited insertion on the scapular spine and clavicle. In so doing, trapezius fibers cover most of the upper half of the intrinsic back musculature.

The sternocleidomastoid has two heads of origin: a tendinous one from the front of the sternal manubrium, and a muscular one from the medial part of the clavicle. Fibers from the heads join one another and pass upwards around the side of the neck to insert on the lateral half of the superior nuchal line and the mastoid process of skull. The sternocleidomastoid covers a tiny bit of the intrinsic back musculature just behind the mastoid process.

The only region where intrinsic back muscles can be seen without further dissection is in the neck between the lateral border of trapezius and posterior edge of sternocleidomastoid.

Some Deeper Immigrant Muscles in the Back--The Rhomboids and the Posterior Serrati

After removing the latissimus dorsi, trapezius, and sternocleidomastoid, one will be able to see much more of the proper back musculature. However, there are still a few muscles that have migrated from elsewhere to obscure a complete view. These immigrants are derived from the hypaxial portions of dermomyotomes and, thus, are innervated by branches from the ventral rami of spinal nerves.

The rhomboid muscle sheet (which be described in greater detail in Chapter 7) runs from the lower end of the ligamentum nuchae and the spines of upper thoracic vertebrae to the vertebral border of the scapula from its spine down to its inferior angle. It lies directly beneath the middle part of the trapezius.

Deep to the rhomboid muscle sheet is the **serratus posterior superior**. More inferiorly, deep to the latissimus dorsi, is the **serratus posterior inferior**. The two posterior serratus muscles have an origin from vertebral spines and insert onto ribs. Serratus posterior superior pulls upper ribs backward and upward. Serratus posterior inferior pulls lower ribs backward and downward. Both muscles are very thin and of dubious functional significance.

The Major Intrinsic Back Muscles

Once the rhomboid muscle sheet and the posterior serrati are removed, we have an unobstructed view of the proper back muscles. Those in the neck are covered only by a thin deep fascia and their fibers can be seen readily. Those in the trunk are covered by a bilaminar deep fascia, of which the deeper lamina is nothing but thin epimysium, whereas the more superficial lamina is the very thick posterior layer of something called the **thoracolumbar fascia**. The aponeurosis of origin of the latissimus dorsi is fused to the posterior layer of the thoracolumbar fascia where the two structures overlap. The actual fleshy fibers of the intrinsic back muscles cannot be seen until the posterior layer of the thoracolumbar fascia has been removed.

The proper back muscles are divisible into a superficial and a deep group. The superficial group consists of four subsets - splenius, spinalis, longissimus, and iliocostalis - differentiated on the basis of origin and insertion. The deep group consists of three subsets--semispinalis, multifidus, and rotatores--differentiated primarily on the basis of length of fiber. Finally, high in the neck there are two rectus capitis and two obliquus capitis muscles that are placed in a group of suboccipital muscles.

In the description that follows, the term "transverse element" will refer both to the transverse processes of thoracic vertebrae and to the transverse elements of vertebrae that have compound transverse processes. Similarly, the term "costal element" will refer to ribs and to the costal elements of vertebrae with compound transverse processes.

Superficial Intrinsic Back Muscles

Splenius. This is a **spinotransversocostal** muscle. That is, it arises from spines and goes to transverse and costal elements at their junction. Specifically, the splenius arises from the spines of the upper thoracic vertebra, and from the lower part of the ligamentum nuchae. The lowermost muscle fibers insert into cervical vertebrae near the posterior tubercles and compose a so-called **splenius cervicis**. The rest of the splenius inserts into a homologous part of the skull, i.e., the mastoid process and lateral half of the superior nuchal line (thus, deep to the origin of sternocleidomastoid). It is called **splenius capitis**. The splenius capitis is a powerful extensor of the neck and head, and it rotates the head to face toward the ipsilateral side.

Spinalis. This is a **spinospinal** muscle. It arises from spines of lower vertebrae and inserts on spines of higher vertebrae. It is flimsy, highly tendinous, and usually only occupies the region between L2 and T2. Sometimes it has a representative in the neck.

Longissimus. This lies lateral to the spinalis and, as its name implies, is the longest of the spinal muscles. Longissimus represents a **transverso-transversocostal** group of muscles. The lower fibers arise from an aponeurosis that attaches to various points on the sacrum. These ascend to insert onto both transverse and costal elements near their junction. Higher fibers of the longissimus arise from transverse elements and insert on yet higher transverse and costal elements near their junction. The most superior fibers of the longissimus insert onto the mastoid process of the skull, deep to the insertion of splenius, and are called **longissimus capitis**.

