CHAPTER 1

Introduction to Spinal Anatomy

MORPHOLOGY

With a newborn infant, the spine as a whole exhibits a dorsal-facing convexity in the sagittal plane. During the first few years of life, this convexity diminishes in the cervical and lumbar regions of the spine, and after the third year this initial kyphosis develops into an opposite curvature, the cervical and lumbar lordosis. The spine attains its definitive morphology after the 10th year, when the curvatures become set. The morphology is determined by the fact that the intervertebral disks—and to a lesser extent the vertebral bodies—are wedge shaped. In lordotic areas, these structures are higher on the ventral side than on their dorsal aspect; in the thoracic area, the opposite is true.

The lordotic morphology of the cervical and lumbar spine helps bear the weight of the head and the torso, respectively, thereby unloading the dorsal anular fibers. In terms of movement, the S-shaped curved and articulated spine has certain advantages over a totally straight spine (**Figure 1–1**). Because the individual vertebrae can move in relation to each other, movements in the lumbopelvic region can be compensated for by movements in the more cranial segments. Without these compensatory abilities, a small range of caudal movement would require a significantly greater range of cervical movement. The formula $R = N^2 + 1$ proposed by Kapandji (1974), in which he indicates that the load-bearing capacity is directly proportional to the number of curvatures squared plus one, appears incorrect. A straight column is always more stable than a curved column is. However, the S-shaped curved spine can absorb more energy because of its greater resistance to deformation.

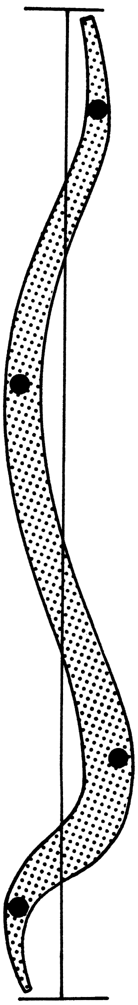

Figure 1–1 The S-shaped spine.

JOINTS BETWEEN INDIVIDUAL VERTEBRAE

The articulation between individual vertebrae is composed of the following components, as shown in **Figure 1–2**:

- Intervertebral disk (a)
- Intervertebral joint (b)
- Ligaments and the joint capsule (c)
- Uncovertebral cervical joint (d)
- Intrinsic lower back musculature
- Intervertebral disk (**Figure 1–3**)

The intervertebral disk is made up of cartilaginous endplates, anulus fibrosus, and nucleus pulposus.

Cartilaginous Endplates

The cartilage plates that form the upper and lower boundaries of the disk are connected to the vertebral bodies. They are composed of hyaline cartilage and are attached circumferentially to the inner rim of the fused ring apophysis of the bony vertebral body. According to Schmorl (1932), these endplates are attached to the vertebral body by a layer of calcium. This layer of calcium has small nutritional pores. The vertebral body is connected to the carti-

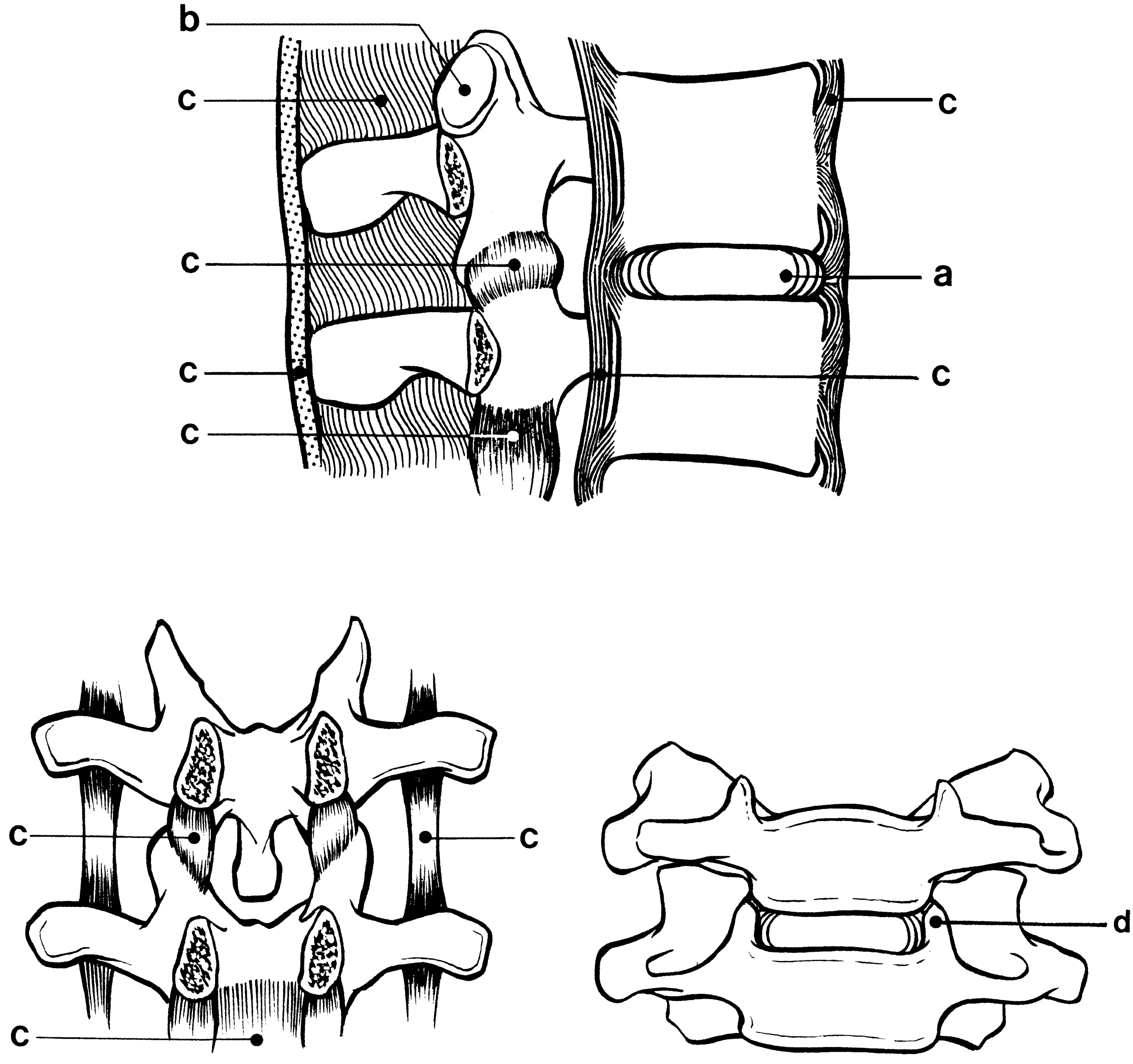

Figure 1–2 Joints between individual vertebrae.

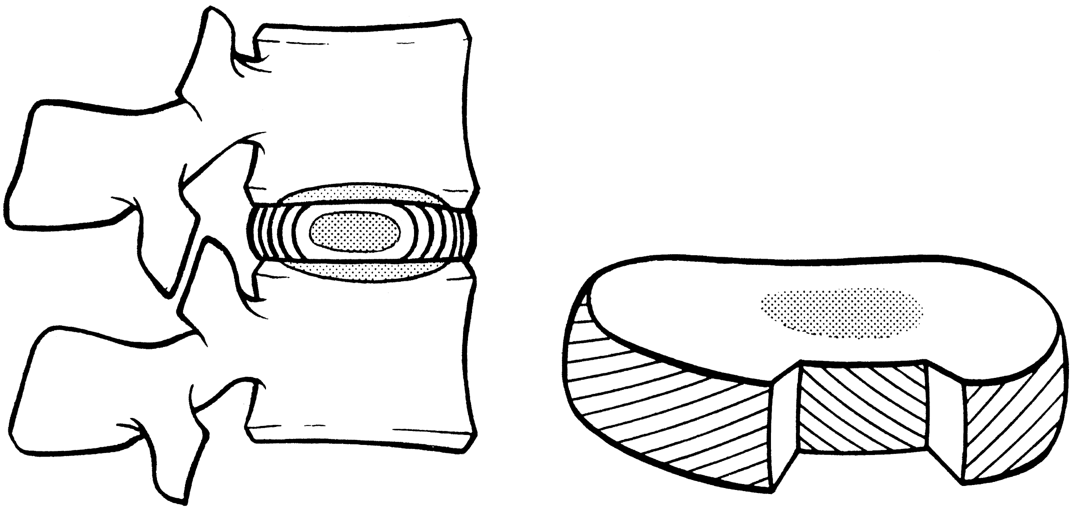

Figure 1–3 Intervertebral disk.

laginous endplate by its sieve-like surface (lamina cribrosa). The greatest part of the metabolic processes within the disk takes place by diffusion through this cartilaginous endplate.

Anulus Fibrosus

The anulus is primarily composed of fibers that are interwoven, like the thread on a screw, connecting one vertebra to the next. The Sharpey's fibers, which radiate outward into the bony outer wall of the vertebral body to which they are anchored, are located in the outermost boundary of the anulus. The ring-shaped lamellae making up the anulus are more numerous and stronger at their ventral and lateral aspect than they are dorsally and dorsolaterally. Whatever the direction of movement, one part of the fibers is tensed and another part is relaxed. The outer anulus bears 25% of the weight (Nachemson, 1966).

At birth, the cervical disks are not distinct from the disks in other regions of the spine—but a pseudodegenerative process occurs in the cervical intervertebral disk in late childhood (roughly from the ninth year onward), which causes tearing in the fibers of the outer anulus. This tearing progresses, and, in many cases, the fibers in the middle between two vertebral bodies appear completely torn in later life (Töndury, 1974; Hoogland, 1988). According to examinations carried out by Bogduk (1990), the ventrally located anular fibers appear to remain intact.

This tearing of the cervical anular fibers causes the disk to split into two parts: caudal and cranial. This cranial and caudal portion consisting of torn anular fibers appears to function as two brushes with the bristles opposing each other.

Nucleus Pulposus

The nucleus pulposus constitutes the central portion of the intervertebral disk between the two vertebral bodies and is considered a remnant of the notochord. The tissue is made up of bladder-shaped notochord cells and notochord strands, which together form the chorda reticulum.

The mesh of this network is filled with a jelly-like substance produced by connective tissue cells. This extensive and widely branched hollow space is initially filled with a synovial-like fluid and later with Gallert tissue. Later in life, this Gallert tissue becomes less homogeneous, leading to a decrease in elasticity. The nucleus pulposus is responsible for bearing 75% of the weight (Nachemson, 1966).

INTERVERTEBRAL JOINT

The intervertebral (or zygapophyseal) joints are synovial joints. The articular facets are covered with hyaline cartilage, and the capsule is made up of two membranes: synovial and fibrous. The hyaline cartilage covering of the superior articular process is thickest in the center, thinning out toward its periphery. This rim is cranially thicker in the cervical and thoracic sections of the spine; in the lumbar section, it is laterally thicker. In both cases, this extra thickness is made up of smooth hyaline cartilage. The thickness of the cartilage on the joints decreases from the caudal to the cranial aspects of the spine—the only exception being the atlanto-occipital joints.

On the inferior articular process, the cartilage covering is also thickest in the center, generally thinning out closer to its periphery. In the lumbar section of the spine, there is a noticeable thickening on the caudal aspect of articular facets; there is often a cartilaginous rim on their cranial aspect. The cartilaginous surfaces of the lumbar inferior articular processes are split in two parts: the thin medial section is located at an obtuse angle to the wider lateral section.

In a movement segment, the articular facets cover each other completely only in certain positions. In most cases, this occurs in the normal physiologic position. In the joints of the cervical and lumbar spine, partial loss of contact can be caused by various kinds of movement. In the end range position, there is often a wedge-shaped opening in the joint. According to Stofft and Müller (1971), corresponding articular facets differ slightly in size; the more they differ, the greater the mobility of a segment. The greatest difference exists in the C5–C6 joint.

In general, concave articular facets are slightly larger than their convex counterparts. In the cervical and thoracic spine, the more caudal articular facets are larger than the more cranially located ones.

In the lumbar area, the superior articular facets are larger than the inferior ones. More information about the intervertebral joints in each region of the spine can be found in the chapters concerning functional aspects of the lumbar, thoracic, and cervical spine.

Spongiosa Structure

The spongiosa structure of the vertebral processes must be able to withstand the stress of both compression and bending. With regard to the superior articular process, the organization of the spongiosa is the same in the sagittal plane of all vertebrae. Short struts of bone stand perpendicular to the articular facets and are attached to each other by struts set at perpendicular angles. In the transverse plane, these bony struts are not arranged in the same way for every articular facet. In the cervical and thoracic areas, they are arranged as they are in the sagittal plane. In the lumbar area and the sacrum, the spongiosa struts form a “pointed arch structure” (Putz, 1981). This implies they are at times exposed to a bending stress in the transverse plane.

