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Editors

Spine Surgery Basics

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To our families for all the support and to Heidi Armbruster for all the organization to make this project possible.

Preface

The stronger the foundation, the grander the possibilities!

The purpose of this textbook is to lay the foundation of spine education for medical students, residents, fellows, and junior attendings. It provides a concise and accurate methodology to understanding and diagnosing different spine conditions followed by the basics of treatment. This textbook will, thus, provide the link between education, optimized clinical evaluation, and evidence-based decision making.

This is especially relevant today as with an enlarging and aging population, spinal diseases will become more prevalent. Already back pain is the second most common complaint for which patients seek care after the common cold. Concurrently, the past two decades have seen an explosion of technology utilization in patient care. This has led to students and naive practioners diagnosing by exclusion-based testing as opposed to using sound clinical judgement. As healthcare funding becomes limited, this current trend in utilization of special high-end testing and imaging will be unsustainable. The skills to obtain an accurate, real-time clinical diagnosis and treatment plan will be in high demand. In the ever growing plethora of diagnoses, adhering to basics will provide the knowledge and framework necessary to make the correct decision for the patient.

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Part I

General

Anatomy

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Christopher M.J. Cain

1.1 Overview

The normal vertebral column, excluding the coccyx, is made up of 25 segments, 7 cervical, 12 thoracic and 5 lumbar vertebrae, and the sacrum. The sagittal profile of the spine is curved with lordosis in the cervical and lumbar regions and kyphosis in the thoracic region (Fig. 1.1). The normal curvature of the spine results in C1, C7 and T12 being aligned vertically over the sacrum. This represents normal spinal balance.

1.2 Embryology

Vertebral formation begins around 3–5 weeks after fertilization of the egg, with segmentation and chondrification occurring around 6–8 weeks. Each vertebra forms from two adjacent sclerotomes. The caudal or posterior half of one sclerotome fuses with the rostral or anterior half of the adjacent one to form each vertebra, making each vertebra an inter-segment structure.

Chondrification centres appear in each mesenchymal vertebra in the 5th to 6th week. The cartilaginous centrum forms with components from each sclerotome, which usually fuse by the end of the embryonic period (from the 15th day to around the 8th week). The centrum ultimately becomes the vertebral body, and defects in formation or fusion of the centrum may result in hemi- or butterfly vertebrae.

Ossification of the vertebrae occurs in three parts, the centrum and the right and left halves of the neural arch. This process begins at the end of the embryonic period.

The two centres in the neural arches usually fuse with each other at the end of the first year and with the centrum in the third to sixth year. Costal elements form separately as the ribs in the thoracic region and articulate with the neural arches. In all other parts of the spine, costal elements become fused to the neural arches and become integrated as morphological parts of the vertebrae, principally the transverse process.

Five secondary centres of ossification appear around puberty in the upper and lower vertebral body and in the tips of the transverse and spinous processes. Ossification is usually complete by 25 years.

1.3 General Anatomy

Each mobile segment, excluding the articulation between the occiput and C1, and C1 and C2, articulates via a three-joint complex. Anteriorly, there is a fibrous articulation via the intervertebral disc, comprised of an outer tough fibrous *annulus fibrosus* and the central *nucleus pulposus*, and posteriorly two synovial facet or *zygapophyseal* joints.

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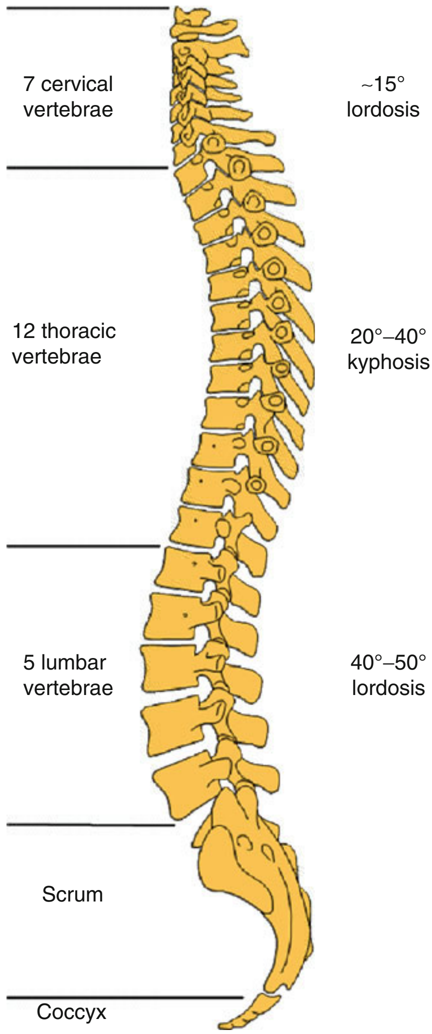


Fig. 1.1 The sagittal profile of the spine showing the normal range of lordosis in the cervical and lumbar regions, and kyphosis in the thoracic region

Ligamentous elements are vital in relation to the maintenance of intervertebral stability, the intervertebral disc being the most significant of these structures, but other elements such as the anterior and posterior longitudinal ligaments extend from the occipital bone to the coccyx. The ligamentum flava extends from the lower half of the anterior aspect of one lamina to the upper border of the lamina below and blends laterally with the facet joint capsule. Thus, for the inferior half of the lamina, the ligamentum flavum sits between the lamina and the dura. The interspinous and supraspinous ligaments are important, along with the posterior longitudinal ligament and facet capsule, in providing a posterior tension band to resist excessive distraction of the posterior elements in flexion. The anterior annulus fibrosus and anterior longitudinal ligament are the principal structures resisting hyperextension. Just about all ligaments act in some way to resist torsion, but it is the annulus and the orientation of the facet joints along with their capsule that are the primary structures resisting this movement.

Muscular elements cannot be ignored when considering both the stability and function of the spine. Details of the origins, insertions, function and relevance in relation to surgical approaches to the spine is beyond the scope of this chapter. Suffice to say that without the maintenance of balanced, toned and appropriately coordinated muscle activity, the function and stability of the spine may be significantly compromised.

1.3.1 Upper Cervical Vertebrae (Occiput to C2)

The first and second cervical vertebrae are atypical in both their structure and function compared to the other cervical vertebrae. Weight bearing between them and the base of the skull is not via the vertebral bodies and intervening disc, like the other vertebrae, but rather via articulations that enable greater movement than other individual motion segments of the spine.

1.3.2 The Atlas (C1)

This vertebra lacks a centrum, or 'body', since it is fused with the centrum of C2 to form the odontoid process or 'dens'. The neural arch on each side is thick and strong and articulates with the occipital condyles of the skull (Fig. 1.2).

The atlanto-occipital joint is a synovial joint between the convex occipital condyle and concave lateral mass of the atlas. This joint allows very little lateral bending or rotation, but a reasonable range of flexion and extension (Table 1.1). In fact, a significant proportion of cervical flexion and extension motion comes from the occiput–C1 junction.

1.3.3 The Axis (C2)

This vertebra is characterized by three main features, the odontoid process or 'dens', the lateral masses with broad superior articular surfaces for articulation with the inferior aspect of the atlas and a large and strong spinous process (Fig. 1.3).

The atlantoaxial joints are synovial joints, one on each side of the dens between the lateral masses of each vertebra and one between the anterior surface of the dens and the posterior aspect of the anterior arch of C1. This articulation provides approximately half of the rotation possible in the entire cervical spine (Table 1.1).

Accessory stabilizing ligaments provide support to the articulation between the occipital and the C1 and C2 vertebra. The *membrane tectoria* is continuous with the posterior longitudinal ligament of the spine and attaches to the back of the body of the Axis and extends up to attach to the anterior half of the foramen magnum. The *cruciform ligament* lies just anterior to the membrane tectoria with the vertical arm extending from the anterior aspect of the foramen magnum to the posterior body of C2. The transverse band attaches to the arch of inner aspect of the arch of C1 behind the dens (Fig. 1.2). The *apical ligament* lies just in front of the superior limb of the cruciform ligament, attaching the tip of the dens to the anterior margin of the foramen magnum. *Alar ligaments* pass obliquely on either side of the apical ligament to the margin of the foramen magnum (Fig. 1.4a–c). Thus, from the standpoint of ligamentous stability, the occiput C1 and C2 act as a motion segment and disruption requires treatment of all three.

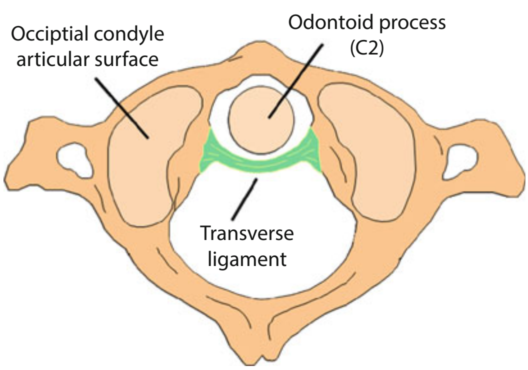


Fig. 1.2 Superior view of the Atlas vertebra (C1) showing the odontoid process of C2 contained by the transverse ligament

1.3.4 Typical Cervical Vertebrae (C3–6) and C7

An image of a typical cervical vertebra is illustrated in Fig. 1.5. During development, the costal elements form the anterior tubercle, the costotransverse bar and the tip of the posterior tubercle produce the vertebral foramen. The vertebral artery typically passes up through the vertebral foramen from C6 to C1, while the vertebral foramen in the lateral mass of C7 contains only the vertebral venous plexus. The vertebral artery passes anterior to the lateral mass of C7.