Iliocostalis. Iliocostalis lies lateral to the longissimus and is a **costocostal** muscle group. The lowermost fibers arise from an aponeurosis that attaches to the sacrum and the medial part of the iliac crest. They insert on the lower ribs near their angles. Higher fibers of the iliocostalis arise from ribs, near their angles, and insert on yet higher ribs or posterior tubercles of cervical vertebrae.

The Terms *Sacrospinalis* and *Erector Spinae*. The iliocostalis and longissimus are so closely adherent at their origins from the sacrum that they sometimes are gathered together under the single name of **sacrospinalis**. They and the spinalis are often called by the name **erector spinae**.

Actions of Erector Spinae. The three components of the erector spinae have pretty much the same action; they extend the vertebral column and, if acting on one side alone, laterally flex it. Clearly the more lateral fibers of the erector spinae (i.e., iliocostalis) have a greater role in lateral flexion than do the more medial fibers.

Deeper Intrinsic Back Muscles--The Transversospinal Group

The deep group of proper back muscles are all **transversospinal** muscles, i.e., the fibers arise from transverse elements and insert on higher vertebral spines (or a region on the occipital bone that is the skull's equivalent of a vertebral spine).

Semispinalis. The most superficial of the transversospinal muscles is the semispinalis, each bundle of which spans 4 to 6 vertebrae. The intervertebral bundles of semispinalis exist between T12 and C2 (thus, the muscle is absent in the lumbar and sacral regions). There is also a large muscle arising from the transverse elements of the upper thoracic and lower cervical vertebrae that inserts on the occipital bone near its midline, between the superior and inferior nuchal lines. This is the **semispinalis capitis** and it occupies much of the space immediately lateral to the ligamentum nuchae, deep to the splenius capitis and trapezius.

Multifidus. The most powerful of the transversospinal muscles is the multifidus, the fibers of which generally span 2 to 4 vertebrae. It exists throughout the whole length of the vertebral column from S4 up to C2. In regions where semispinalis and multifidus coexist (T12-C2), the multifidus is the deeper of the two. Although arising primarily from transverse elements of vertebrae, the multifidus also gains an origin from the posterior end of the iliac crest.

Rotatores. The smallest and deepest of the transversospinal muscles are the rotatores. The bundles span one or two intervertebral spaces. They are so deep that their insertions are onto the spines where they join laminae. They are well developed only in the thoracic region.

Actions of Transversospinal Muscles. The transversospinal muscles on one side will laterally flex and (if the intervertebral joints permit) rotate the trunk toward the opposite side. Acting bilaterally, the transversospinal muscles contribute to extension of the spine.

Suboccipital Muscles

There are four intrinsic back muscles that either connect the axis to the atlas or connect one of these bones to the skull. They all lie deep to the semispinalis capitis.

The smallest of these suboccipital muscles is the **rectus capitis posterior minor**, which runs from the posterior tubercle of the atlas to the nuchal plane of the occipital bone, just dorsal to the foramen magnum and just deep to the insertion of semispinalis capitis.

The **rectus capitis posterior major** is a muscle that runs from the spine of the axis up to the skull just lateral to the insertion of rectus capitis posterior minor. Also arising from the spine of the axis is the **obliquus capitis inferior**, which runs to the tip of the transverse process of the atlas. Arising from the transverse process of the atlas and passing upward to insert on the skull just superficial to the rectus capitis posterior major is the **obliquus capitis superior**. The last three muscles described form a triangle called the **suboccipital triangle.** In the floor of this triangle one finds the posterior arch of the atlas on whose upper surface rests the vertebral artery and the 1st cervical spinal nerve.

Of the four suboccipital muscles, two (rectus capitis posterior minor and obliquus capitis superior) cross only the atlanto-occipital joints and therefore cannot rotate the head. In theory , the rectus capitis posterior minor extends the head. The obliquus capitis superior laterally flexes the head. The two suboccipital muscles arising from the spine of the axis rotate the head to face toward the ipsilateral side -- one by acting directly on the skull (rectus capitis posterior major), the other by acting on the atlas (obliquus capitis inferior).

Some Trivial Epaxial Muscles--the Interspinales and the True Intertransversarii

There exist small **interspinal muscles** lying on either side of the interspinous ligaments in both the cervical and lumbar regions of the vertebral column. Additionally, one finds **intertransverse muscles** that run from the transverse elements of one vertebra up to the transverse elements of the next higher vertebra. These are usually replaced by connective tissue in the thoracic region.