Transverse forces are caused by rotation resulting from local pressure of the inferior articular process of the vertebra above and from tensile stress of ligaments and muscles whose insertion is on the mamillary process. These are mainly the transverse reinforcing fibers of the joint capsule and the short (segmental) rotator muscles.

For the inferior articular process, the spongiosa structure in the sagittal plane is generally constructed similarly throughout the entire spine. Pointed arch structures extend from the roots of the vertebral arch, implying bending stress in the sagittal plane. This arrangement is most obvious in the lumbar section, which corresponds to the change in joint space morphology required during extreme flexion. Determining the spongiosa structure of the inferior articular process in the transverse plane with any degree of certainty has proven difficult.

Joint Capsule

The joint capsule, as shown in **Figure 1–4**, is composed of the following structures:

- Synovial membrane
- Synovial folds and protrusions
- Fibrous membrane

Synovial Membrane

The synovial membrane is attached to the periphery of the articular facet, on the outside edge of the cartilage. Because the cartilage covering ends abruptly, there is a deep split, largely covered by the adjacent synovial membrane. This membrane also completely covers the articular cavity, with the exception of the joint cartilage, and is at times separated by an interstitial tissue from the overlying fibrous membrane. On the top and bottom of the articular cavity, the synovial membrane exhibits extensive bulging; these

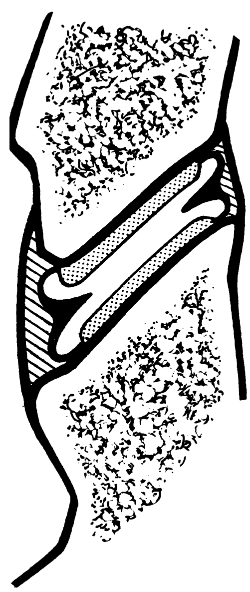

Figure 1–4 Joint capsule.

bulges are somewhat smaller on the lateral aspects of the articular cavity. This recess serves as reserve space for extreme movements. The synovial and fibrous membranes are separated by adipose and connective tissue.

Meniscoid Folds

Between the articular facets of all intervertebral joints, there are also folds and protrusions of variable shapes and sizes. These often extend a significant distance into the joint cavity. According to Putz (1981), they can be arranged in many different ways and are mostly found in the lordotic areas of the spine, where they are both numerous and ubiquitous.

In the cervical spine, there are large synovial folds in the caudal and cranial aspects of the joints, and smaller ones laterally. In the thoracic spine, there are small folds throughout the joints. In the medial aspect of the thoracic joints, these folds can be somewhat larger. The lumbar spine contains many synovial folds of varied composition. They are predominantly situated in the cranial and medial part of the joint cavity. In the cervical and thoracic spine, the folds are broad extensions of the joint capsule. In the lumbar spine, they are more pointed and can intrude up to 6 mm into the joint space.

Attempts have been made to explain the function of these protrusions in histological terms. Schminke and Santo (1932) described them as articular disks. In reference to the cervical spine, Töndury (1940, 1958) described them as meniscoid folds. According to Kos and Wolf (1972) and Benini (1978), meniscoid folds are all constructed in the same way. They are composed of a peripheral adipose tissue section that is fixed to the capsule, a blood-vessel-rich middle section, and a relatively blood-vessel-free rim that is composed of compact collagenous connective tissue containing cartilage cells.

According to examinations by Putz (1981), large and strong folds can be found in the cervical spine, especially in the atlantoaxial joint. These folds are mostly composed of compact connective tissue and extend at their base into the fibrous membrane. Adipose tissue can be found at the base. In the thoracic spine, the folds are mostly composed of connective tissue. In the lumbar spine, these folds vary in structure and morphology. They are predominantly composed of adipose tissue, rich in blood vessels.

The T12, L1, and L2 folds are almost exclusively composed of connective tissue that is extensively attached to the fibrous membrane. Their free rims are often frayed. The joint cavity often contains particles that have been torn off.

The meniscoid folds are not spare folds for extreme movements, as is the function of the capsular recess. They remain present during large movements. They are tissues that by way of limited deformation adapt to changes of the joint cavity. Sometimes the folds fill the space left behind when cartilage has been lost. They play a role in pressure transfer in the joints. The ligaments and muscles bordering on the meniscoid folds can exert pressure from the outside, depending on the position of the spine.

The meniscoid folds also have another function: the prevention of capsular impingement in the joint.

Fibrous Membrane

A number of authors have described the fibrous membrane as generally flaccid; others as either flaccid or firm, depending on the level of mobility in a specific area. The collagenous connective tissue of the joint capsule extends beyond the adjacent periosteum. Depending on the spinal region, membranes of different sizes can develop. Here, reinforcement fibers can exist that cannot be distinguished as independent capsular ligaments. According to Putz (1981), the differentiation of the fibrous membrane in the various spinal regions has to do with the thickness, the orientation of the reinforcement fibers, and the relation to the adjacent ligaments and muscles. The insertion site for the fibrous membrane is more or less the same in every region of the spine.

The fibrous membrane originates at the base of the articular process. In the thoracic and lumbar area, the place of attachment is farthest from the periphery of the articular surfaces. This leaves the innermost aspects of the articular processes exposed within the articular cavity.

At its medial aspect, the fibrous membrane is very thin, so it appears as though the intracapsular tissue is connected to the extracapsular tissue. The development of the fibrous membrane's bandlike reinforcement fibers mentioned earlier determines both the firmness of the capsule and the degree of mobility of the joint. In the lumbar spine, the highly developed fibers run from the lateral aspect of the inferior articular process to the mamillary process and the parts of the superior articular process located caudally to these mamillary processes. They run in the transverse plane and are particularly well developed in the middle.

They often diverge laterally (**Figure 1–5**). These transverse reinforcement fibers can also be found in the lower thoracic vertebrae where the joint cavity orientation corresponds to that found between the lumbar vertebrae. They serve to inhibit flexion and—to a lesser extent—extension and rotation. In the cervical and thoracic joints, the capsule is thinner and there are no bandlike reinforcement fibers.

In the cervical spine, the outer fibers of the fibrous membrane course almost longitudinally and are slightly more

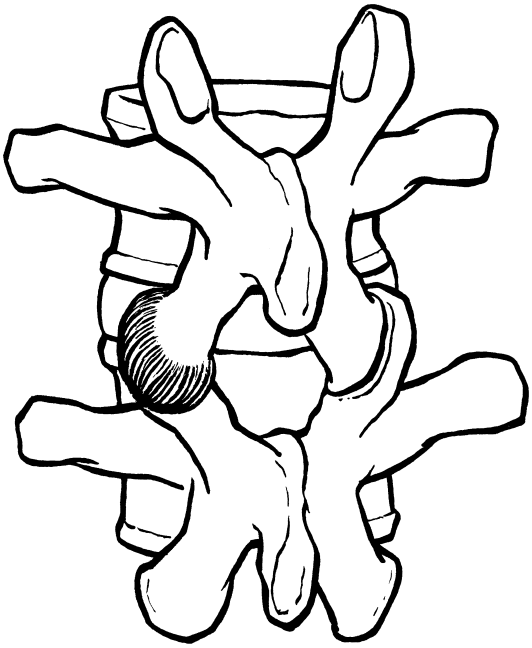

Figure 1–5 Fibrous membrane (Transverse reinforcing fibers).

developed. In the thoracic spine, they have less tensile strength and a less orderly arrangement, exerting little influence on mobility.

Ligamentous Relationships

In the cervical and lumbar spine, the intertransverse ligaments are close to the joint capsule—in the lumbar spine, there is even direct contact, whereas in the thoracic spine, these ligaments and the fibrous membrane are clearly separated. In each of the spinal regions, the intertransverse ligaments differ in strength, size, and orientation.

In the cervical spine, the thin intertransverse ligaments border on the ventrolateral part of the fibrous membrane. Small foramina allow blood vessels and nerves access to the outer surface of the vertebral arches.

In the thoracic spine, the intertransverse ligaments run more or less along the front of the transverse process, leaving space in their midsection for blood vessels and nerves.

In the lumbar spine, the intertransverse ligaments form the medial edge of an aponeurosis that extends laterally into the deep lamina of the lumbar dorsal fascia. They contain large openings through which course the dorsal branches of the spinal nerves and blood vessels. The ligaments have a protective function for these tissues.

In the cervical spine, the lateral portion of the flaval ligaments is attached at an angle to the joint capsules in the form of a small vertical sheet. A small space, filled with loose tissue, is left between the joint capsule and the flaval ligament.

In the thoracic spine, the flaval ligaments diverge cranially. At their medial aspect, they partially enclose the tops of the superior articular processes and lie close to the joint capsules.

In the lumbar spine, the superior articular processes are surrounded by the lateral surfaces of the flaval ligaments all the way to the base of the inferior articular process. The ligaments have a thicker portion at the level of the superior articular process. In the thoracolumbar and lumbosacral transitional area, sharp bony ridges can often be found in the attachment area for the flaval ligaments. Junghanns (1954) sees these as an expression of a general chronic degenerative change.

The most lateral bony ridges can be found at the level of the anterior-most part of the joint capsule of the intervertebral joints. They can cause dysfunctions and pain in the intervertebral joints.

Not directly adjacent to the joint capsules, the interspinous ligaments are relevant to spinal function because of their fiber orientation.

According to Heylings (1978), they run dorsally from the root of the caudal vertebra's spinous process to the underside of the cranial vertebra's spinous process in a fanlike S shape (**Figure 1–6**). This structure allows the spinous processes to separate and inhibits the dorsal translation of the cranial vertebra in relation to the caudal vertebra.

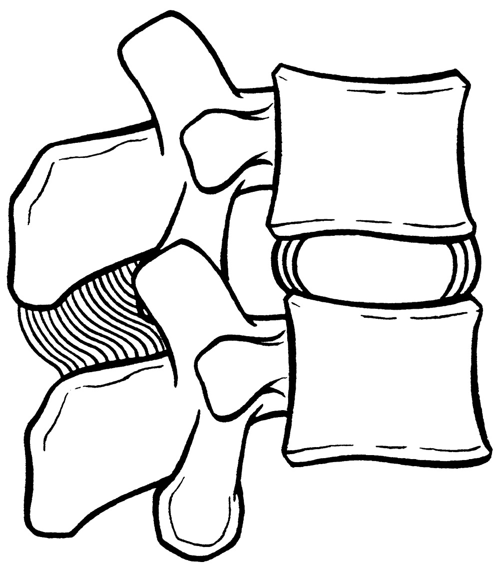

Figure 1–6 S-shape fiber structure.

Muscular Relationships

In the cervical and thoracic spine, the deepest fascicles of the intrinsic musculature are not interconnected with the joint capsules. When contracting with the thoracic spine in a flexed position, the long rotator muscles use the inferior articular process and the adjacent joint capsules as their fixed point against which to exert force. In the lumbar spine, fascicles of the multifidi muscles originate from the joint capsules and the mamillary processes and can, therefore, increase capsular tension.

During global contractions of the intrinsic back musculature, pressure increases in its surrounding osseofibrous structures. As a result, the meniscoid folds of the joint capsule are forced to move into the joint cavity, which causes the weight-bearing surface to enlarge. This occurs particularly with forceful flexion, side bending, and rotation.

Arterial Circulation

In the different spinal regions, the arterial blood supply to the intervertebral joints and surrounding area is organized in different ways.

In the lumbar and thoracic spine, articular branches originate from the segmental arteries (lumbar and posterior intercostal arteries). A branch originating in the iliolumbar arteries supplies the most lumbosacral joint (**Figure 1–7A** and **1–7B**).