The spinous processes of the typical cervical vertebrae are usually bifid and relatively short. Spinous processes elongate in the lower segments with the C7 level being transitional between the cervical and thoracic region. The spinous process of C7, the vertebra prominens, can be easily palpated posteriorly at the base of the neck and is not typically bifid. [4]

Table 1.1 Representative values of the range of motion at each motion segment in the cervical spine [1]

Motion segment	Combined flexion/ extension (degrees)	One side lateral bending (degrees)	One side axial rotation (degrees)
C0–C1	25	5	5
C1–C2	20	5	40
C2–3	10	10	3
C3–4	15	11	7
C4–5	20	11	7
C5–6	20	8	7
C6–7	17	7	6
C7–T1	9	4	2

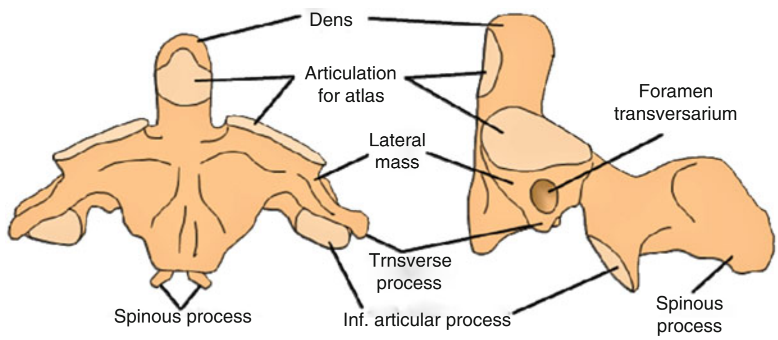


Fig. 1.3 Anterior and lateral view of the Axis vertebra (C2)

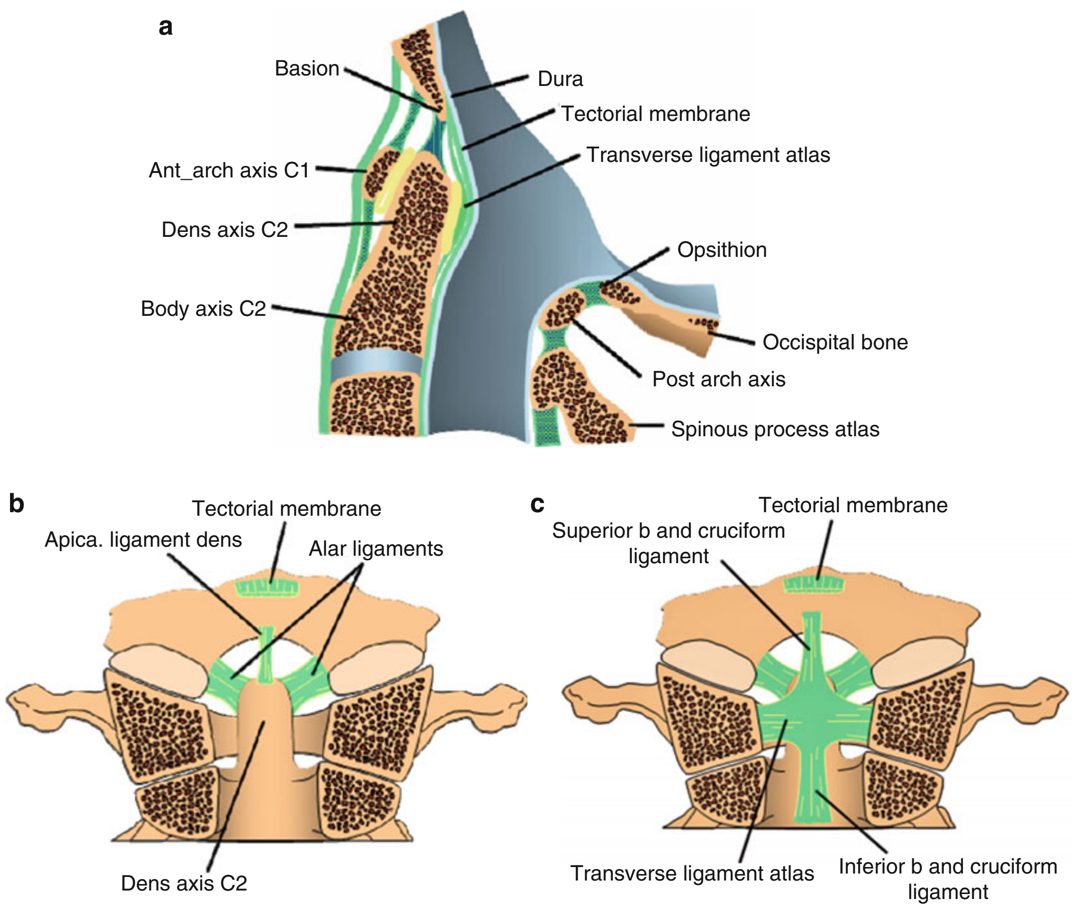


Fig. 1.4 Mid sagittal (**a**) and coronal (**b** & **c**) sectional views of the the upper cervical spine and base of the skull showing the stabilizing ligamentous structures

1.3.5 Thoracic Vertebrae

The typical thoracic vertebra is characterized by the presence of costal facets. There are six of these facets on the vertebrae from T1 to T10. Each has articular facets on each side of the posterolateral inferior and superior aspects of the body for articulation with its like-numbered rib *and* the rib below. There are also costal articular facets on the ventral tips of the transverse processes (Fig. 1.6).

The 11th and 12th vertebrae only articulate with their like-numbered rib via an articulation on the posterior part of the lateral surface of the body. The transverse processes of both the 11th and 12th vertebrae are usually stunted and are projected more directly back dorsally. The 12th thoracic vertebra is transitional between the thoracic and lumbar regions with the superior facet orientated in a way similar to other thoracic vertebrae, but the inferior facet is lumbar in type for articulation with the superior facet of L1.

1.3.6 Typical Lumbar Vertebra

Lumbar vertebra may be slightly wedge shaped, particularly at L5, with greater anterior than posterior height. More often than not, at least the upper four lumbar vertebrae show no wedging; in this case, it is the wedging of the discs that produces the normal lumbar lordosis. The width of the vertebral bodies increase from above down, with progressive widening of the articular processes, and the bodies also become more kidney shaped from proximal to distal. The transverse processes are variable in width, with the 4th usually being the longest, and the transverse process of L5 is shorter, wider and pyramidal in shape, and its base is attached further forward on the base of the pedicle. The L5 pedicle is therefore usually wider. Spinous processes are roughly horizontal (Fig. 1.7).

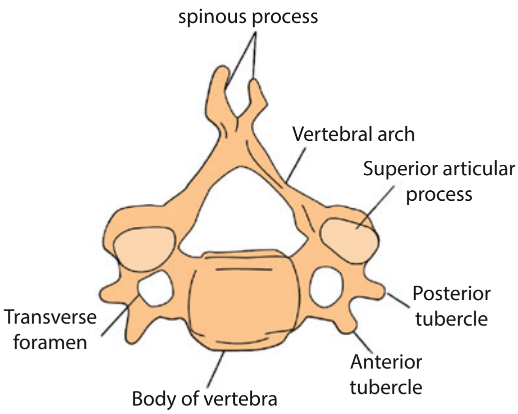
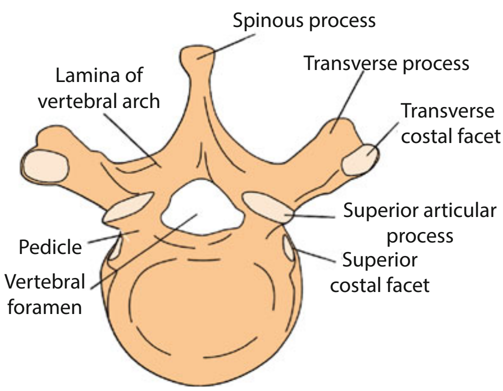


Fig. 1.5 Superior view of a "typical" cervical vertebra

1.3.7 The Sacrum

Five sacral vertebral segments fuse to form the triangular sacrum which is curved to create a concavity facing forward. The sacrum joins the spine to the pelvis and transmits the entire weight of the upper body through to the pelvis and lower limbs. The sacroiliac joint is however not a typical weight-bearing joint, as it is slung on ligaments above and behind the joint. It is these ligaments that carry the weight of the body and transmit this load to the pelvis. The upper surface of the sacrum slopes down at an angle of approximately 30° with the upper posterior surface inclined backwards before the distal portion curves down to articulate with the coccyx (Fig. 1.8).



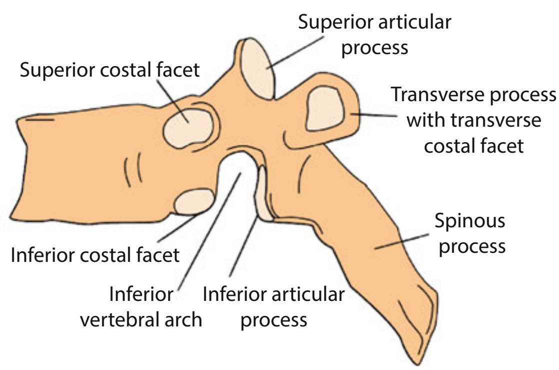


Fig. 1.6 Superior and lateral view of a "typical" thoracic vertebra

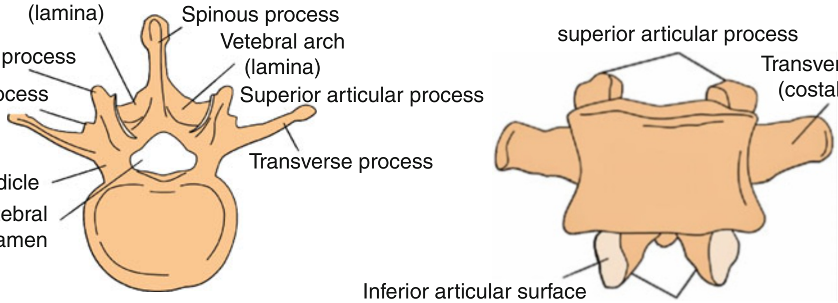


Fig. 1.7 Superior and anterior view of a "typical" lumbar vertebra

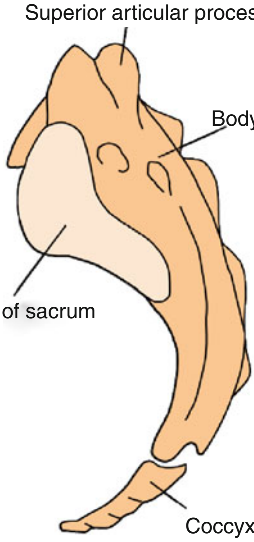


Fig. 1.8 Lateral view of the sacrum and coccyx

1.4 Range of Motion

The orientation and alignment of the facet joints in each region of the spine is a major factor in relation to the range of motion possible in each vertebral motion segment.

1.4.1 Lumbar Spine

Examining the lumbar vertebrae, it is evident that the lumbar facets are fairly vertically orientated and lie in a relatively anteroposterior plane in the upper lumbar region, with rotation into a more coronal plane as you move distally towards the lumbosacral level. These facet joints enable reasonably free flexion and extension and reasonable lateral bending, but resist anterior translation or shear and also limit the rotation that can be achieved at each level (Table 1.3).

1.4.2 Thoracic Spine

Here, the facet joints are inclined at around 60° with the superior facet facing both dorsally and laterally so that the articular surface lies on the circumference of a circle centred in the anterior vertebral body, thus enabling reasonably free rotation in the mid to upper thoracic segments. There is a transition to more lumbar type facet orientation in the lower thoracic spine which limits rotation in this region. The presence of the rib cage limits flexion and extension possible in the upper to mid thoracic region (Table 1.2).

1.4.3 Cervical Spine

Simplistically, around half of the motion in the cervical spine occurs between the occiput and C2 with the remainder distributed throughout the segments C2–T1. Facet joints from C2–3 to C7 T1 are similar to those in the thoracic spine with the exception that they both lie in the same plane, not on the circumference of a circle centred in the vertebral body. While flexion and extension are free, rotation is limited (Table 1.1).