(There are muscles running between the anterior tubercles of adjacent cervical vertebrae, between the posterior tubercles of adjacent cervical vertebrae, and between the costal elements of adjacent lumbar transverse processes. These are in reality "intercostal" muscles, and as such are not proper muscles of the back and are not innervated by dorsal rami. Nonetheless, they are also called intertransverse muscles. The rectus capitis lateralis and rectus capitis anterior are in this same category. These two muscles, and the cervical intertranversarii, will be discussed in Chapter 7.)

> Although the title of the preceding section implies that some epaxial muscles are important, this refers more to their general location and function than to specific details about their origins, insertions, and locations. I know orthopaedists who refer to the intrinsic spinal muscles as “those muscles I have to push out of the way to get to the spine”.

DORSAL RAMI OF SPINAL NERVES

The dorsal rami of spinal nerves exist for the purpose of innervating the body wall associated with the epaxial portions of dermomyotomes. Each dorsal ramus leaves the spinal nerve to run between adjacent transverse elements into the intrinsic musculature of the back.

A Typical Dorsal Ramus

A typical dorsal ramus will divide into a medial branch for the muscles closest to the midline and a lateral branch for muscles further away. The medial branches also supply nearby vertebral bone, joints, and ligaments. From the 6th thoracic nerve upward, these medial branches, after supplying muscles, go to the skin of the back. From the 7th thoracic nerve downward, it is the lateral branches that supply the skin. The area of the skin innervated by dorsal rami is indicated in Figure 3-15.

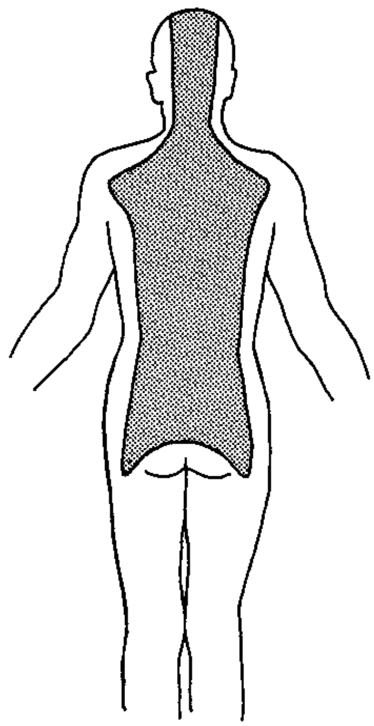

Figure 3-15. Posterior view of the body illustrating area of skin (*shaded*) innervated by dorsal rami of spinal nerves.

The First Three Dorsal Rami (C1, C2, and C3)

The first three cervical dorsal rami are exceptional and have special names. The dorsal ramus of C1 is called the **suboccipital nerve**, for it innervates the four suboccipital muscles. It also sends a branch to part of the overlying semispinalis capitis. The first cervical spinal nerve often has no dorsal root and thus no sensory component. In such cases the suboccipital nerve will not innervate skin, its area of cutaneous supply being taken over by the dorsal ramus of C2. It is also obvious that if C1 has no dorsal root it cannot carry sensory innervation from the suboccipital muscles. This function too will be assumed by the dorsal ramus of C2.

The medial branch of the dorsal ramus of C2 is unusually large and is given the name **greater occipital nerve**. It turns around the lower border of the obliquus capitis inferior (sending a communication to the suboccipital nerve) and enters the semispinalis capitis, part of which it innervates. The nerve then emerges from the semispinalis capitis to lie deep to the trapezius. It passes superolaterally toward to superior nuchal line, where it either pierces the trapezius or passes lateral to it, to enter the superficial fascia of the scalp. The greater occipital nerve runs in the superficial fascia of the scalp toward the vertex of the skull, supplying skin along the way.

The medial division of the dorsal ramus of C3, called the **3rd occipital nerve**, pierces (and innervates part of) the semispinalis capitis, and then pierces the trapezius to enter the superficial fascia of the neck. It ascends in this fascia near the posterior midline, supplying the skin up to the external occipital protuberance.

Dorsal Rami of C6, C7, C8, L4, and L5

Most texts report that the dorsal rami of C7 and C8 (and sometimes C6) have no cutaneous distribution. The dorsal rami of L4 and L5 have an insignificant cutaneous distribution.

The Last Three Dorsal Rami (S4, S5, and Co)

Of the 31 dorsal rami, all but S4, S5, and Co1 innervate epaxial muscles. The epaxial portions of the last three dermomyotomes degenerate. Thus, the last three dorsal rami only innervate skin and superficial fascia over the lower sacrum and coccyx (as well as the bones themselves).