In the cervical spine, branches from the vertebral artery and the cervical ascending pharyngeal artery supply arterial

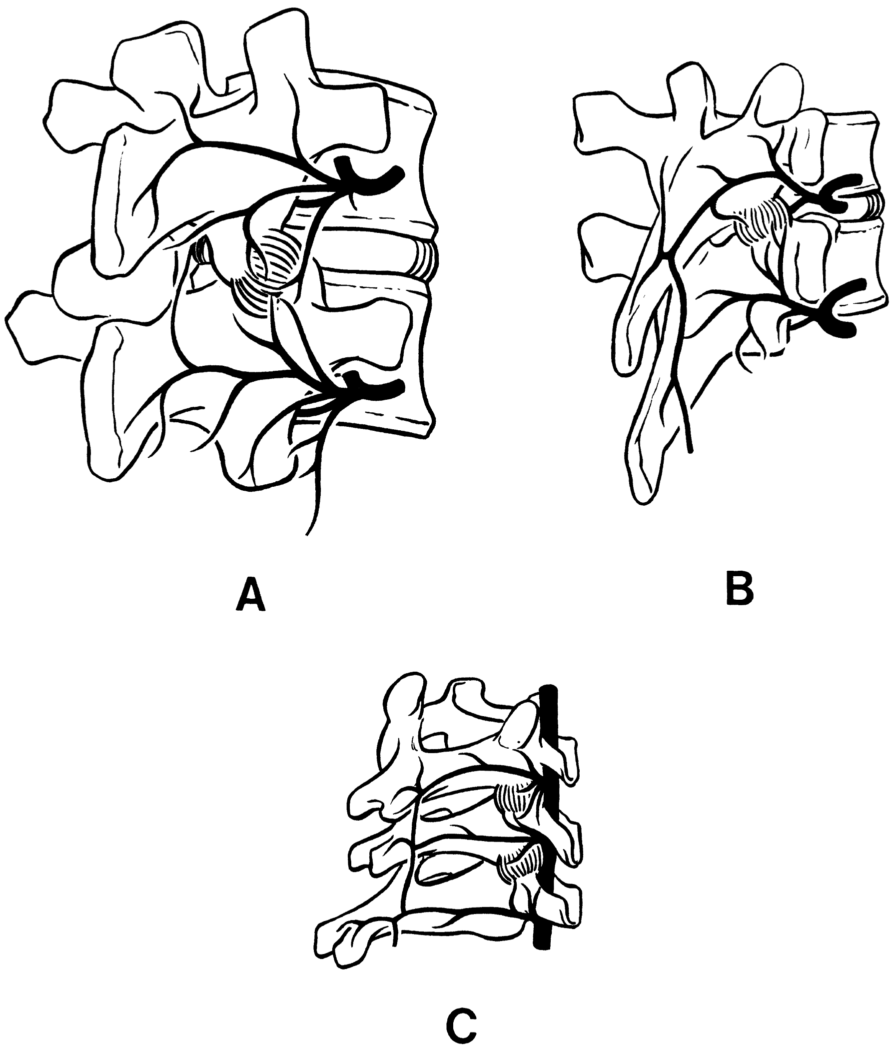

Figure 1–7 Arterial circulation of the lumbar (A), thoracic (B), and cervical (C) intervertebral joints.

blood to the joints. The lower cervical joints are also supplied by branches from the deep cervical artery (Kos, 1969) and the supreme intercostal artery (Jellinger, 1966) (**Figure 1–7C**).

In the cervicothoracic transitional area, blood is also supplied by way of the inferior thyroid artery (Yu Che, 1966). All arteries mentioned lead into the dorsal ramus at the lateral exit of the respective intervertebral foramen. This dorsal ramus then gives rise to the spinal ramus and the medial and lateral cutaneous ramus.

The medial cutaneous arterial ramus is primarily responsible for the arterial supply to the superior and inferior articular processes. Runge and Zippel (1976) named the sub-branches extending laterally from this medial cutaneous ramus the superior and inferior lateral vertebral arch arteries. These provide arterial supply to the superior and inferior articular processes, respectively. The lateral and caudal part of the joint capsule is supplied by sub-branches that originate from these branches or from the medial cutaneous branch itself. The cranial part of the joint capsule is supplied by a branch directly derived from the dorsal ramus. The medial cutaneous branch runs over the base of the relevant spinous process both caudally and cranially, forming—together with the branches above and below it—intersegmental anastomoses.

Their branches reach the medial part of the joint capsule (Lewin, 1968b). The branches of the medial cutaneous branch are unlikely to supply enough blood. It is, therefore, assumed that branches of the dorsal ramus supply the cranial part of the joint capsule as well as the medial part. The branches leading to the intervertebral joint also supply the adjacent periosteum and the bone in which the fibrous membrane originates. Thin arterial branches enter the marrow space of the bone via large foramina located on the lateral and caudal part of the base of the superior articular process and on the lateral surface of the inferior articular process. They partially originate in the dorsal ramus and the medial cutaneous ramus (Yu Che, 1966).

According to Clemens (1961), the bone is supplied from the periosteum by way of Volkmann's canals. Throughout the entire spine, the intervertebral joints' arterial network of dorsal rami is connected to the networks above, below, and on the opposite side (Ferguson, 1950; Louis, 1978). As is the case with the intervertebral joints of the other cervical vertebrae, the arterial needs of the atlanto-occipital joints are met by branches of the vertebral artery (Fischer, Garret, Gonan, and Sayfi, 1977). These branches form anastomoses with the frontal deep neck arteries. The branches from the vertebral artery, which supply the dorsal parts of the joint capsules, correspond to the dorsal rami of the segmental arteries. The anterior ascending artery, which supplies the frontal parts of the joint capsules, originates below the level of the axis out of the vertebral artery and runs cranially along the ventral aspect of the axis (Schiff and Parke, 1973). Together with the branch from the other side, this artery forms the apical axis arch (**Figure 1–8**).

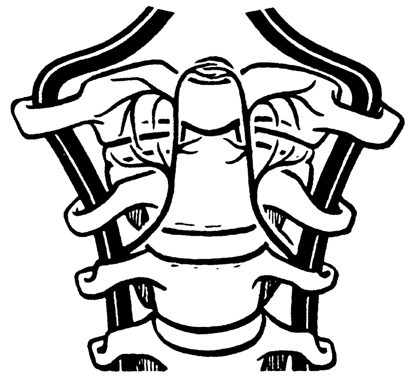

Figure 1–8 Apical arch of the axis. <FCR>Schiff and Parke, 1973.

The superior articular processes of the axis are supplied from the dorsal side; a direct branch of the vertebral artery enters the axis arch on the lateral side of the vertebral foramen.

Venous Circulation

The two dense venous plexuses, which can be found near the spinal column, are described in detail by Batson (1957) and Clemens (1961).

The posterior external vertebral venous plexus lies between the base of the spinous process and the transverse process, against the vertebral arches and the posterior aspect of the joints. The posterior internal vertebral venous plexus courses longitudinally within the spinal canal.

Here, the veins are connected to each other by transverse anastomoses. Bone veins of the vertebral arches and the articular processes flow into the adjacent plexus. According to Clemens (1961), the absence of valves can alter the direction of the flow in the vertebral plexus. Depending on the current local pressure ratio, the blood from the vertebral arches and the articular process can flow into either the dorsal or ventral plexus.

According to research by Putz (1981), small veins connect the plexus veins to the vertebral, intercostal, and lumbar veins. These veins run parallel to the arteries that supply the joint capsule. From the base of the skull to the sacrum, the vertebral venous system forms a chain of anastomoses. According to Ghazwinian and Kramer (1974), the filling of the lumbar epidural veins is dependent on the central venous pressure, which is dependent on position. A crawling position causes the least pressure. Coughing, sneezing, or pushing causes a pressure increase in the skull, thorax, and abdomen, which can also cause an increase in the venous pressure.

Innervation

The intervertebral joints are supplied by branches of the spinal nerves coursing through the respective intervertebral foramina. As shown in **Figure 1–9**, the dorsal ramus (a) and the meningeal ramus (b) branch off these spinal nerves before leaving the intervertebral foramen.

Running in a gutter between the superior articular process and the transverse process, the dorsal ramus courses around the base of the articular process and reaches the base of the spinous process via the arch of the lamina. Along with the relevant blood vessels, the dorsal ramus is closely connected to the medial fibers of the intertransverse ligament (Braus and Elze, 1921, 1954). According to Putz (1981), these medial fibers often ossify.

The joint capsule, the musculature, and the skin are innervated by the dorsal ramus and its branches, the medial (c) and lateral rami (d). Emminger (1954), Clemens (1971), Frick, Leonhardt, and Starck (1977) state that the dorsal ramus is solely responsible for innervation of the intervertebral joints. Loeweneck (1966) reports that the dorsal branch of the respective spinal nerves is solely responsible for innervation of the joint capsules of the lumbar joints. The meningeal ramus (Luschka, 1862) or sinuvertebral nerve, also known as the recurrent or dural ramus (Clara, 1959), returns into the intervertebral foramen and the vertebral canal, where it creates a neural plexus.

The meningeal ramus sometimes originates from the dorsal ramus (Stofft, 1977). According to Luschka (1862), it originates distally in the spinal ganglion and absorbs a number of the fibers from the sympathetic trunk before returning to the intervertebral foramen.

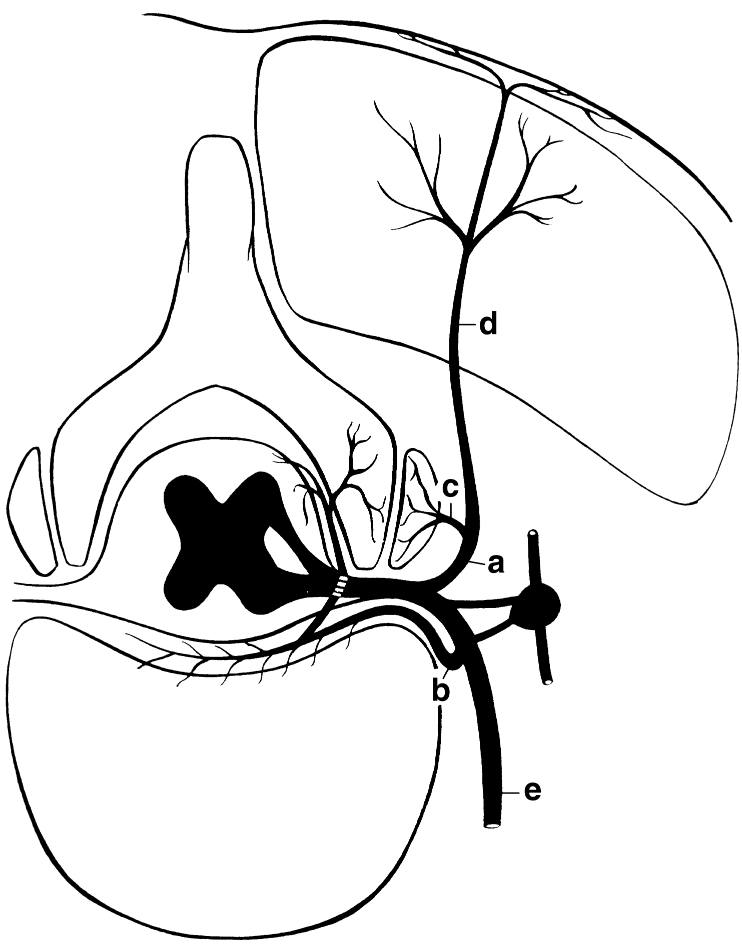

Figure 1–9 Innervation of intervertebral joints.

Grieve (1975) observes a close correlation between the meningeal ramus and the sympathetic system. In the cervical area, the meningeal branch originates in the plexus of sympathetic fibers surrounding the vertebral artery; in the thoracic area, it originates in the ganglia of the sympathetic trunk.

According to Krämer (1978), the meningeal ramus (together with its branches) supplies the innermost part of the joint capsule, periosteum, and posterior longitudinal ligament, as well as the meninges, with efferent, afferent, and sympathetic fibers.

With regard to pain in the spinal area, Vélé (1968) and Tilscher (1982) attribute a special significance to the meningeal ramus; the nerve branches for the dorsal parts of the atlanto-occipital joint capsule emerge from the ventral ramus (e) of the C1 and C2 spinal nerves (Loeweneck, 1966). Direct branches from the meningeal ramus also supply these capsules, in particular the ventral part of the atlantoaxial joint.

Schmorl and Junghanns (1968) point out that a motion segment is never supplied in a monoradicular way. Anastomoses between dorsal rami above and below occur predominantly in the cervical and lumbar area. The current view is that each segment helps meet the needs of adjacent superior and inferior segments (Paris, 1982) (**Figure 1–10**).

The outermost connective tissue layer of the ventral nerve root is probably innervated by sub-branches of the meningeal ramus; the dorsal nerve root is supplied by fibers from the spinal ganglion.