Table 1.2 Representative values of the range of motion at each motion segment in the thoracic spine [1]

Motion segment	Combined flexion/ extension (degrees)	One side lateral bending (degrees)	One side axial rotation (degrees)
T1–T6	4	5–6	8–9
T6–T10	5–6	6	4–7
T10–L1	9–12	6–9	2–4

Table 1.3 Representative values of the range of motion at each motion segment in the lumbar spine [1]

Motion segment	Combined flexion/ extension (degrees)	One side lateral bending (degrees)	One side axial rotation (degrees)
L1–2	12	6	2
L2–3	14	6	2
L3–4	15	8	2
L4–5	16	6	2
L5–S1	17	3	1

1.5 Neuroanatomy

An important part of understanding the spine and assessing spinal disease relates to the contained neural elements and the structures they innovate. Understanding major sensory and motor innervation and basic spinal cord anatomy is paramount in determining the clinical significance of clinical and imaging findings when assessing the level of spinal cord or neurological dysfunction.

Figure 1.9 illustrate the approximate sensory innervation of the upper and lower limbs [2]

Despite the fact that there are only seven cervical vertebrae, there are eight cervical nerve roots, with the C1 root emanating from the spinal canal above the first cervical vertebra and the C8 root emerging through the C7–T1 foramen. There are 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal nerve roots, all emerging from the spinal canal below the pedicle of the vertebra of the same number.

The myotomal innervation of muscles, a myotome being the amount of muscle supplied by a single segment of the spinal cord, is a little more complicated. Last [3] has simplified, what on the surface appears to be quite complicated, into four facts:

1. Most muscles are supplied equally from two adjacent segments.
2. Muscles sharing a common primary action on a joint, irrespective of their anatomical situation, are supplied by the same, usually two, segments.
3. Their opponents, sharing the opposite action on the joint, are likewise all supplied by the same, usually two, segments, and these segments usually run in numerical sequence with the former.
4. For joints more distal in the limbs, the spinal centre lies lower in the cord. For a joint one segment more distal in the limb, the centre lies, en bloc, one segment lower in the cord.

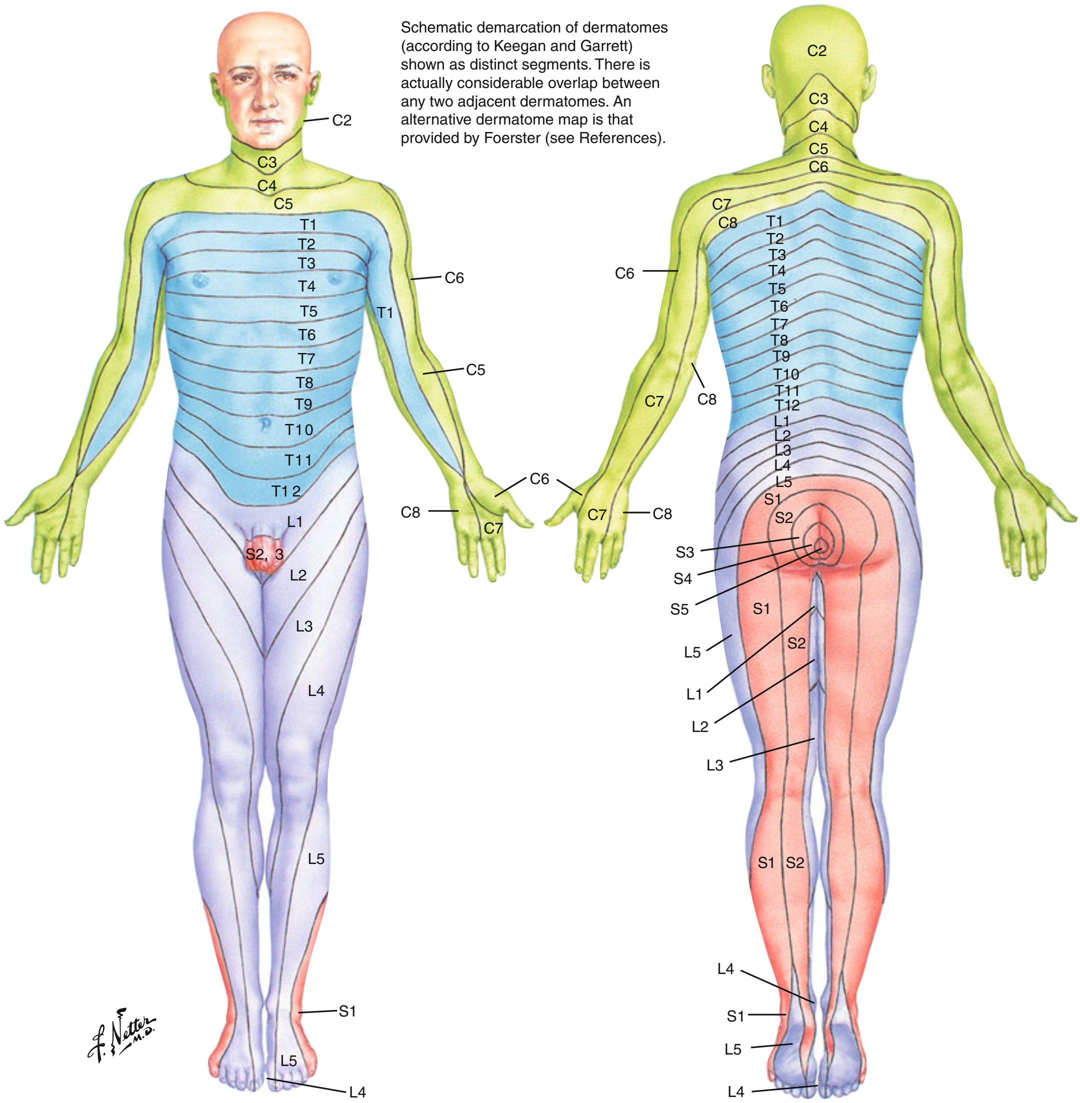
This is summarized in Table 1.4.

1.6 Spinal Cord Anatomy

The spinal cord is the conduit for motor and sensory impulses between the brain and the rest of the body. It is important to have an understanding of basic spinal cord anatomy, as this has relevance in relation to assessing vertebral column and spinal cord pathology.

The spinal cord is divided into segments, corresponding to the relevant exiting nerve root. Anterior and posterior roots emanate from the spinal cord to form a segmental nerve root, with both sensory and motor components. On the dorsal root is the dorsal root ganglion, a junction box where peripheral sensory nerves synapse with spinal nerves to transmit sensory impulses to the brain.

The cross-sectional anatomy of the spinal cord is similar in each region of the cord, with



Levels of principal dermatomes

C5	Clavicles	T10	Level of umbilicus
C5, 6, 7	Lateral parts of upper limbs	L1	Inguinal or groin regions
C8, T1	Medial sides of upper limbs	L1, 2, 3, 4	Anterior and inner surfaces of lower limbs
C6	Thumb	L4, 5, S1	Foot
C6, 7, 8	Hand	L4	Medial side of great toe
C8	Ring and little fingers	S1, 2, L5	Posterior and outer surfaces of lower limbs
T4	Level of nipples	S1	Lateral margin of foot and little toe
		S2, 3, 4	Perineum

Fig. 1.9 Diagram of the dermatomal distribution of the sensory innervation of the upper and low limbs. Reproduced from "Aids to the examination of the peripheral nervous system" [2]

some variation in the diameter of the cord, with enlargements in the cervical and lumbar regions of the cord to accommodate additional input and output for the upper and lower limbs.

Figure 1.10 illustrates the cross-sectional anatomy of the spinal cord. There is a central 'H'-shaped grey matter containing spinal nerve cell bodies, short interneurons, dendrites, glia

Table 1.4 Segmental innervation of movements in the upper and lower limb

Upper limb				
Shoulder	Shrug	C3,C4		
	Abduction	C5	Adduction	C6, C7 (C8)
Elbow	Flexion	C5, C6	Extension	C7, C8
Forearm	Pornation	C6	Supination	C6
Wrist	Flexion	C6, C7	Extension	C6, C7
Finger	Flexion	C7, C8	Extension	C7, C8
Intrinsic muscles	Abduction/adduction	T1		
Lower limb				
Hip	Flexion	L2, L3	Extension	L4, L5, S1
	Adduction	L2, L3	Abduction	L4, L5 (S1)
Knee	Extension	L3, L4	Flexion	L5, S1
Ankle	Dorsiflexion	L4, L5	Plantar flexion	S1, S2
	Inversion	L4	Eversion	L5, S1
Toe	Flexion	L5, S1	Extension	L5, S1
	Small muscles of foot	S1, S2		

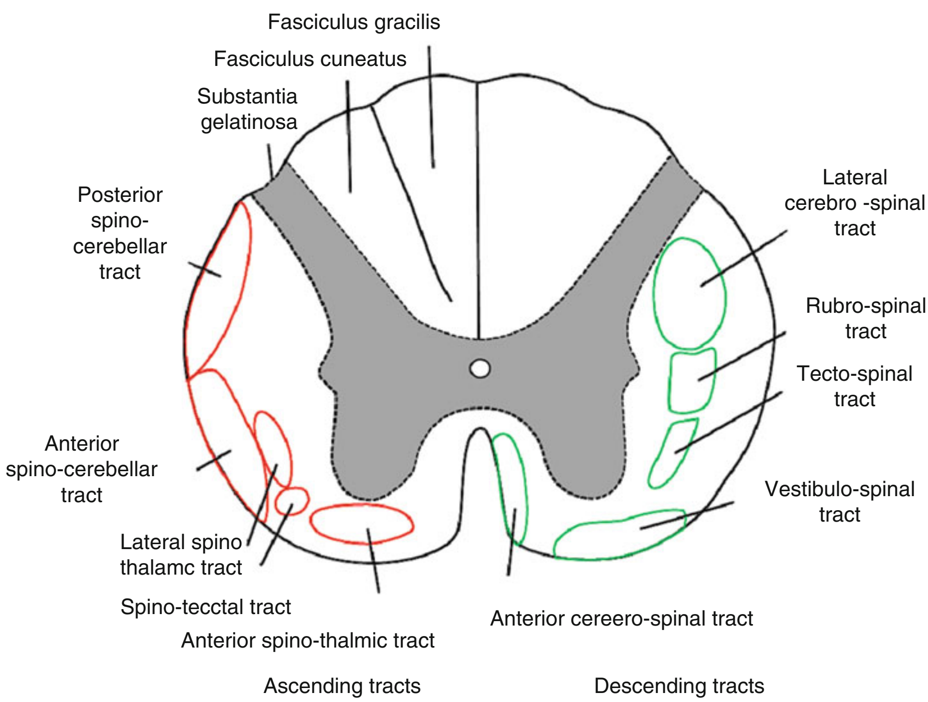


Fig. 1.10 Cross-section of the cervical spinal cord showing the approximate locations of the ascending and descending spinal tracts

and blood vessels, and an outer white matter made up of bundles of mostly myelinated longitudinal spinal tracts, glia and blood vessels. The white matter contains ascending, descending and intersegmental or connecting fibres and is divided into three main columns. The posterior column lies between the posterior grey horn and posterior median septum and contains ascending sensory fibres. The lateral column lies between the anterior and posterior grey horns and contains predominantly descending, but also some ascending tracts, and the anterior column which lies between the anterior grey horn and the anterior median fissure contains descending motor tracts.