The peri- and epineurium of the ventral and dorsal ramus are supplied by branches of the nerve's own axons and by sub-branches of the perivascular nerve. The blood vessels inside and outside the vertebral canal and the intervertebral foramen are surrounded by plexi of unmyelinated, autonomic afferent and efferent nerve fibers. Running independently from the peripheral nerves, these nerves are hypothesized to provide the primary joint innervation of capsule and ligaments. From this, one might conclude that

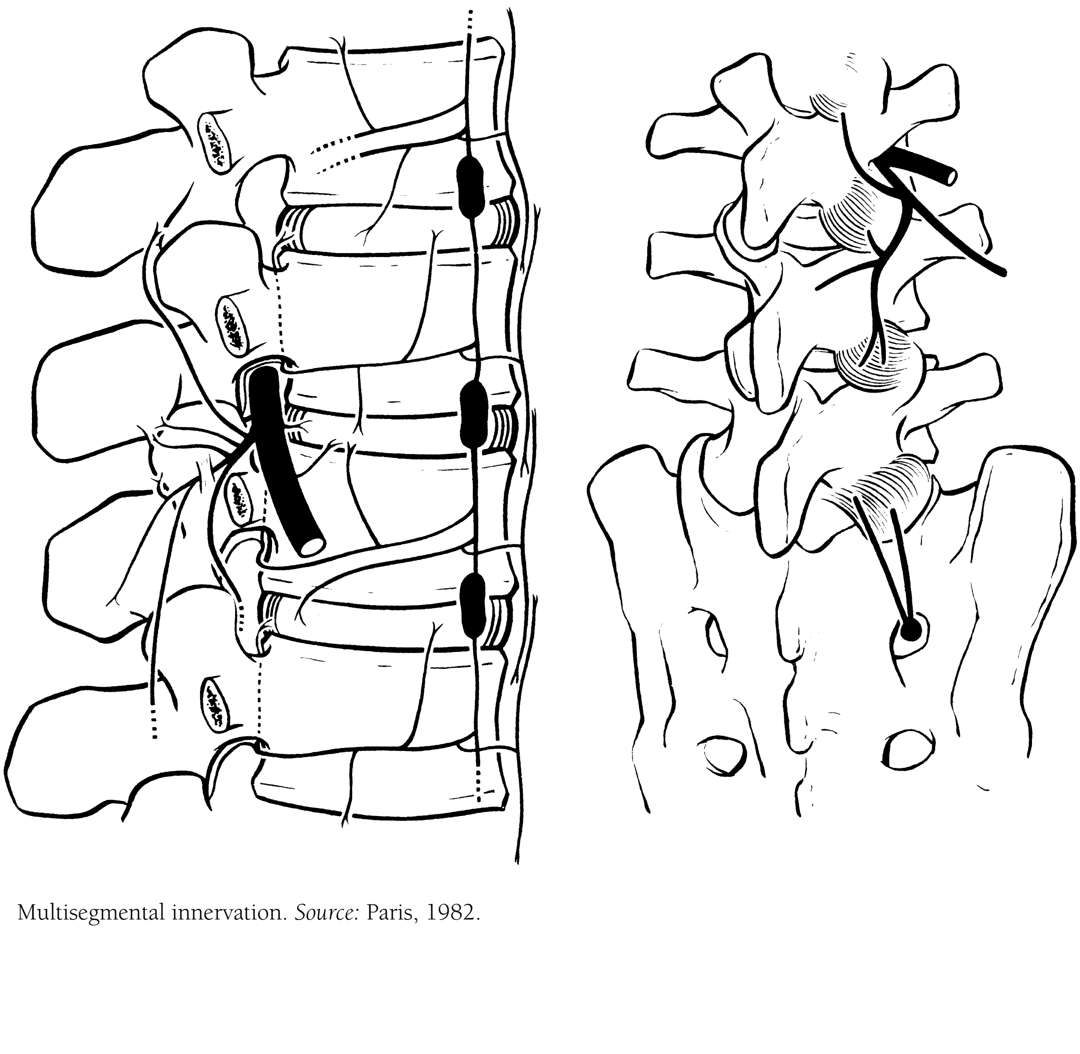

Figure 1–10 Multisegmental innervation. *Source:* Paris, 1982.

these nerves conduct nociceptive impulses (among others) from both blood vessels and the joint.

Ligaments

The anterior longitudinal ligament (a in **Figure 1–11**) runs as a broad band over the front of the vertebral bodies and anulus fibrosus, becoming the anterior atlanto-occipital membrane above the level of C2. The ligament is firmly attached to the intervertebral disk, the middle portion of the vertebral body, leaving free the ring apophyses (where osteophytes sometimes form).

The posterior longitudinal ligament (b) runs over the posterior aspect of the vertebral bodies and anulus fibrosus. This ligament is firmly attached to the intervertebral disk and the upper- and lowermost sections of the vertebral bodies, leaving the vertebral body mid portions free for the venous plexus. This ligament grows thinner as it courses from cranial to caudal.

In the lumbar section, it presents as a thin cord that does not cover the dorsolateral surfaces of the disk. At the same level as the disk, a few fibers of the ligament run obliquely in a caudal direction toward the roots of the vertebral arches. In disk pathology, these fibers can become tensioned and cause periosteal pain, which must be differentiated from joint pain.

The flaval ligament (c) extends between two adjacent arches over the entire dorsal side of the spine and is,

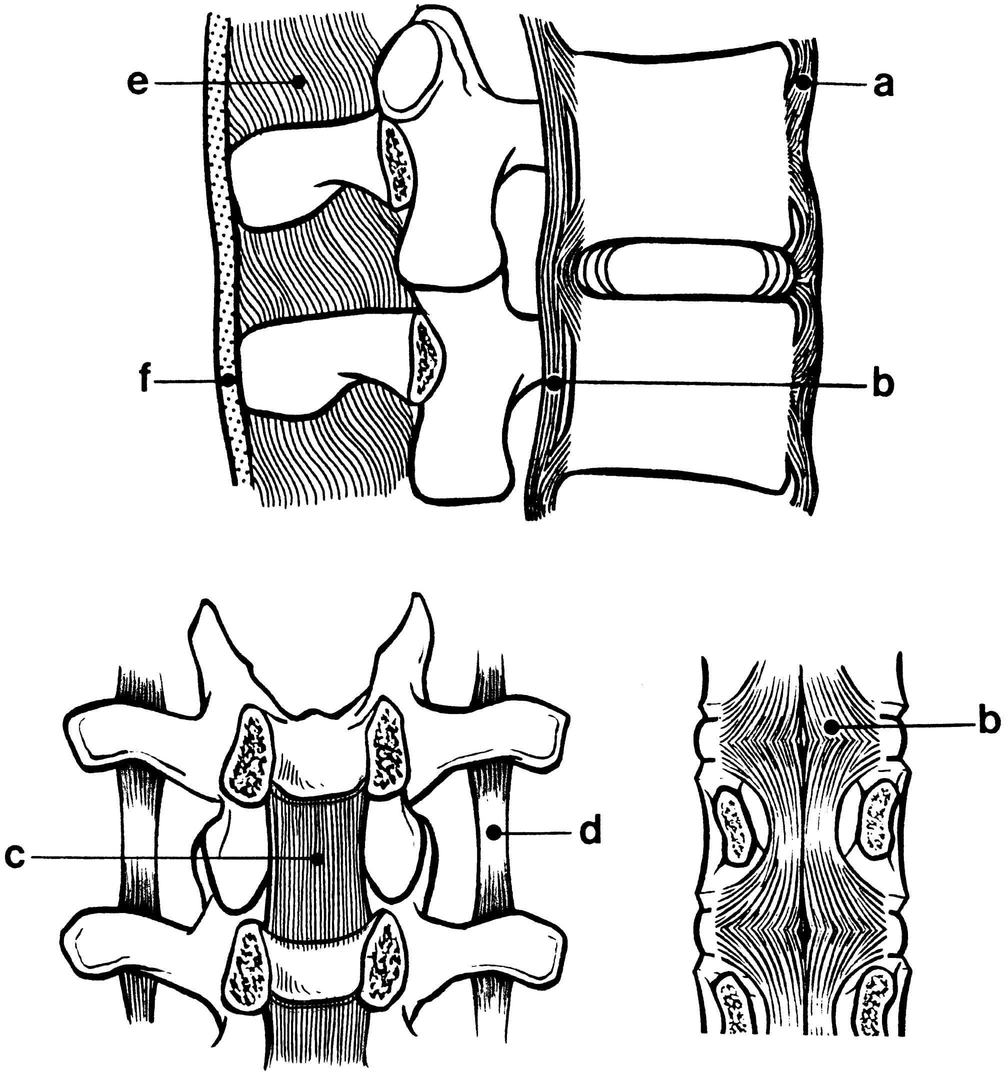

Figure 1–11 Ligaments.

therefore, a component of the spinal canal. The ligament thickens caudally—it is also highly elastic, which is of extreme functional importance to the spinal cord. When flexion occurs, its length increases by 40% (Penning, 1978). All the way down the spine, the intertransverse ligament (d) and interspinous ligament (e) extend between two adjacent transverse and spinous processes, respectively.

The supraspinous ligament (f) connects the posteriormost aspects of the adjacent spinous processes along the whole length of the spine and, at the level of the C7 spinous process, becomes the elastic nuchal ligament, which connects the cervical spinous processes from T2 to C5 inclusive with the posterior tubercle of the atlas, the external occipital crest, and the external occipital protuberance. The ligaments referred to here guarantee both the stability of the spine and its mobility. In terms of movement, they have a guiding and movement-limiting function in keeping with their position relative to the axis of movement.

Uncovertebral Joint

As well as intervertebral joints, the cervical spine contains uncovertebral joints (Luschka's joints; Luschka, 1862). These joints are located on the dorsolateral aspect of the cervical vertebral bodies (**Figure 1–12**). They are bony ridges that articulate with each other and provide lateral stability. These uncovertebral joints are the first place where decompensation caused by excessive strain will show up in X-rays (Penning, 1978)—this is known as uncarthrosis.

Because the axis of rotation is located below the plane of the disk, the movement of flexion/extension results in a translatory movement between adjacent vertebrae and consequently a functional disk deformation, which is greatest at the location of the uncovertebral joints. As a result of the vertical position of the uncinate process, this is where the distance between two vertebral bodies is smallest, while the distance to the axis of rotation is largest.

The load on the uncovertebral joints increases as the disk grows thinner with age. Usually, the thinning of the disk begins in segment C5–C6, where the average level of mobility is greatest.

Joints Between the Occiput, Atlas, and Axis

The joints between the occiput, atlas, and axis (**Figure 1–13**) can be classified as follows:

- Atlanto-occipital joint (a)
- Atlanto-odontoid joint (b)
- Atlantoaxial joint (c)

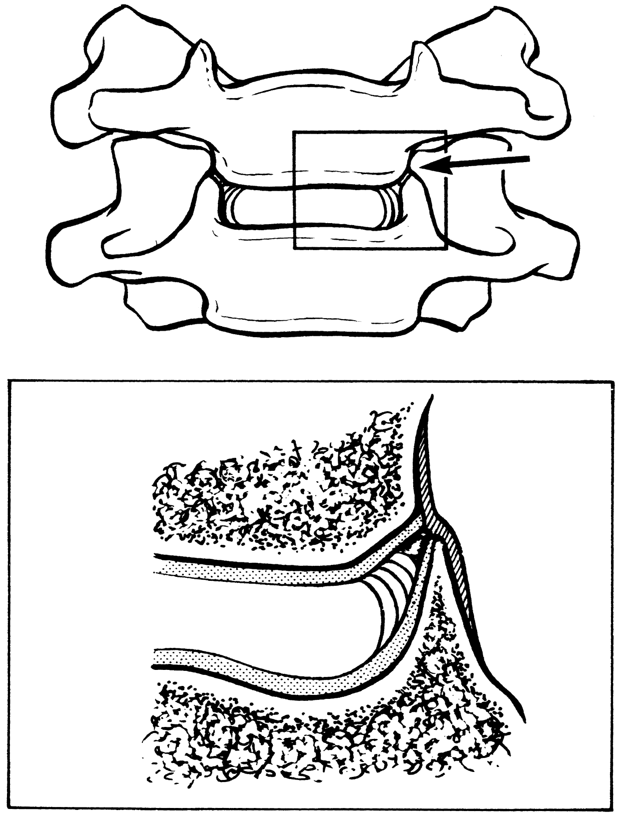

Figure 1–12 Uncovertebral joint.

These joints are constructed differently from any other intervertebral joints. There is no intervertebral disk between the atlas and the occiput and between the atlas and the axis, and the dens of the axis takes the place of the body of the atlas. On the superior aspect of the lateral masses of the atlas, there are two oval articular facets that are concave in both the sagittal and the frontal planes. The longitudinal axes converge medioventrally. The convex occipital condyles articulate with these articular facets.

The connection between atlas and axis is composed of three joints: the atlantoaxial joints are located laterally and are made up of biconvex articular facets both on the lower side of the atlas and on the upper side of the axis.

In the center is the median atlantoaxial joint, the joint composed of the dens of the axis, the anterior arch of the atlas, and the transverse atlantal ligament. The transverse atlantal ligament and the anterior arch of the atlas have an articular facet (cava articularis) on their inner surface.

The individual joints are reinforced by a number of ligamentous structures. The transverse atlantal ligament is

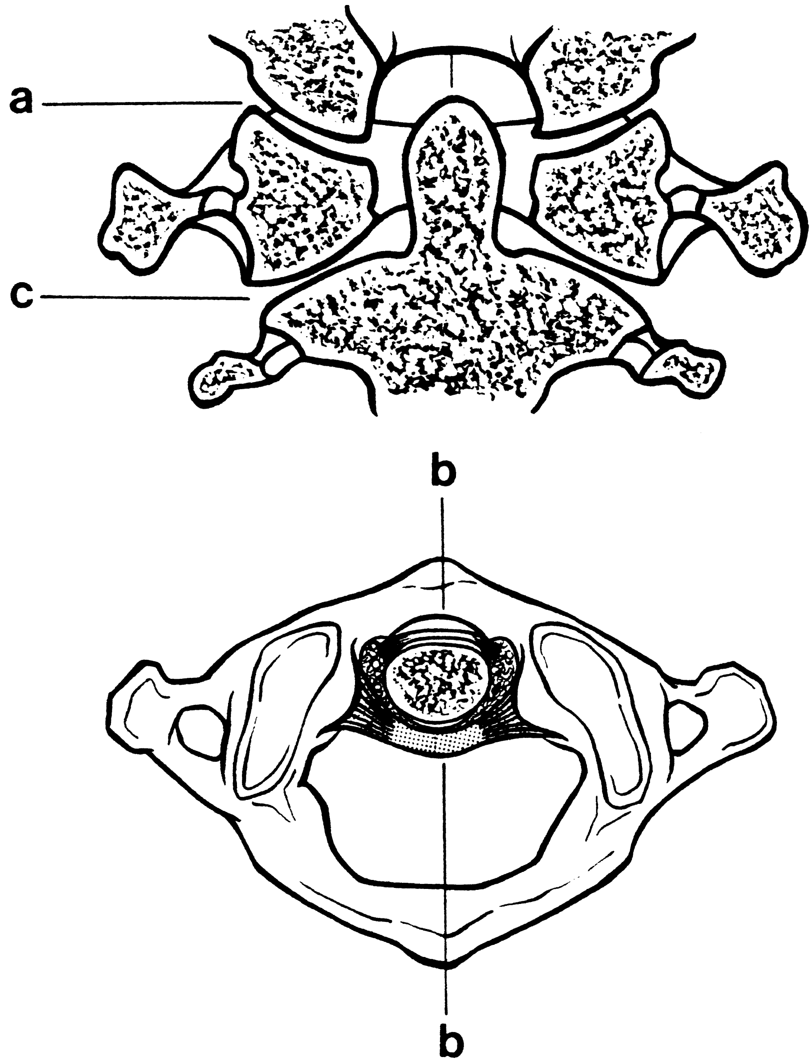

Figure 1–13 Joints between the occiput, atlas, and axis.

complemented by longitudinal fibers running cranially toward the anterior aspect of the foramen magnum and caudally toward the body of the axis. Together, they form the cruciate ligament of the atlas.

From the tip of the dens, the apical ligament of dens also runs toward the anterior aspect of the foramen magnum.

The alar ligaments extend between the back and the front of the tip of the dens and the lateroventral side of the foramen magnum and the medial side of the occipital condyles. Furthermore, in many of the cases mentioned previously, they form a connection between the dens and the lateral masses of the atlas. All ligaments noted previously course within the vertebral canal and are covered by the tectorial membrane. The anterior atlanto-occipital membrane is located on the front between the occiput and the atlas; the posterior atlanto-occipital membrane is located posteriorly.

The anterior and posterior atlantoaxial membranes are located between atlas and axis. The specific motion characteristics of the C0–C2 complex are determined by the variations in morphology and the ligamentous structure as well as by the absence of an intervertebral disk.

With their local musculature, the atlanto-occipital and atlantoaxial joints are the only joints in the entire spine capable of independent movement.

Costovertebral Joints and Costosternal Connections

Costovertebral Joints

Costovertebral joints are made up of two synovial joints, the costovertebral and the costotransverse joint (**Figure 1–14**).

The costovertebral joints 1, (in some subjects 10), 11, and 12 are formed by the head of the rib and the superior costal facet of the thoracic vertebra of the same number.

For ribs 2 to 9 (10) inclusive, the superior costal facet of the vertebra of the same number, the intervertebral disk above, and the inferior costal facet of the vertebra above combine to form the joint cavity. These ribs contain a bony crest on the head of the rib, connected to the outermost layers of the anulus fibrosus by way of the intra-articular ligament of the head of the rib (a). This ligament divides the joint cavity into two incompletely separated compartments.

The capsular radiate ligament of the head of the rib (b) radiates from the head of the rib over the periphery of the corresponding joint. Three sections—superior, intermediate, and inferior—can be distinguished in this ligament. Their respective attachment places are the vertebra above, the intervertebral disk, and the vertebra of the same number.

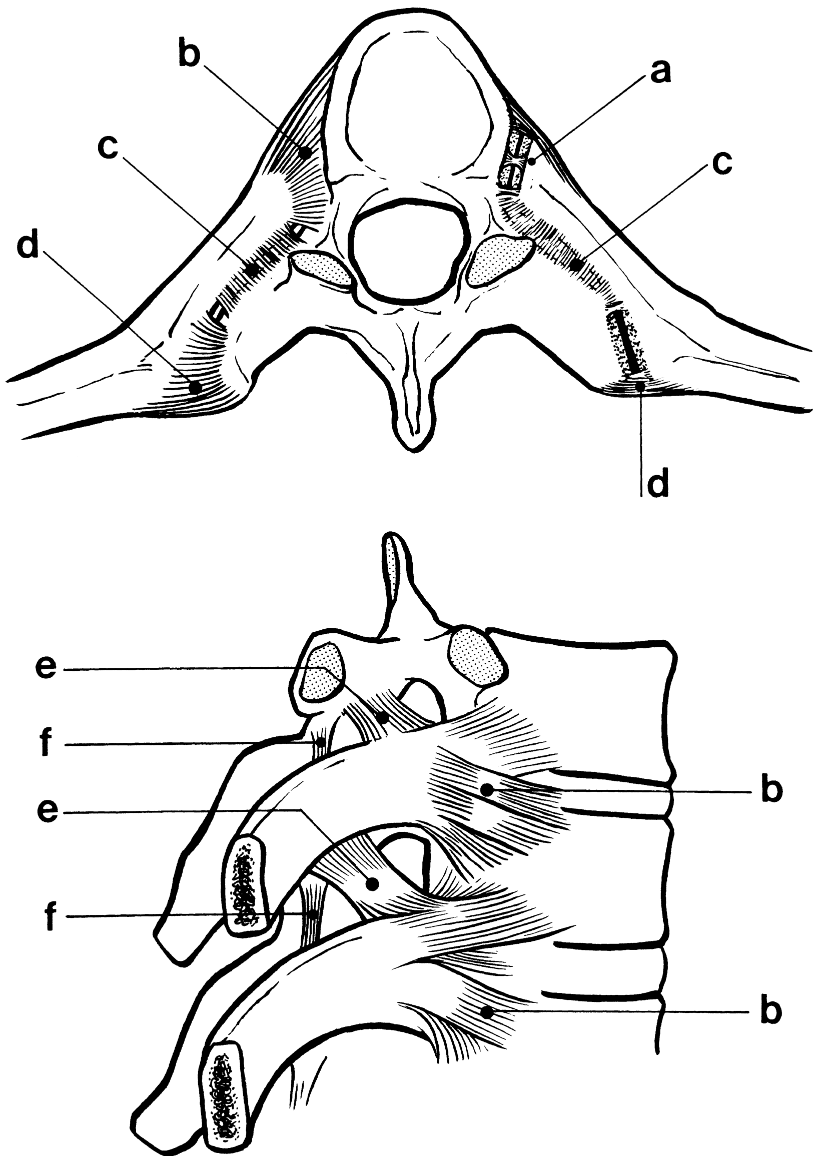

Figure 1–14 Costovertebral joints.

The costotransverse joint is formed by the articular facet of the tubercle of rib and the costal facet on the transverse process. This joint is absent in the 11th and 12th ribs. Relatively loose, the capsule is strengthened by a few extracapsular ligaments.

The costotransverse ligament or ligament from the neck of the rib (c) extends from the dorsal side of the neck of the rib to the ventral side of the transverse process, completely filling the space between them. The lateral costotransverse ligament or ligament from the tubercle of the rib (d) connects the tubercle of the rib with the tip of the transverse process.

The anterior costotransverse ligament (e) connects the bony crest on the neck of the rib with the ventrocaudal aspect of the transverse process above. The posterior costotransverse ligament (f) connects the neck of rib with the dorsocaudal side of the transverse process above and the base of the lamina above. The lumbocostal ligament connects the caudal side of the 12th rib with the tips of the costal processes of the first and second lumbar vertebrae.

The two costovertebral joints form a mechanical entity with the axis of movement (axis of rotation) running through the middle of both joints. The axis of the upper costovertebral joints runs in more or less a frontal orientation.

The axis of the middle thoracic costovertebral joints runs obliquely at an angle of 45° to the sagittal plane. The axis of the lower costovertebral joints runs in a sagittal orientation.

Costosternal Connections

The costosternal connections consist of synovial joints called the sternocostal joints (**Figure 1–15**). These joints are formed where the costal notches of the sternal body join the cartilaginous tips of the true ribs 2 to 7 inclusive.

The first rib, which has no joint cavity, is a synchrondosis and is attached to the manubrium. This rib is attached to the clavicula by way of the costoclavicular ligament. The costal notch of the second rib is located at the transitional area between the manubrium and the body of the sternum (**Figure 1–16**).

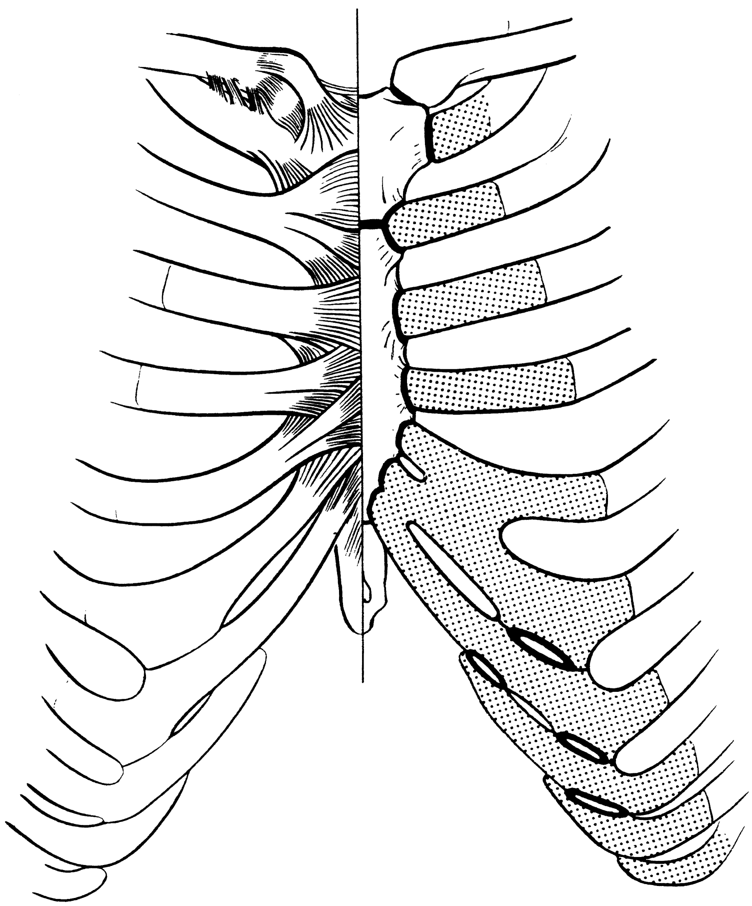

Figure 1–15 Costosternal connections.

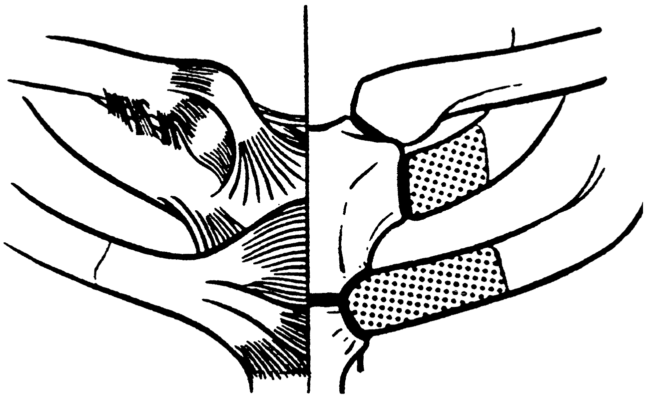

Figure 1–16 Costosternal connection of ribs 1 and 2.