The posterior white columns convey normal sensation, warmth and coolness and joint position or proprioception. Their cell bodies lie in the dorsal root ganglia of the spinal nerves and more distal fibres, from the sacrum, lie medially, with fibres from the lumbar, thoracic and cervical regions layered more laterally. Sensory fibres synapse in the nucleus gracilis and cuneatus near the base of the fourth ventricle in the medulla oblongata and cross to the opposite side of the brain via the sensory decussation.

Anterior white columns contain uncrossed pyramidal fibres whose cell bodies lie in the brainstem near the floor of the fourth ventricle. Motor fibres from the cerebral cortex cross in the motor or pyramidal decussation, also in the medulla oblongata.

Pain and temperature fibres entering the cord via the posterior spinal roots enter the dorsal horn of the grey matter synapse and cross the spinal cord to the lateral spinothalamic tract on the opposite side. As a result of this, hemisection of the spinal cord results in a dissociated sensory loss, with loss of joint position and light touch sensation, along with motor function, on the same side as the cord injury, with loss of pain and temperature on the opposite side of the body below the lesion.

Neurons are also layered in the various tracts, with sensory fibres entering the cord first, distally, lying closest to the midline, and those entering last, in the cervical region, lying more laterally. The same is also true for motor tracts, with those leaving the cord first, cervical fibres, lying more laterally. This arrangement leads to the typical features of a central cord lesion that may result from stenosis and a hyperextension injury, conditions such as a syringomyelia and spinal cord tumours, where motor tracts are affected more than sensory, the upper limb more than the lower limb, and distal parts of the limb more than proximal.

Anterior spinal cord pathology such as anterior spinal artery occlusion, compression due to a kyphotic deformity or a central disc protrusion will result in anterior cord syndrome where there is loss of motor function and pain and temperature below the lesion with preserved posterior column function.

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Physical Examination of the Cervical Spine

2

Virgilio Matheus and Edward C. Benzel

2.1 Anatomy of the Cervical Spine

The cervical spine is gifted with the capacity to provide a wide range of motions which facilitate head movements. Based on its functions, the cervical spine can be divided into two segments: an upper portion, which involves the occipitoatlantoaxial complex, and a lower portion, consisting of C3–C7.

Due to the unique anatomical features associated with the atlas and the axis, the upper segment of the cervical spine forms an extremely versatile and complex articulation that allows for a wide range of head and neck movements.

The atlas is formed by a ring of bone, which can be divided into a ventral and dorsal arch. It lacks a central vertebral body but displays large lateral masses. The latter serve to accommodate the occipital condyles and form the only weight-bearing articulation between the skull and the spine. A small flattening at the rostral border of the dorsal arch represents the trough through which the vertebral artery passes over C1 on its trajectory toward the intradural space.

The axis resembles the typical cervical vertebra with the peculiarity of having a ventral bony process projecting rostrally from its rudimentary vertebral body known as the odontoid process or dens. This process serves as an anchoring point for several ligaments that provide support between the atlas, axis, and condyles. This ligamentous complex is referred to as the cruciate ligament complex. Added stability is provided by the anterior and posterior longitudinal ligaments, which run ventral to and dorsal to the vertebral bodies, up to the skull base. The C1–C2 segment lacks an intervertebral disc. The most rostral disc is, hence, located between the axis and C3. Usually the spinous processes of C2 through C6 display a bifid appearance. In the majority of the cases, the vertebral artery enters a bony ring on the lateral aspect of C6 known as the transverse foramen. The artery follows this path rostrally until exiting the foramen of the axis and curving over the arch of the atlas - to finally pass between the atlas and the condyle as it passes through the foramen magnum.

In addition to the ligamentous support, the cervical spine relies on muscular support for both support and mobility. A combination of unique features exhibited by these muscles and the cervical spine permits extreme flexion, extension, and tilting of the head, without adverse consequences.

2.2 Palpation

The ventral and lateral aspects of the cervical spine are covered by surrounding structures that can lead or suggest potential underlying pathologies, which in some cases might show no relationship with cervical spine pathology. Prior to laying

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hands on the patient, the examiner must look for points of skin erythema or diaphoresis, which could represent painful areas that must be approached carefully to avoid unnecessary pain [1]. Careful palpation of the sternocleidomastoid muscle and all of the triangles it forms is performed next. One should begin by instructing the patient to turn his head toward one side, after which the examiner proceeds to "travel" with his hand along the full extent of the ipsilateral muscle. The examiner should look for masses and tender points. He should repeat this maneuver on the opposite side. It is important to compare muscle bulk and appearance. Next, the examiner should proceed with palpation of the carotid pulse, using the second and third digits. It is normally located medial to the sternocleidomastoid muscle. The examiner should pay attention to strength and symmetry, and to not forget to auscultate the underlying structures, seeking bruits, etc. It is also important to assess anatomical landmarks relevant for surgical approaches such as the thyroid and cricoid cartilages, hyoid bone, and trachea as well as, if possible, palpate the carotid tubercle which usually is palpable at the C6 level. The examiner should palpate, with the same fingers, the supraclavicular region. Abnormal masses or tenderness may represent lymphadenopathy, apical lung masses, or even clavicular fractures. If the palpable structure seems to be bony, suspect an accessory cervical rib.

When palpating the dorsal aspect of the cervical spine, one must remember that the cervical spine is covered by large muscles, most notably the splenius and trapezius muscles, which have insertions on the suboccipital, scapular, and shoulder regions. It, therefore, is important to begin palpating from the occiput down to the cervicothoracic region as well as lateral over the scapula. It is useful to use a systematic approach, first examining the soft tissue and subsequently the bony structures or vice versa. Inflammation and tenderness can be due to muscle spasm. Potential etiologies include trauma, muscle fibrosis, and fibromyalgia. Reproducible focal points of tenderness, with palpation over the scapula or shoulder joint, may indicate ligamentous damage due to overuse.

Finally, one should proceed to palpating the spinous processes. The patient should sit up and perform gentle flexion of the neck. Palpation of spinous process in the midline is appropriate. Tenderness, masses, absence of processes, or any other abnormalities should be noted. One should pay close attention to alignment and tenderness, so underlying fractures and/or luxations are not missed.

2.3 Range of Motion

The most important step prior to performing a range of motion examination is to obtain a thorough history to assess for instability. If the patient is aware of specific painful movements, elicitation of such movements should be reserved for the latter portion of the examination in order to avoid muscle spasm and the carrying of the pain through the remaining steps of the examination. Flexion, extension, lateral flexion, and head rotation are performed in order to seek sources of pain. One should begin with active movements and follow them with passive movements. Compare among them for differences. While performing these movements, the examiner should assess for resistive isometric muscle testing (resistive strength). Careful attention should be paid to pain associated with specific muscles, as well as weakness and/or atrophy - both of which may indicate a muscle strain or a neurological injury [2].

Flexion: Instruct the patient to bring the chin down to the sternum without flexing the chest.

Extension: Instruct the patient to bring the head back without extending his chest. The mouth can be kept open to avoid traction over the anterior neck structures.

Lateral rotation: Instruct the patient to rotate his head to each side at the time. The chin should be above the shoulder joint at the point of maximal rotation (approx. 80–90°). Asymmetry on rotation should raise concern for an underlying problem.

Lateral bending: Instruct the patient to bend his neck sideways, without performing any neck rotation or raising the ipsilateral shoulder. The ear should touch or almost reach the shoulder joint. Pay careful attention to asymmetry while performing the maneuver.

2.4 Fractures

Fractures can be classified as stable vs. unstable, with or without compromise of the spinal canal. If suspicion of a fracture is present, imaging of the spine should be obtained prior to performing any manipulation. Signs of underlying fracture include pain, muscle spasm, limited range of motion, neurological dysfunction, and any obvious deformity. One should pay close attention to the mannerisms of the patient; with severe injuries, it is not uncommon to observe a patient holding his head with his hands, in an attempt to provide extra support and self-limit the range of motion.

Following observation of the neck by the examiner, gentle percussion of the spine can be performed with the patient in the sitting position (assuming that the spine has been otherwise cleared) with his head gently tilted forward. During this test, the development of pain and/or neurological symptoms can represent an underlying fractured vertebra. This test is very nonspecific and may be positive in cases of a ligamentous sprain or strain. Paraspinal muscle percussion can elicit pain in many cases of muscle strain.

2.5 Instability

Similar to fractures, instability usually arises as consequence of an underlying trauma or a degenerative or infection-related process. Instability may be occult or obvious. It, nevertheless, is imperative that imaging tests be performed prior to attempting the maneuvers that are presented here [3].

2.6 Vascular Assessment

2.6.1 Vertebrobasilar Circulation

It is imperative to assess for normal posterior circulation in a patient with whom cervical traction or manipulation is planned. The posterior circulation is most vulnerable with rotation of C1 over C2. Under normal circumstances, the vertebral artery can be compromised with rotation from 30 to 45°, thus collapsing the contralateral vertebral artery. Provocative or functional testing can compress the circulation at several points between the foramen magnum and the transverse process of C6. This compression can be due to rotation itself but also may be due to underlying spondylotic alterations of the uncinate joints. Auscultation for bruits and palpation for pulses are an integral part of the examination.

After performing any test, it is important to provide an examination free time interval in order to prevent confusing any latent symptoms with symptoms elicited by performing maneuver. Signs and symptoms of posterior circulation insufficiency include vertigo, lightheadedness, diplopia, dysarthria, dysphagia, gait ataxia, nausea, and paresthesias. Many different stress-inducing maneuvers are described, most of them involving head rotation with extension.

2.6.2 Subclavian Artery

Both subclavian arteries, after branching off the aorta, eventually give rise to the vertebral arteries in most people. Compromise of this vessel results in symptoms in the upper extremities that may mimic cervical lesions as well as symptoms of posterior circulation insufficiency. Compression of the subclavian artery may arise from hypertrophy or spasm of the anterior scalene muscle, atherosclerotic plaque, and apical lung masses. Symptoms include arm pain, cold limb, supraclavicular region pain, and paresthesias [4].

With the patient in the seated position, the blood pressure is taken in both arms. There should be no more than 10 mmHg difference between them. If the difference is greater than 10 mm and the radial pulse is weak, subclavian artery compromise should be considered. One should also auscultate the supraclavicular area in search of a bruit. If the index of suspicion for pathology is elevated, one may proceed to imaging of the chest (X-rays, CT, MRI) and/or vascular imaging (US, CTA, MRA).

2.7 Neurologic Assessment

2.7.1 C1–C4

A lesion at this level will compromise the innervations to the diaphragm, often resulting in the need for ventilator support.

2.7.1.1 Motor

Scapular elevation (C3–C4). To assess its integrity, the examiner stands behind the patient and instructs him to shrug his shoulders. He then places his hands over the shoulders – pushing them downward. In normal conditions, one should not be able to force the shoulders downward. One should also pay careful attention to asymmetry during the elevation phase.

2.7.1.2 Sensory

The C1–C4 dermatomes provide sensation to the back of the head and neck (Fig. 2.1).

2.7.2 C5

2.7.2.1 Motor

The most recognized specific function of C5 involves arm abduction through innervation of the deltoid muscle. The examiner should instruct the patient to keep his arm resting lateralized to his body, with the elbow flexed to 90°. The examiner should place his hand over the lateral shoulder region and instruct the patient to bring his arm up to the side away from his body until perpendicular to the chest cavity.

It also provides control over the internal and external rotation of the shoulder. Internal rotation is less reliable since muscles involve in carrying out this function receive also innervations from C6, C7, C8, and T1. Elbow flexion is also supplied by these two roots through the functions of the biceps, brachioradialis, and supinator muscles. Ask the patient to sit down and keep his arm flexed in a 90° posture while you hold it with one hand under the elbow and the other under his wrist. Instruct him to perform an internal and external rotation of the shoulder while you assess his tone and strength. Following this, ask him to flex his arm from the resting position at 90° attempting to reach for his shoulder.

2.7.2.2 Sensory

The C5 root supplies, through the axillary nerve, sensation to the upper lateral arm (Fig. 2.1). The bicipital reflex (C5) also should be tested. Instruct the patient to keep his arm at a 90° flexion, resting over your arm while you gently strike with the reflex hammer over the biceps insertion tendon. Compare both sides always.

2.7.3 C6

2.7.3.1 Motor

Wrist extension is predominantly mediated by the extensor carpi ulnaris and radialis. The examiner should have the patient rest his forearm over the examiner's nondominant hand. With your dominant hand over the dorsum of his hand, instruct him to extend his wrist without and then with resistance from your overlaying hand.

2.7.3.2 Sensory

Through its contributions to the musculocutaneous nerve, it provides sensation to the lateral aspect of the forearm and the two first digits.

2.7.4 C7

2.7.4.1 Motor

Its primary function is to elicit elbow extension through contraction of the triceps muscle. The examiner should instruct the patient to hold his hand at his face level with his elbow flexed as in a boxing position. The examiner should grab the patient's elbow with his nondominant hand to prevent usage of other muscles. The examiner should place his dominant hand over the patient's wrist and instruct him to perform extension of his elbow. The examiner should compare without and with resistance bilaterally.

2.7.4.2 Sensory

This root provides sensation to a narrow area of the hand being most specific over the volar region of the middle finger.

Fig. 2.1 Dermatomes of the cervical and brachial plexus

2.7.5 C8

2.7.5.1 Motor

C8 function refers to the flexion of the fingers. This function is mediated through the flexor digitorum and lumbrical muscles. The examiner should instruct the patient to flex his fingers. Then, the patient should be asked to attempt extension, with and without resistance from the examiner's fingers.

2.7.5.2 Sensory

The dermatome to this root is localized over the fifth digit and lateral aspect of the fourth digit (Fig. 2.1).

2.7.6 T1

2.7.6.1 Motor

T1 controls abduction of the fingers through innervations of the dorsal interossei and adduction through innervations of the palmar interossei. To test for abduction, the patient is instructed to spread apart his fingers. The examiner should pinch together every set of fingers to try to force them together. To test for adduction, the examiner should instruct the patient to keep his fingers together on extension after the examiner places a piece of paper between them and pulls it out.

2.7.6.2 Sensory

Sensation over the medial aspect of the forearm (Fig. 2.1).

2.8 Miscellaneous

"Space-occupying para- and intraspinal lesions" can present in many ways, including neurological deficits. Specific tests can be performed during the physical examination to exacerbate these symptoms and confirm the presence of one of these lesions. Unspecific symptoms patients can complain of include neck pain and paresthesias of the upper and lower extremities.

2.8.1 Valsalva Maneuver

With the patient in sitting position, instruct the patient to hold his breath and bear down as if defecating. Inquire about worsening symptoms. This maneuver will raise the intrathecal pressure and possibly exacerbate any symptoms caused by the compressive intraspinal, particularly intradural, lesion [5].

It is important to evaluate the patient's swallowing function during the physical examination. Patients may complain of dysphagia or odynophagia that could be due to an expansive cervical spine mass compressing the esophagus. These and other pathological findings that are observed during swallowing could be manifestations of cranial nerve compression.

2.8.2 Cervical Neural Compression

Both spinal cord and nerve root compression can lead to neurologic compromise. Such may be the case with herniated discs, osteophytes, fractures, luxations, or tumors. Patients with neural compression and/or irritation may complain of cervicalgia, radicular pain, paresthesias, weakness, and myelopathy. It goes without saying that when suspecting high-grade neural compression, one should complement the history and physical examination with the pertinent imaging studies. The following tests can help clinically localize the offending pathology.

2.8.3 Foraminal Compression Test

With the patient in the sitting position and the head in a neutral position, the application of strong downward pressure with both hands for a few seconds can elicit radicular symptoms. Repeating these steps with the patient's head rotated to each side can increase sensitivity.

By applying axial loading, the intervertebral disc is compressed, the foraminal cross-sectional area should decrease, and pressure will hence be exerted upon the apophyseal joints. If the patient develops symptoms or worsening of the preexisting symptoms, the dermatome should be relatively identifiable based on classical dermatomal distributions.

2.8.4 Extension Compression Test

With the patient in the sitting position, he is asked to extend his neck. The examiner then applies his hands on the forehead and applies downward pressure. Such axial loading in an extended spine results in compression of the dorsal apophyseal joints and thus results in the worsening of existing or the development of localized pain related to joint disease. Simultaneously, it decreases the cross-sectional area of the foraminal space which may result in radicular pain.

2.8.5 Flexion Compression Test

The examiner asks the patient to flex his head while in the sitting position. He then applies downward pressure on the cranial vertex. With the head flexed and with axial loading, the compression of the ventral aspect of the disc induces dorsal displacement of a bulging disc into the central canal, thus potentially causing symptoms related to compression of the spinal cord. At the same time, pressure is taken off the dorsal apophyseal joints. Hence, preexisting facet origin pain may improve.

2.8.6 Spurling's Test

With the patient in a sitting position, the examiner applies downward pressure over the patient's head while maintaining a lateral flexed posture (Fig. 2.2). If radicular pain is elicited, the test is considered positive. If no symptoms are elicited, the patient is asked to assume a neutral position. A moderate blow is delivered to the head vertex (Fig. 2.3). With lateral flexion, pressure is applied over the apophyseal joints, worsening any related pain.

2.8.7 Maximal Foraminal Compression Test

With the patient in the sitting position, he is asked to extend his neck while rotating his head. This test exerts compression over the dorsal apophyseal

Fig. 2.2 Spurling's test: Examiner applies downward pressure over the patient's head while maintaining a lateral flexed posture which applies pressure over the apophyseal joints exacerbating any related pain

Fig. 2.3 Spurling's test: If no symptoms are elicited during the initial step of this maneuver the patient is asked to assume a neutral position. A moderate blow is delivered to the head vertex (*arrow*). Symptoms that might not be elicited by the first step of this maneuver might become evident following this step

joints and compresses the foraminal spaces, thus exacerbating pain related to nerve root encroachment [6].

2.8.8 L'hermitte's Phenomenon

With the patient in a relaxed seated position, he is asked to perform head flexion. This results in stressing of the dorsal ligaments and elements of the spine plus compression of the ventral segment of the intervertebral disc. This in turn displaces dorsal disc bulges into the central canal, while the flexion stretches the spinal cord over the ventral compressive masses (sagittal bowstring effect). A positive test involves the development of sudden electrical tingling or shocks down the spine and/or extremities. Such a finding is consistent with significant stenosis and is a sign of myelopathy. Local cervical pain during the test could represent muscle sprain, meningeal irritation from an underlying inflammatory process, apophyseal joint disease, or radiculopathy [7].

Fig. 2.4 Distraction test: Vertical traction to the head is applied (*arrow*) which removes the pressure from the joints and enlarges the foraminal spaces, resulting in the alleviation of the symptoms in cases of joint disease, foraminal root encroachment, and disc herniation in the case of radicular symptoms

2.8.9 Distraction Test

The patient is asked to assume the sitting position. The examiner places his palms over the mastoid processes of the patient bilaterally. Vertical traction to the head is then applied. This maneuver removes the pressure from the joints and enlarges the foraminal spaces, resulting in the alleviation of the symptoms in cases of joint disease, foraminal root encroachment, and disc herniation in the case of radicular symptoms. If pain arises during the test, suspect muscle strain or facet capsulitis (Fig. 2.4).

Table 2.1 Relevant signs and tests of the cervical spine

Name	System	Action	Pathologic finding	Reasoning
Maigne's test	Vascular	Head rotation and extension	Vertigo, dizziness, fainting	Compression of vertebral artery
Dekleyn's test	Vascular	Head extension and rotation while supine with head off the table	Vertigo, dizziness, fainting	Compression of vertebral artery
Hautant's test	Vascular	Sitting, head extension and rotation with arms extension	Vertigo, dizziness, fainting, arm drift	Compression of vertebral artery, stenosis of subclavian artery, posterior circulation insufficiency
O'Donoghue's maneuver	Muscular	Range of motion passive vs. resisted	Pain during resisted motion	Muscle strain elicits worsening pain with motion against resistance
Rust's sign	Osteomuscular/ligamentous	Head supported by patient's own hands at all times	Self-attempt to immobilize the neck and support head's weight	Immobilization and weight limitation
Valsalva maneuver	Space-occupying lesion	Force exhalation against closed airway	Pain localized to cervical spine	Maneuver increases intrathecal pressure
Jackson's compression test	Radiculopathy, apophyseal joint disease	Seated, lateral neck flexion, downward pressure	Radicular symptoms +/– local pain	Foraminal compression, disc compression, facet joint loading
Extension compression test	Radiculopathy, apophyseal joint disease	Seated, neck and head extension, downward pressure	Radicular symptoms +/– local pain	Foraminal compression, facet joint loading, decreased loading over dorsal annular disc. Relief of symptoms could represent disc material displacement ventrally
Flexion compression test	Radiculopathy, apophyseal joint disease	Seated, head and neck flexion, downward pressure	Radicular symptoms +/– local pain.	Foraminal compression, disc compression, decreased loading over facet joints. Relief of symptoms could represent joint disease
Spurling's test	Radiculopathy, apophyseal joint disease	Seated, same as Jackson's test. If negative proceed with head vertical blow on neutral position	Radicular symptoms +/– local pain	Foraminal compression, intervertebral disc compression, facet joint loading
Distraction test	Radiculopathy, apophyseal joint disease	Seated, upward traction of patient's head	Relief of radicular symptoms +/– local pain	Expansion of foramen, unloading of disc, unloading of facet joints
L'hermitte's sign	Myelopathy	Seated, passive neck and head flexion	Electrical tingling down the spine and/or extremities	Traction of the spinal cord

2.8.10 Bakody's Sign/Shoulder Abduction Test

With the patient in the sitting position, the examiner instructs the patient to place his hand over his head – thus keeping his arm in abduction. This maneuver reduces stretch on the lower trunk of the brachial plexus and relaxes tension on tethered nerve roots at the foraminal level. Amelioration of the pain usually represents extradural compression of a root around C6–T1 (Table 2.1).