The interarticular sternocostal ligament attaches the tip of the second rib's cartilage with the cartilage between the manubrium and the body of the sternum. The relatively tight capsules of the costosternal joints are strengthened at the front by the radiate sternocostal ligament, which radiates into the ventral aspect of the sternum, where it strengthens the periosteum of the sternum. Together they are called the sternal membranes.

Finally, the costoxiphoid ligaments attach the ventral aspect of the xiphoid process to the cartilaginous tips of the sixth and seventh ribs. The cartilage components of ribs 8 to 10 inclusive, the vertebrochondral ribs, are attached to each other and have indirect contact with the sternum by way of the cartilage of the seventh rib. These cartilaginous joints, also located between the fifth, sixth, and seventh ribs, are called interchondral joints.

The internal and external intercostal membranes, with fibers that take the same path as those of the internal and external intercostal muscle, are located in between the cartilaginous parts of the ribs. They are considered syndesmoses.

Sternum

The sternum (**Figure 1–17**) is composed of the sternal manubrium, the body of the sternum, and the xiphoid process.

At its superior aspect, the sternal manubrium has a jugular notch; bilaterally, it has a clavicular notch and a costal notch for the first and second ribs. The joint between manubrium and body of the sternum is called the sternal synchondrosis, and the angle between the two bones is the sternal angle. The body of the sternum contains the costal notch of ribs 2 to 7 inclusive. The ventral aspect of the body of the sternum is called the sternal plane.

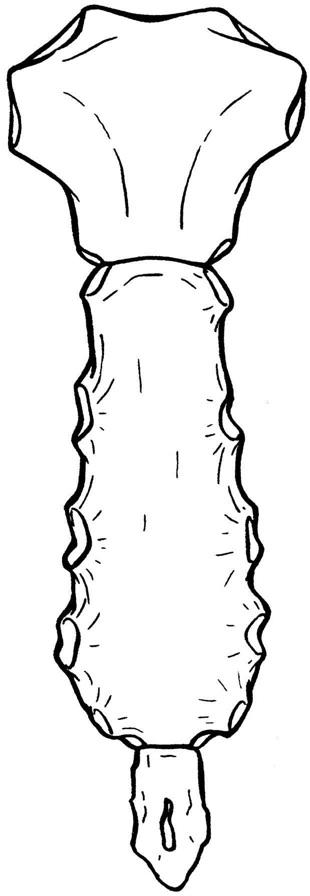

Figure 1–17 Sternum.

The efficient functioning of the costovertebral and costosternal joints is important not only to the breathing process, but also to the movement of the thoracic spine and everything related to it (see Chapter 15, "Examination of the Thoracic Spine").

Pelvis

Together with the diaphragm and the abdominal, back, and pelvic floor muscles, the pelvis (**Figure 1–18**) forms the abdominal and pelvic cavity and connects the spine to the lower extremities. The pelvis is a closed bony ring, composed of three joints and three bones—the two innominates and the sacrum. The innominates (**Figure 1–19**) are formed by the union of three initially separate bones: the ilial bone, the ischial bone, and the pubic bone.

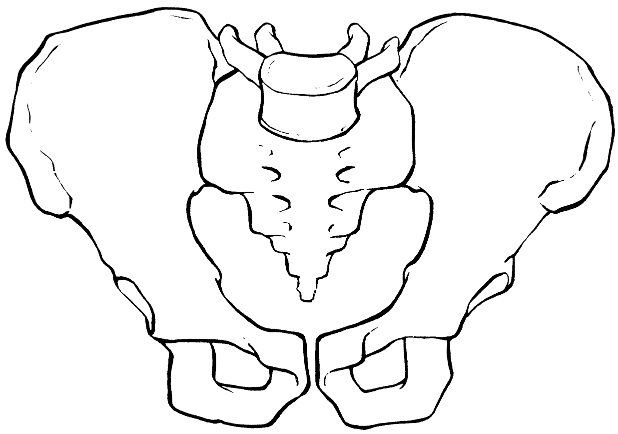

Figure 1–18 Pelvis.

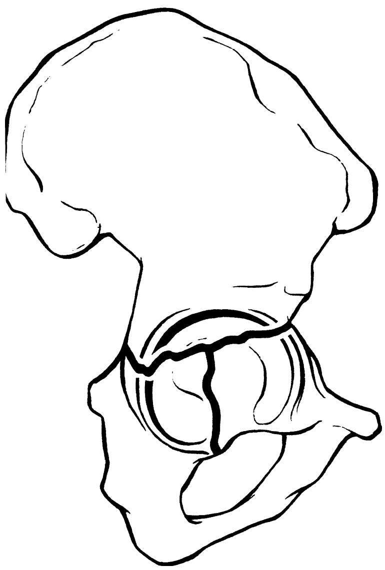

Figure 1–19 Innominates.

Ilial Bone

The components of the ilial bone are the ilial body; the ilial wing; ventromedially, the arcuate lines on the ilial wing; cranially, the ilial crest, with the superior and inferior anterior ilial spines on the ventral aspect, and the posterior superior and inferior ilial spines on the dorsal aspect; the ilial fossa on its ventral aspect; on the dorsal aspect, the gluteal surface with the anterior, posterior, and inferior gluteal line and the auricular surface on its medial aspect.

Ischial Bone

The ischial bone is composed of the ischial body, the superior and inferior ischial branches, the ischial tuberosity, the ischial spine, and the greater and lesser ischial notches.

Pubic Bone

The pubic bone is formed by the pubic body, the superior and inferior pubic branches, the pubic arch (made up of both inferior pubic branches), the symphyseal surface, the pubic crest, the pectineal line, the pubic tubercle, the iliopectineal eminence, and the posterior obturator crest.

Acetabulum

The acetabulum is made up of the bodies of the three bones described previously and the following: the acetabular fossa, the acetabular notch, and the lunate surface.

The obturator foramen is composed of the bodies of the innominate bones and branches from the pubic bone and the ischial bone.

Sacrum

The sacrum (**Figure 1–20**) is formed by the union of five initially separate sacral vertebrae and articulates caudally to the coccyx. The elements of the sacrum are, cranially, the sacral base, the sacral promontory, and the superior articular processes with the mamillary processes; caudally, the sacral apex, and the sacral hiatus with the sacral horns; ventrally, the pelvic surface, the pelvic sacral foramina, and the transverse lines; dorsally, the dorsal surface, and the dorsal sacral foramina; laterally, the lateral part with the auricular surface on the side of its uppermost portion. The lateral mass is located craniolaterally.

From medial to lateral, there is on the dorsal side the median sacral crest, the intermediate sacral crest, and the lateral sacral crest.

Coccyx

The coccyx is composed of three or four coccygeal vertebrae.

Pelvic Parameters

The pelvis is composed of the pelvic inlet, the pelvic midplane, and the pelvic outlet (**Figure 1–21**).

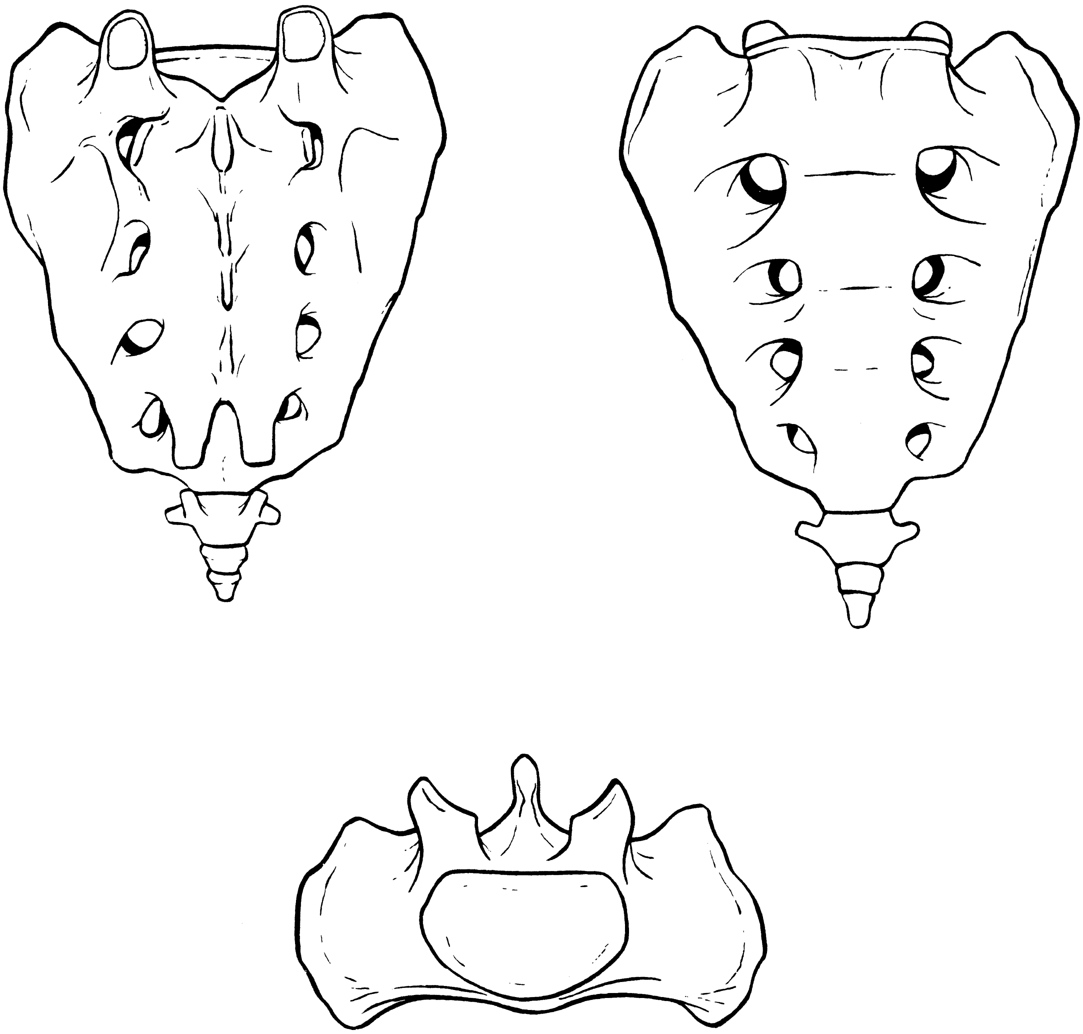

Figure 1–20 Sacrum.

The pelvic inlet is defined by the arcuate line, which extends to the pubic crest and the promontory, thus forming the iliopectineal line (a). This line divides the pelvis into the false and true pelvis. The pelvic midplane is the level defined by an imaginary line between the middle of the posterior aspect of the pubic symphysis and the middle of the connection of the ischial spines.

The pelvic outlet is defined by the pubic arch, the ischial tuberosities, and the coccygeal apex.

Other morphologic characteristics of the pelvis include the true conjugate diameter (b) between the sacral promontory and the superior aspect of the symphysis, the diagonal conjugate diameter (c) between the inferior aspect of the symphysis and the sacral promontory, the transverse diameter (d) between the left and right sections of the iliopectineal line, where the distance between these sections is the greatest, the sagittal diameter (e) between the coccygeal apex and the inferior aspect of the symphysis, and the oblique diameter (f) between the sacroiliac joint and the iliopectineal eminence.