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Examination of Back Pain

3

Jennifer Malone, Ravi Madineni, Niti Cooper, Angud Mehdi, and Ashwini Sharan

Low back pain is a common musculoskeletal disorder affecting 60–80 % of people at some point in their lives. In the USA it is the most common cause of job-related disability, a leading cause of missed work. Low back pain is classified as acute (less than 4 weeks), subacute (4–12 weeks), or chronic (greater than 12 weeks) [1].

Understanding the causes of low back pain, performing a thorough history and physical examination, and looking for "red flags" for potentially serious conditions allow health-care providers to accurately classify and treat most causes of back pain [2].

The majority of lower back pain is nonspecific and arises from mechanical soft tissue sprain or strain and can be treated within a few weeks of onset with conservative management. In addition to spinal or mechanical causes, lower back pain can arise from nonmechanical etiologies such as failed back syndrome, visceral pain, and multitude of other non-spinal causes [3, 4]. A comprehensive listing of the various etiologies of lumbosacral pain is included for the clinician's consideration.

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3.1 Physical Examination

Successful evaluation of low back pain begins with a thorough history and physical examination leading to an appropriate diagnosis. In performing a physical exam, one can utilize a process of elimination as dictated by the history to uncover the diagnosis and treat it effectively. The patient history should uncover whether there is systemic disease, neurologic impairment that may necessitate surgery, and social or psychological disease that can intensify or prolong pain.

Ask the patient about the onset of pain (sudden, gradual, fleeting), the location of pain (have the patient point to the area of pain or trace with one finger the pain pattern if the pain radiates), the duration of pain (the length of time the pain has been present), and the characterization of pain (have them use adjectives or descriptive words such as "aching," "burning," "sharp," and "electrical"); ask about alleviating and aggravating factors, timing (constant, intermittent), and history (previous history of current symptoms); and inquire about the mechanical nature of the pain (differences in laying, standing, sitting, pain worse on extension).

As with any other physical examination, vital signs as well as height, weight, and assessment of body mass index (BMI) are essential in evaluating the patient. A survey of the patient's skin may reveal surgical scars, lesions from herpes zoster, injection sites (hinting to history of drug abuse), or even undiagnosed cancer areas. Areas of hair loss, skin and nail changes, erythema, and

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cyanosis should be noted, as they may delineate the sympathetic nervous system as the source of pain. Temperature, color, and pulses should be evaluated in the legs to differentiate neurogenic claudication from vascular insufficiencies.

The spine must be palpated midline and laterally. Lateral tenderness implies possible facet disease. In addition, the sacroiliac joint which is a common source of pain can be palpated for tenderness.

3.1.1 Motor Examination

It is always imperative and helpful to evaluate baseline muscle mass and tone. The examiner must look for areas of muscle wasting, increased tone, contractures, fasciculation, and postural abnormalities. This will suggest the chronicity effects of pain and compensation mechanisms. Muscles of both the upper and lower extremities should be tested for strength and graded accordingly. This maintains a very good objective baseline on function and needs to be accurately maintained in cases of compressive spinal problems.

Grade	Clinical signs
0	No evidence of contractility
1	Slight contractility, no movement
2	Full range of motion, gravity eliminated
3	Full range of motion with gravity
4	Full range of motion against gravity, some resistance
5	Full range of motion against gravity, full resistance

3.1.2 Sensory Examination

The sensory exam should be focused to information detailed by the patient in the history. Use of tools differentiating sharp (pinprick), light touch (von Frey filament), and vibration (tuning fork) sensations may further delineate the extent of the lesion. Correlations should be made between the sights of numbness or allodynia and the dermatomal or non-dermatomal nature of the pain. In our practice, we find it particularly helpful to use pain maps filled out together with the patient as an aid to categorizing the neuropathic versus radicular components of pain (Fig. 3.1).

3.1.3 Neurological Examination

This portion of the physical examination of the spine is the most objective. The physician should check deep tendon reflexes of the biceps (C5–6), triceps (C7–8), patellar (L3–4), and Achilles (S1) and grade them accordingly.

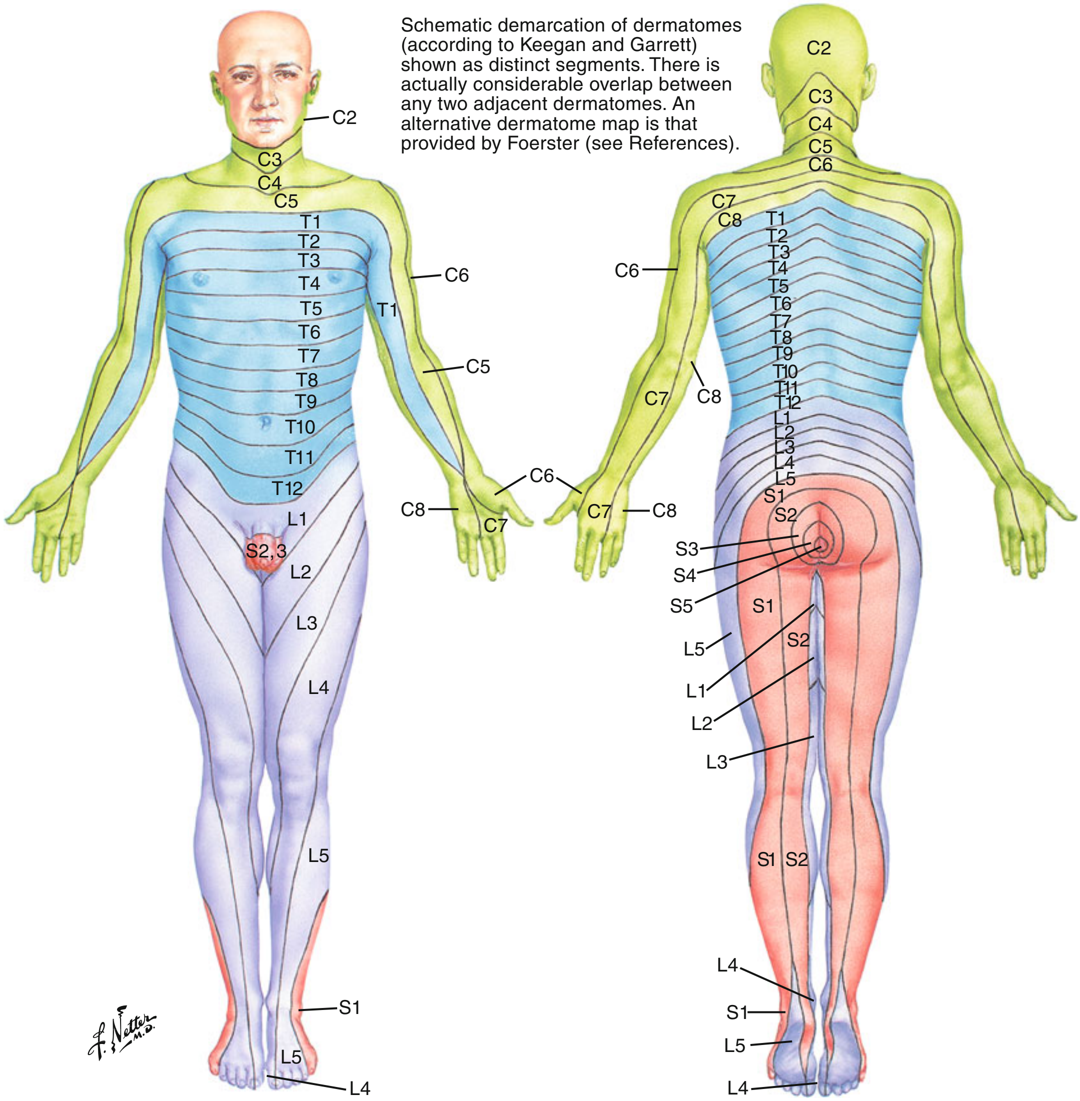
Grade	Clinical signs
0+	No response
1+	Sluggish
2+	Active or normal
3+	Brisk, hyperactive
4+	Abnormally hyperactive, with clonus

Clonus is tested by dorsiflexing the foot and watching for repetitive involuntary plantar flexion and dorsiflexion at the ankle. Clonus, hyperactive reflexes, and a positive Babinski sign (dorsiflexion of the toes, especially the big toe, with stimulation of the lateral aspect of the sole) may suggest upper motor neuron injury. It is important that these clinical signs be further evaluated with more advanced spinal imaging with consideration of magnetic resonance imaging. Diminished or absent reflexes imply lesions present in the peripheral nerve, nerve root, or spinal cord.

3.1.4 Range of Motion and Gait

Flexion, extension, and lateral rotation should be tested in the cervical, thoracic, and lumbar regions. Mechanical versus painful limitations should be documented as they can provide clues to the diagnosis. For example, pain elicited with extension and lateral rotation of the spine along a facet joint implicates the facet joint as the etiology of the pain.

In addition, a straight leg raising test, also known as Lasegue's test, will give information as to whether a radicular type of pain is caused by a dysfunctional disc. This test is performed by



Levels of principal dermatomes

C5	Clavicles
C5, 6, 7	Lateral parts of upper limbs
C8, T1	Medial sides of upper limbs
C6	Thumb
C6, 7, 8	Hand
C8	Ring and little fingers
T4	Level of nipples
T10	Level of umbilicus
L1	Inguinal or groin regions
L1, 2, 3, 4	Anterior and inner surfaces of lower limbs
L4, 5, S1	Foot
L4	Medial side of great toe
S1, 2, L5	Posterior and outer surfaces of lower limbs
S1	Lateral margin of foot and little toe
S2, 3, 4	Perineum

Fig. 3.1 Diagram of the dermatomal distribution of the sensory innervation of the upper and low limbs. Reproduced from "Aids to the examination of the peripheral nervous system"

having the examiner passively raise the patient's leg as the patient is lying supine. A positive test is when the pain is reproduced as the leg is raised between 30° and 70° [5]. Similarly, a Spurling's test can be performed for the cervical spine. A positive test occurs when radicular pain is felt with extension, lateral rotation, and compression of the head [6].

A positive FABER test, also known as Patrick's test, will lead to the sacroiliac joint as the cause of pain [7]. The patient is positioned supine, and the affected lower extremity is flexed at the knee with the ankle placed over the opposite knee, and abducted and externally rotated at the hip. Pain in the region of the sacroiliac joint with compression of the affected knee and opposite anterior superior iliac spine is a positive test and indicates degenerated joint disease, malalignment, or inflammation at the joint.

It is important to have the patient walk and observe their gait. The examiner must note if the patient favors one side, has a wide-based gait, or demonstrates some of the typical patterns of movement disorders (i.e., shuffling gait of Parkinson's disease). The patient should be asked to perform tandem gait and heel-to-toe movements and assess impairment in proprioception or position sense.

If suspicions are raised, check for malingering by observing for overreaction and Waddell's nonorganic signs [8].

Tenderness	Superficial and diffuse and/or nonanatomic tenderness on palpation
Simulation	Pain produced by axial loading (pressing down on the top of the head) or when the patient is asked to passively rotate side to side with the shoulders and pelvis in the same plane
Distraction	Positive tests, such as a positive straight leg raise, are rechecked while the patient is distracted. A nonorganic sign may be present if the finding disappears with distraction
Regional disturbance	Regional weakness or sensory changes not consistent with neuroanatomy. Cogwheel or "giveaway" weakness
Overreaction	Disproportionate verbalizations, facial expression, guarding, tremor, collapse, or sweating

When three or more nonorganic signs are discovered, there is clinical significance as this was found to correlate positively for depression, hysteria, and hypochondriasis. The presence of nonorganic signs should alert the clinician to the need for additional psychological testing [8].

In conclusion, the pain medicine physical examination should be focused on information delineated by the patient in the history. Appropriate skin survey, motor, sensory, neurologic, range of motion, and gait examination must be performed. The results of the physical examination will not only give insight into the pathology of the pain but will also dictate treatment.

3.2 Etiologies of Lumbosacral Pain

3.2.1 Spinal Mechanical

3.2.1.1 Lumbosacral Strain/Sprain

Lumbosacral strain/sprain is the most common cause of low back pain. It is defined as a stretch injury to the large muscles of the low back and/or the ligaments and tendons, leading to microscopic tears and inflammation in these soft tissues [9]. It manifests as pain in the lower back and upper buttocks. Low back muscle spasm can also occur, and patients will often feel a stiffness or describe a "locking up" of the lower back.

Lumbosacral strain/sprain typically occurs because of overuse, improper use of muscles, such as lifting a heavy object improperly, twisting the back in an unusual manner, or trauma. Poor conditioning or deconditioned core muscles of the abdomen and lower back, obesity, smoking, employment, or circumstances that require heavy lifting and improper lifting technique are common risk factors for lumbosacral strain/sprain [4]. Pain is made worse with activities and generally relieved with rest, ice, and nonsteroidal anti-inflammatory agents [10].

3.2.1.2 Degenerative Spine Disease

Degenerative spine disease is not a specific disease but rather a clinical syndrome referring to any dysfunction of the spinal column resulting from the normal aging process and from degeneration that occurs to the bone, joints, muscles, ligaments, nerves, intervertebral discs, and paravertebral tissues of the spine. It encompasses many types of disorders including herniated disc, spinal stenosis, and spondylosis [9].

Degenerative spine disease of the lumbar spine is a major cause of lower back and lower extremity pain and chronic disability and a common reason for referral for medical treatment.

3.2.1.3 Herniated Disc

A herniated disc refers to localized displacement of the nucleus pulposus through a tear in the annulus fibrosus beyond the limits of the intravertebral disc space [11]. The tear in the annulus fibrosus may result in the release of inflammatory mediators which may cause severe pain even without nerve root compression. Only 1–3 % of people presenting with low back pain have lumbar disc herniation and only 1 % will have a nerve root symptom. Most common level for lumbar disc herniations occurs between L4–5 and L5–S1 [12].

Risk factors for herniated lumbar disc include age (between 30 and 50), male gender, lifting a heavy object especially when using a twisting motion of the spine, occupation in a physically demanding job, cigarette smoking, and obesity [13].

Symptoms of lumbar disc herniation often include acute lower back pain and muscle spasm, followed by sudden or gradual radicular leg pain, then typically a reduction in the degree of lower back pain. Bladder symptoms such as urinary urgency, frequency, and hesitancy may be present in up to 18 % of patients with acute disc herniations without cauda equina syndrome [14]. Outright urinary retention or overflow incontinence may however be seen in cauda equina syndrome (see below).

When lumbar disc herniation is associated with heavy lifting, pulling, pushing, or twisting, some patients state that they hear and/or feel a "pop" in their back. They may describe the initial pain as "searing" or "hot" [14]. Patients with radicular leg pain may find relief flexing the knee or the thigh of the affected leg because full extension creates nerve root tension. Patients will generally avoid excessive activity, and yet they cannot remain in one position (sitting, standing, lying) for too long either, prompting them to frequent position changes. Valsalva maneuvers (coughing, sneezing, and straining at the bowel or bladder) may also worsen radicular pain.

3.2.1.4 Cauda Equina Syndrome

Cauda equina syndrome, CES, is a serious neurologic condition involving impairment of the nerves of the lumbar plexus from compression of the cauda equina. CES frequently necessitates emergent or urgent surgical decompression to prevent permanent deficits and/or incontinence.

CES is prevalent in only 0.04 % of all patients with low back pain and only 1–2 % of all patients with lumbar disc herniations [14]. CES is caused by any compressive lesion causing pressure on the nerve roots in the lumbar spinal canal below the conus medullaris; the most common cause of this problem however is a central disc herniation. Other causes include metastatic disease; intrinsic spinal tumors; burst fractures; direct trauma from anesthetic, diagnostic, or therapeutic lumbar puncture; spinal epidural hematoma; penetrating trauma such as knife or bullet injuries; compressive abscess; and spinal stenosis [12].

Spontaneous low back and radiating lower extremity pain with severe or progressive weakness usually involving more than one nerve root may be the most prominent symptom in CES. Pain in a radicular distribution is more prominent than back pain in these cases. Saddle anesthesia is the most common sensory deficit in CES with a distribution involving some or most of the anus, genitals, perineum, buttocks, and posterior-superior thighs. This can be unilateral and asymmetric as well. A patient with CES or developing CES will often describe symptoms of sphincter disturbance; urinary retention is the most common, but other symptoms include bladder frequency, urgency, overflow incontinence, fecal incontinence, and diminished anal sphincter tone. Retention can be evaluated and documented by performing post-void residual measurements either by catheterization or ultrasound measuring residual. Diminished or absent patellar and Achilles reflex may be found [2, 12]. No single sign or symptom defines a CES, but it is a constellation of findings instead.

3.2.1.5 Spinal Stenosis

Spinal stenosis refers to a condition of narrowing in and around the spinal canal, causing compression on the neural elements. It is classified as central canal stenosis, foraminal stenosis, or lateral recess stenosis. Central canal stenosis refers to narrowing of the anteroposterior dimension of the spinal canal, causing compression of the spinal cord or cauda equina. Foraminal stenosis refers to narrowing of the neural foramen, causing compression on spinal nerves, and lateral recess stenosis, a type of lumbar spinal stenosis, arises from hypertrophy of the superior articular aspect of the facet joint. In the lumbar spine, lateral recess stenosis most commonly affects the L4–5 facet [15].

The most common cause of stenosis is related to degeneration and the aging process, osteoarthritis, disc degeneration, and thickened spinal ligaments. Other causes include spinal trauma, previous spinal surgery, spinal tumors, Paget's disease, and having a congenitally small central canal as seen in achondroplasia [12].

Symptoms of spinal stenosis depend on the location of the narrowing and resultant impingement or compression. Any one or combination of the following symptoms of stenosis can be present: low back pain; numbness, paresthesias, cramping, weakness, and pain in the buttocks, legs, and feet; radiating leg pain; and bowel and/or bladder dysfunction.

Symptomatic lumbar stenosis is most common at L4–5 then L3–4 followed by L2–3 and then L5–S1. Lumbar stenosis is classified as stable, facet hypertrophy, thickening of the ligamentum flavum, and disc degeneration. Unstable stenosis is marked by the addition of degenerative spondylolisthesis or degenerative scoliosis [16].

Neurogenic claudication is a common symptom of lumbar spinal stenosis. It can be unilateral or bilateral buttock, hip, leg, or foot discomfort, pain, or weakness that is aggravated by standing and walking and alleviated by sitting or lying. Patients with neurogenic claudication may develop "anthropoid posture," an exaggerated flexion at the waist which possibly creates a reduced lumbar lordosis and opens the facet joints [12]. The patient may reveal that they are also more comfortable leaning forward, for example, on a counter at home or, classically, a grocery cart in the supermarket.

3.2.1.6 Fracture

Most fractures of the spine occur in the thoracic and lumbar spines and most commonly at the thoracolumbar junction, T12–L1. These fractures are typically caused by major trauma such as motor vehicle accidents, falls, or sports accidents, but even minor trauma in a compromised spine can lead to fracture. Persons with bone weakened by osteoporosis, long-term corticosteroid use, substance abuse, or systemic disease and spinal tumors can suffer a nontraumatic fracture during normal daily activities [2, 4].

Types of spinal fractures include compression, burst, flexion/distraction, seatbelt, or Chance fracture, transverse process, fracture dislocation, pathologic fracture from infection or tumor, and osteoporotic fracture [12].

Plain radiography is recommended in patients with persistent pain, history of trauma, fever, unexplained weight loss, cancer, substance abuse, and age greater than 50. Computed tomography (CT) and magnetic resonance imaging (MRI) are more useful for the detection of infection and fracture caused by cancer [4].

Nonsurgical treatment includes 6–8 weeks of bracing, activity modification, analgesics, physical therapy and a gradual return to normal physical activity, and treatment of the underlying systemic disease if present. Surgery is typically reserved for unstable and comminuted fractures, the presence of neurologic deficit, progressive spinal deformity, and pain refractory to nonsurgical management.

3.2.1.7 Spondylolisthesis

Spondylolisthesis is slippage of the superior vertebra over inferior vertebra. This condition most commonly affects the lumbar spine and is less common in the cervical spine. There are five types of lumbar spondylolisthesis:

1. Dysplastic spondylolisthesis – this is caused by a congenital defect in the facet that allows the vertebra to slip forward.
2. Isthmic spondylolisthesis – this results from a defect in the part of vertebra called pars interarticularis. This defect is thought to be caused by repetitive trauma and is more common in athletes due to hyperextension motion.
3. Degenerative spondylolisthesis (DS) – this type occurs due to arthritic changes in the facet joints of vertebra. It is more common in older patients and represents the most common form of spondylolisthesis.