Pelvic Joints

The four joints of the pelvis are the following:

- Two sacroiliac joints
- Pubic symphysis
- Sacrococcygeal joint

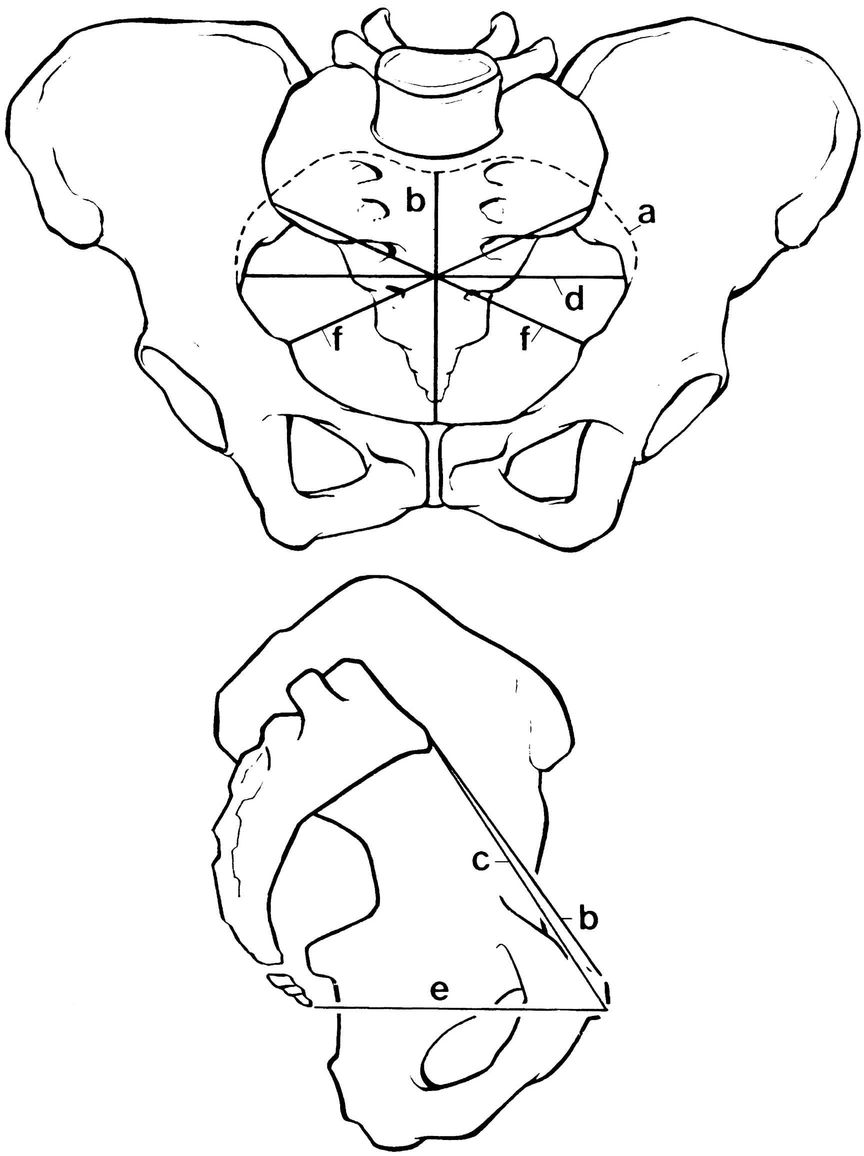

Figure 1–21 Pelvic parameters.

Sacroiliac Joint

The sacroiliac joint (**Figure 1–22**) is composed of the auricular surfaces of the ilial bone and of the sacrum. The articular facets are covered with fibrocartilage. Although these joint surfaces are largely irregular, some researchers have attempted to establish a relationship between a specific morphology and its function. Faraboef (Kapandji, 1974) described a long crest along the length of the auricular surface of the ilial bone, which he considered part of a circle with its midpoint situated on the S2 sacral tuberosity. Strong sacroiliac ligaments are also attached here. In the center of the auricular surface of the sacrum there are two crests, which are also part of a circle with a center located at the S1 transverse tubercle. Here, too, strong sacroiliac ligaments are attached.

According to Faraboef (Kapandji, 1974), the crests mentioned here are matching—although research based on a few dissections indicated that this is not entirely true. Delmas (1950) established that in the dynamic type with a

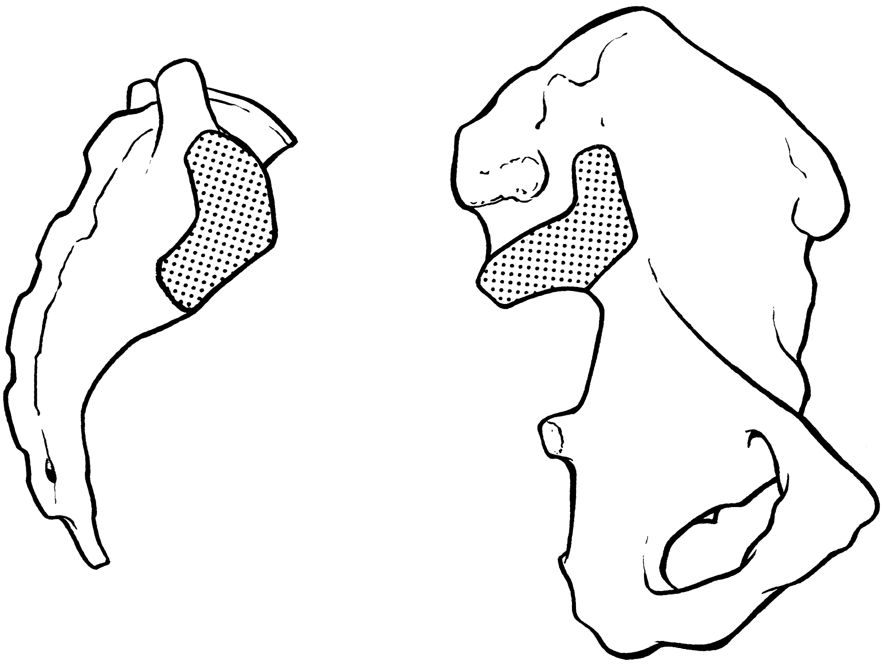

Figure 1–22 Sacroiliac joint.

horizontal pelvis, the sacroiliac joints allow more movement than is allowed by the joints in the static type that are longer in a vertical direction.

Weisl (1955) specifically studied the surface contours of the articular surfaces. He established that of the two segments the cranial is normally longer and thinner than the caudal. He also described a small depression in the center where the two segments of articular surface of the sacrum meet, and two small bulges near the corners of both segments. On the ilial articular surface, the center of the transition between the two segments exhibits a small prominence, known as Bonnaire's tubercle (Kapandji, 1974). Weisl suggested that it may correspond to the depression in the center of the sacral joint surface.

The ligamentous structure of the sacroiliac joint consists of the following structures, as shown in **Figure 1–23**:

- The superior iliolumbar ligament (a) extending from the inner rim of the ilial bone to the L4 transverse process
- The inferior iliolumbar ligament (b) extending from the inner rim of the ilial bone (and the sacrum) to the L5 transverse process
- The superior interosseous sacroiliac ligament (c) extending from the ilial crest to the S1 transverse sacral tuberosity
- The posterior sacroiliac ligaments (d) extending from the dorsal rim of the ilial bone to the sacral tuberosity
- The superior (e) and inferior (f) anterior sacroiliac ligaments between the ventral rim of the ilial bone and the ventral side of the sacrum
- The sacrospinous ligament (g) extending obliquely from the lateral rim of the sacrum and the coccygeal bone to the ischial spine
- The sacrotuberous ligament (h) extending between the dorsal rim of the ilial bone, the sacrum, the first two vertebrae of the coccyx, and the ischial tuberosity and ramus of the ischial bone

These last two ligaments form the superior and inferior ischial foramina. The obturator foramen is covered by the obturator membrane.

Pubic Symphysis

The pubic symphysis (**Figure 1–24**) is composed of the two cartilage-covered symphyseal surfaces of the pubic bone and the fibrocartilaginous interpubic disk. The disk has a fissure in the center and is connected to the pubic bone by the interosseous ligament (a). It is a secondary cartilaginous joint (amphiarthrosis) and not very mobile.

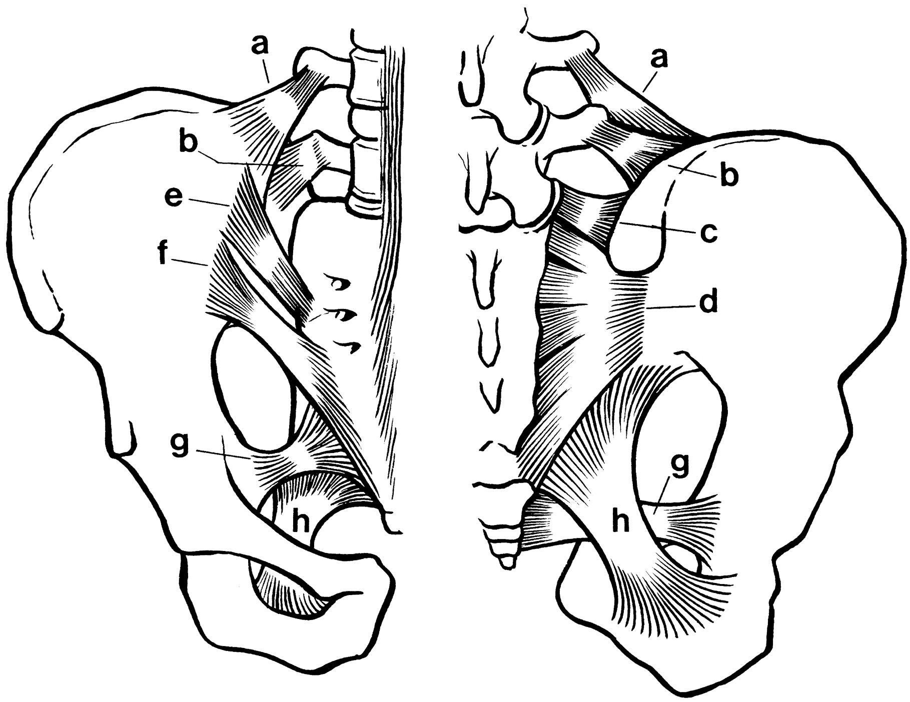

Figure 1–23 The ligamentous structure of the sacroiliac joint.

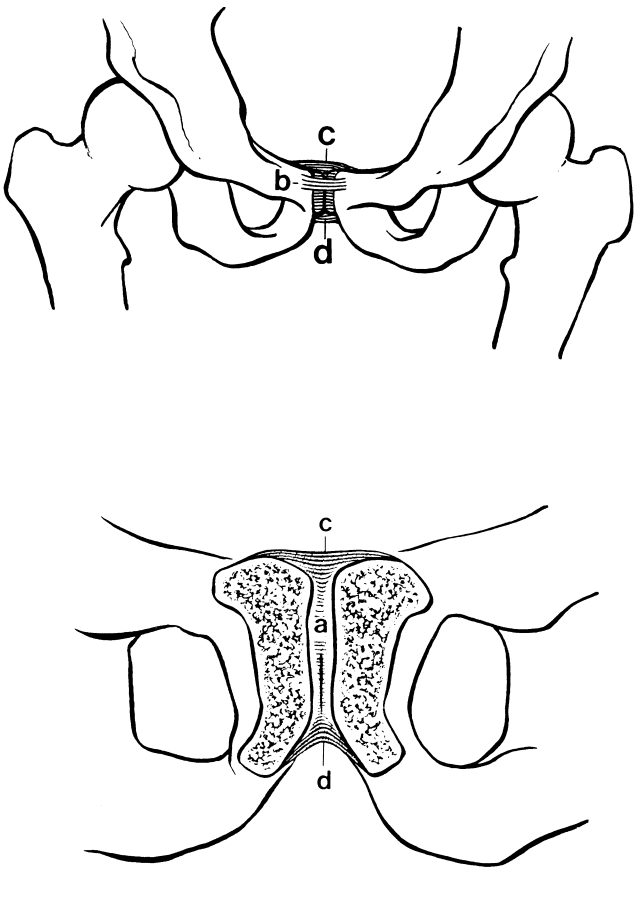

Figure 1–24 Pubic symphysis connections.

The following ligaments are part of this joint:

- The anterior pubic ligament (b), a thick ligament covering the joint at the front and composed of diagonal and oblique fibers.
- The extensions of the aponeurosis of the transverse abdominis, rectus abdominis, pyramidalis, internal oblique, and adductor longus muscles that run obliquely over the anterior aspect of the joint, together forming a tight fibrous network.
- The posterior pubic ligament (d), a fibrous membrane that represents an extension of the periost at the back.
- The posterior pubic ligament (c), a thick fibrous ligament on the superior aspect of the joint. The arcuate pubic ligament turns into the interosseal ligament on the inferior aspect of the joint.

Sacrococcygeal Joint

The sacrococcygeal joint (**Figure 1–25**) is a secondary cartilaginous joint (amphiarthrosis). The sacral articular facet is convex and the coccygeal one is concave. The joint has an interosseous ligament (a), an anterior sacrococcygeal

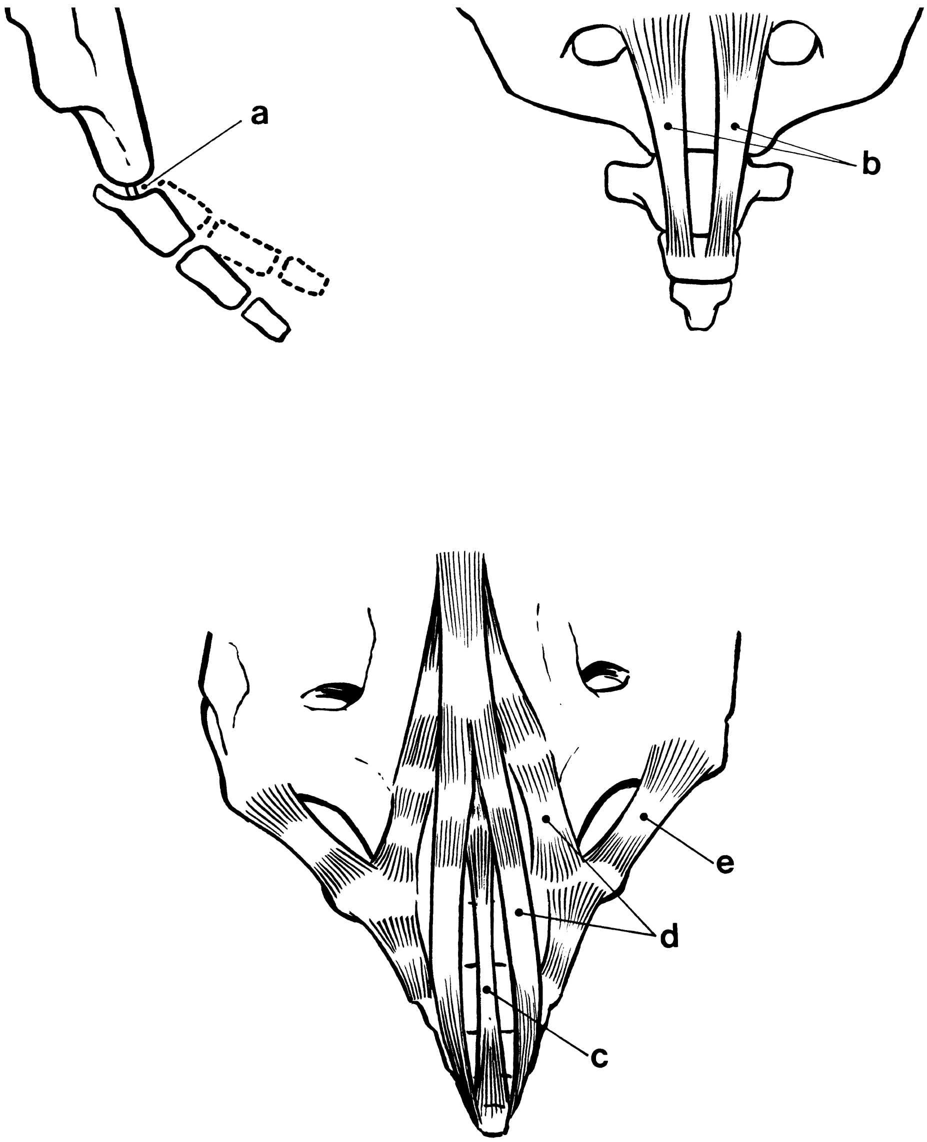

Figure 1–25 Sacrococcygeal joint and ligaments.

ligament (b), deep (c) and superficial (d) posterior sacrococcygeal ligaments, and a lateral sacrococcygeal ligament (e).

Lumbopelvic Angles

De Sèze (1961) provides some average angular values (measured while at rest) in relation to the lumbosacral junction, as shown in **Figure 1–26**:

- The lumbosacral angle, formed by the L5 to sacrum transition, is 140° (α).
- The sacral inclination angle, formed by the base of the sacrum and the horizontal plane, is 30° (β).
- The pelvic inclination angle, formed by the true conjugate diameter and the horizontal plane, is 60° (γ).

The lumbar lordosis is considered normal if the line between the posterior border of the superior aspect of L1 and the superior border of the inferior aspect of L5 coincides with a plumb line descending from the back of the superior aspect of L1. The apex of the lordosis should be at L3 (a).

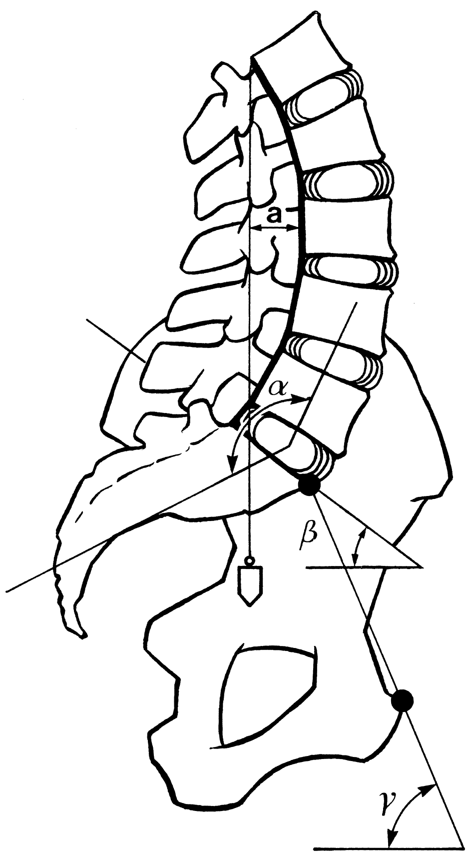

Figure 1–26 Lumbopelvic angles.

Spinal Musculature

Muscle Location

The muscles responsible for maintaining the shape of the spine and for carrying out movements are represented schematically in **Figure 1–27**. They are largely part of the erector muscles of the spine. Although it is often hard to distinguish the individual muscles of the erector of the

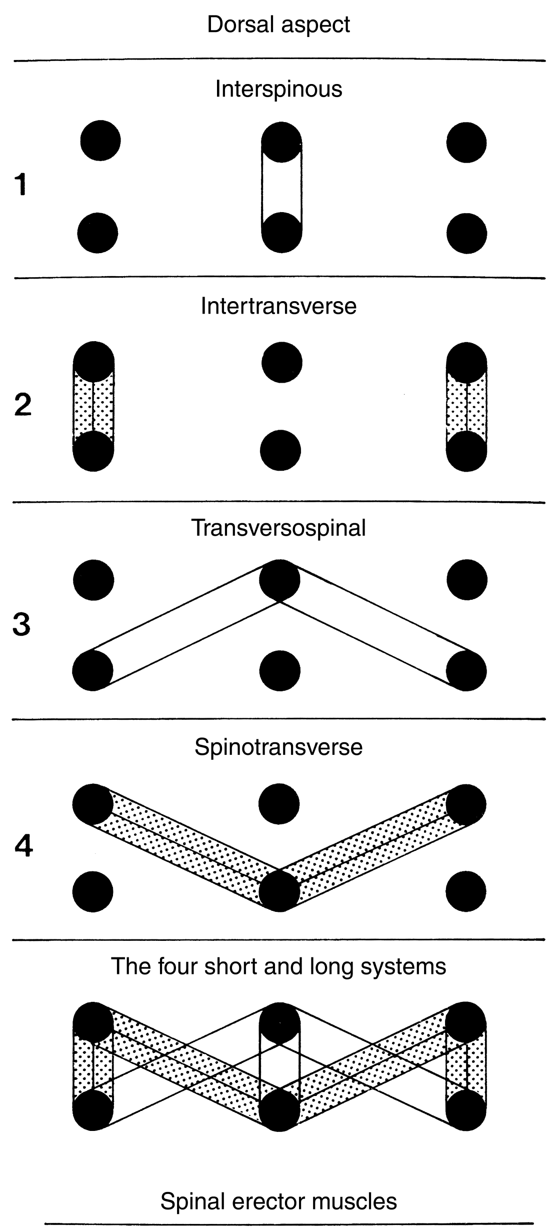

Figure 1–27 Schematic functional outline of spinal erector muscles.

spine in tissue preparations, it is functionally useful to make a distinction between short and long elements within this group.

The short muscles are medially located and fill the space between the spinous processes and the costal angles. The interspinous, intertransverse, and transversospinous muscles belong to this group.

The transversospinous muscles run between the transverse process and the higher spinous processes and include the rotatores muscles (which insert one or two spinous processes higher up), the multifidi muscles (which span four vertebrae), and the semispinalis muscles (which as a group span six vertebrae).

The semispinalis muscle is divided into the semispinalis thoracis, the semispinalis cervicis, and the semispinalis capitis, which inserts into the superior nuchal line of the back of the head. Of the long muscles, only the spinalis muscle is positioned medially. The short fibers of this muscle lie deep and connect a few adjacent vertebrae; the long fibers connect more remote spinous processes with each other. The lateral long muscles are composed of the longissimus and the iliocostalis muscles positioned lateral to the longissimus. The longissimus muscle runs both cranially and laterally from the sacrum and also from the transverse processes to the costal angles. The uppermost section, the longissimus capitis, inserts into the back of the mastoid process.

The lumbar part of the iliocostalis muscle originates from the pelvis and attaches laterally to the costal angles of the lowermost ribs. The thoracic part of the iliocostalis runs from the lowest ribs to the costal angles of the more cranial ribs. The cervical part of the iliocostalis runs from the rib angles of the uppermost ribs to the transverse processes of the cervical vertebrae. In the cervical portion of the spine, the erector muscles of the spine are complemented by the more superficially located splenius muscles. The splenius cervicis muscle originates from the spinous processes of the uppermost thoracic and lower cervical vertebrae and inserts into the transverse processes of the upper cervical vertebrae.

The splenius capitis muscle originates from the lateral portion of the nuchal ligament and from the four uppermost cervical spinous processes. The muscle inserts into the superior nuchal line and into the mastoid process.

As shown in **Figure 1–28**, The sternocleidomastoid muscle (a), the scalene muscles (b), and the short suboccipital muscles (c) also belong to the group of muscles that perform an important function with regard to movements of the head and neck.

The sternocleidomastoid muscle has a sternal origin at the ventral surface of the sternal manubrium and a clavicular origin at the sternal end of the clavicle. The two heads join and insert into the mastoid process.

The anterior, middle, and posterior scalene muscles originate from the anterior tubercles, the spinal grooves, and the posterior tubercles of the transverse processes of the third to seventh cervical vertebrae, respectively.

The anterior and middle scalene muscles insert into the tubercle of the anterior scalene muscle and the subclavian artery groove of the first rib, respectively.

The posterior scalene muscle inserts into the second rib.

The brachial plexus and the subclavian artery run through the triangular foramen formed by the anterior and middle scalene muscles.

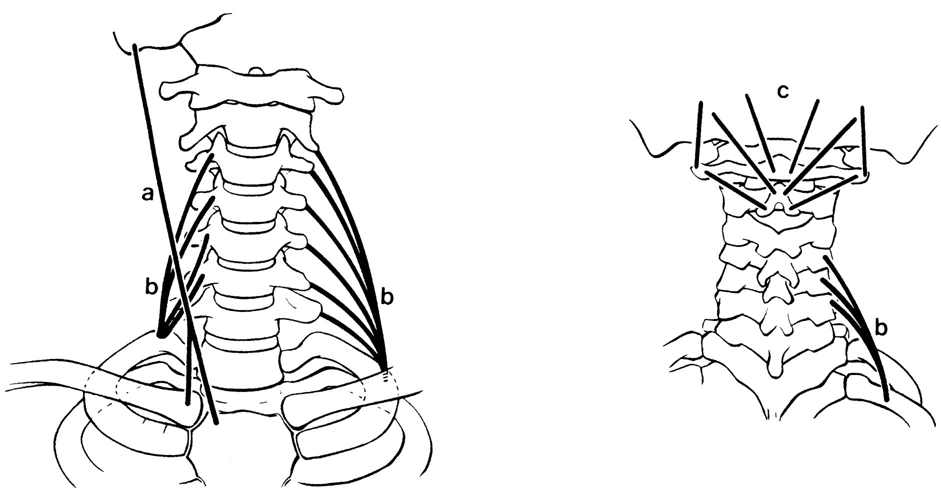

Figure 1–28 Mid- and upper-cervical muscles.

The suboccipital muscles connect the upper two cervical vertebrae with the occipital bone. The rectus capitis posterior major muscle lies dorsally, running from the spinous process of the axis to the lateral part of the inferior nuchal line. The rectus capitis posterior minor muscle originates from the posterior tubercle of the atlas and inserts into the middle portion of the inferior nuchal line.

The obliquus capitis inferior muscle connects the spinous process of C2 with the transverse process of the atlas; the obliquus capitis superior muscle connects the transverse process of the atlas with the lateral part of the inferior nuchal line.

On the ventral aspect, the rectus capitis anterior muscle runs from the lateral mass of the atlas to the basilar portion of the occipital bone, and the rectus capitis lateralis muscle runs from the transverse process of the atlas to the jugular process of the occipital bone.