4. Traumatic spondylolisthesis – this occurs secondary to direct trauma and can include a fracture of the pedicle, lamina, or facet joints
5. Pathological spondylolisthesis – this type is caused by bony defect due to tumor which causes bone to be abnormal.

Spondylolisthesis is graded based on extent of slippage of lateral radiograph by Meyerding. This measurement is distance from the posterior edge of upper vertebra to posterior edge of lower vertebra and is reported as a percentage of total upper vertebral body. There are five grades of slippage: grade1, 0–25 %; grade 2, 25–50 %; grade 3, 50–75 %; grade 4, 75–100 %; and grade 5, spondyloptosis when upper vertebra is completely fallen off in relation to lower vertebra.

Among these five types of spondylolisthesis, DS is most commonly seen in patients over 50 years and a common cause of low back pain (LBP). It also commonly involves L4–L5 level and to lesser extent L5–S1. DS is approximately four to five times more common in females than in males, due to greater ligamentous laxity and hormonal effects [17, 18].

LBP is the most common presentation in patients with DS; however, some of them may be asymptomatic. LBP may be mechanical type to pain and relieved with rest. This condition is also associated with neurogenic claudication. Leg pain can be radicular or diffuse and involving dermatomal distribution of L4, L5, and S1 nerve roots, although single nerve root, most commonly L5, involvement may also be seen. These symptoms are seen in 42–82 % of patients who see a spine surgeon for help. Bladder and bowel dysfunctions due to DS can occur but less profound than cauda equina syndrome from disc herniation. This can be seen in severe stenosis in 3 % of patients [19].

Patients with mechanical type of LBP and neurogenic claudication should be investigated with standing lumbar spine x-rays including flexion and extension films. Supine films may not demonstrate the slippage. CT scan and MRI of lumbar spine add to diagnosing this condition accurately with degree of slippage and extent of stenosis causing neural compression.

3.2.1.8 Kyphosis

Kyphosis is a term to describe the natural forward curve of the thoracic and lumbosacral spines where the lumbar and cervical spines have a natural lordosis or lordotic curve. When kyphosis is used to describe a spinal deformity, it refers to an exaggeration of the forward curve in a portion of any part of the spine, also called a kyphotic deformity. Kyphotic deformities can create symptoms that vary from pain and neurologic deficit to compensatory and cosmetic deformities [13].

Kyphotic deformity has a multitude of causes including degenerative (osteoporotic compression fracture, Paget’s disease), traumatic, developmental (scoliosis), iatrogenic (following spinal decompressive laminectomy or radiation to the spine), neoplastic (primary spinal tumor or metastatic disease), congenital (achondroplasia), infectious (Pott’s disease, osteomyelitis), inflammatory (ankylosing spondylitis, rheumatoid arthritis), and neuromuscular (cerebral palsy) or from Scheuermann’s disease [13].

A careful history and exam will reveal presence of deformity, underlying or contributing conditions, neurologic impairment (from spinal cord or spinal nerve compression), and the development of compensatory deformities. Standing or upright x-rays of the entire spine in one view, commonly referred to as “scoliosis x-rays” with anterior-posterior and lateral views, are used to evaluate the structure of the spine and measure the degree of kyphosis or other abnormal curves. When neurologic deficits are discovered, worsening pain or spinal instability is suspected; further imaging with CT and/or MRI is warranted.

3.2.1.9 Scoliosis

The term scoliosis originates from Greek word skoliosis meaning obliquity or bending. Adult scoliosis is a de novo development of curved spinal architecture after completion of skeletal maturity. It is also seen in children and adolescents; however, adult scoliosis differs from child or adolescent scoliosis in terms of curve types and patterns, rate of deformity progression, rigidity of deformity, patient comorbidities, and clinical symptoms and presentation [20]. Some of adolescent scoliosis can be asymptomatic and get detected during adult life due to progression of curvature. Other patients may develop scoliosis after spine surgery for disc degeneration or spinal fusion surgery as adjacent-level degeneration with scoliosis.

The prevalence of adult scoliosis is probably on the rise due to increasing life expectancies. The most common types of scoliosis encountered in adults are idiopathic and degenerative scoliosis. The former condition starts in childhood or adolescence and progresses over a period of time with added degeneration of disc and facets. Degenerative scoliosis is a de novo development of scoliosis secondary to asymmetric involvement of disc degeneration, facet arthrosis, and disc collapse [21].

Patients with scoliosis may present to spine surgeons with symptoms of back pain due to spine deformity or symptoms of neural compression unrelated to deformity. Adult patients with scoliosis present with axial low back pain, neurogenic pain, as well as changes in gait and posture. Physical examination of the back while palpating spine will reveal abnormal curvature of spine and asymmetry of the pelvic crests. Patients with stooped posture may have sagittal imbalance forcing them to walk with walker or cane. Imaging studies begin with plane x-rays of the spine standing, and scoliosis films which determine the severity of sagittal and coronal imbalance and pelvic tilt.

3.2.2 Spinal Nonmechanical

3.2.2.1 Neoplasia: Intradural or Vertebral Tumors/Pathologic Fracture

Diagnosis of spinal neoplasia begins with the history. Patients who complain of subacute back pain that is worse at night or with rest should raise the clinician's suspicion for a possible neoplastic process especially if the patient reports unintentional weight loss and general malaise.

3.2.2.2 Infections: Osteomyelitis, Discitis, and Epidural Abscesses

Spinal infections arise from bacteria carried through the bloodstream to the spine from a site of infection elsewhere in the body, urinary and respiratory tract infection, soft tissue (infections on the skin), dental flora, or through intravenous drug use, surgery, injection treatments, or as a result of direct trauma. Infections are most frequently seen in the lumbar spine, followed by thoracic, cervical, and sacrum.

Back pain may be a result of an infection in the bone (osteomyelitis), in the disc (discitis), or on the spinal cord (epidural abscess). Vertebral body collapse with kyphotic deformity is common. Necrotic bone and disc fragments as well as abscess formation can cause spinal cord or cauda equina compression [12]. Presenting symptoms can be as generalized as back pain, low-grade temperatures, malaise, and anorexia. Unexplained back pain following a recent infection or iatrogenic procedure with a strong mechanical component should be considered for a spinal infection.

3.2.3 Inflammatory Arthropathies

3.2.3.1 Ankylosing Spondylitis

Ankylosing spondylitis (AS) is a chronic, systemic inflammatory disease of the joints and the axial skeleton characterized by back and neck pain and progressive stiffening, or ankylosing, of the spine. Pain and stiffness is typical in the thoracic spine or sometimes the entire spine, with referred pain to the buttocks and hamstrings. Pain is often present in the morning, is severe at rest, and improves with physical activity. Sacroiliitis is present in greater than 95 % of persons with AS.

The onset is gradual, typically beginning in late adolescence and early adulthood, and is slightly more common in men than in women in whom the disease evolves more slowly. Approximately 90 % of AS patients express the HLA-B27 genotype, meaning there is a strong genetic association. However, only 5 % of individuals with the HLA-B27 genotype contract the disease [13, 22].

3.2.3.2 Rheumatoid Arthritis

Rheumatoid arthritis (RA) is a systemic inflammatory autoimmune disease which is chronic and progressive in nature. RA affects multiple tissues and organs but predominantly attacks synovial joints, leading to destruction of articular cartilage and ankylosis. It occurs in 0.3–1.5 % of the population, with women affected 2–3 times more often than men. Onset occurs most frequently between the ages of 40 and 50, but people of any age can be affected [22]. Often a disabling and painful condition, it has an insidious onset marked by fatigue, anorexia, weight loss, and generalized aching and stiffness (especially morning stiffness). RA can lead to substantial loss of function and mobility if not adequately treated.

3.2.3.3 Reiter's Syndrome

A reactive arthritis usually occurring 1–3 weeks following certain bacterial infections (commonly Chlamydia, Shigella, Salmonella, Yersinia, and Campylobacter) with involvement of at least one other non-joint area, specifically urethritis, uveitis/conjunctivitis, skin lesions, and mucosal ulcerations. Between 75 and 90 % of patients are also HLA-B27 positive [13].

3.2.3.4 Paget's Disease

Paget's disease (PD) is a metabolic disorder with abnormal bone remodeling, causing spinal stenosis and facet arthropathy. In this disorder, there is excessive breakdown of bone and formation of weak bone, causing pain, fracture, and joint arthritis. Etiology of Paget's disease remains unclear, and it has been thought to be caused by viral infection [23]. Paget's disease also can be inherited as autosomal dominant trait with high penetrance [24]. Reported incidence of back pain in PD patients ranges from 11 to 42 % [25]. Several mechanisms have been described in neural symptoms in patients with PD: (1) compression of neural elements by pagetic process, (2) neural ischemia, and (3) pagetic sacromatous degeneration [26]. Diagnosis of PD is by x-rays, bone scan, and CT scan and MRI. Once PD is confirmed as underlying pathology, treatment is initiated with biphosphonates with goal of relieving bone pain and arrest progression of disease. In addition to biphosphonates, other drugs used are calcitonin and mithramycin.

3.2.3.5 Sacroiliitis

Inflammation of the sacroiliac joint, sacroiliitis is a frequent initial manifestation of one of the seronegative spondyloarthropathies. Sacroiliitis most commonly presents in young people who are HLA-B27 positive and/or have ankylosing spondylitis, psoriatic arthritis, or Reiter's disease. The pain of sacroiliitis most commonly occurs in the lower back and tops of the buttocks, but it can also radiate to incorporate the groin, legs, and feet.

3.2.3.6 Scheuermann's Kyphosis

Scheuermann's kyphosis most commonly affects the vertebral bodies of the thoracic spine but can also occur at the thoracolumbar junction. It is best described as a growth abnormality of one or more vertebral bodies where the anterior portion of the vertebrae stops growing, yet the posterior portion continues to grow, creating an abnormal amount of kyphosis at the apex of the deformity. It is most often seen in males and typically occurs in the final growth spurt of adolescence. Pain and discomfort are common along the site of the kyphotic deformity [13].

3.2.4 Arachnoiditis

Arachnoiditis is a neuropathic disease caused by inflammation of the arachnoid membrane of the spinal cord and spinal nerves. It can be caused by chemical irritation, infection, injury, previous spinal surgery, or other invasive spinal procedures. Arachnoiditis can lead to adhesions, causing the spinal nerves to "clump." The presenting symptoms of arachnoiditis may include constant chronic low back pain unrelated to and unrelieved by specific positions, radiating leg pain, perineal pain, and pseudoclaudication. Treatment is insufficient with the main focus on medication and intrathecal steroid injections [9].

3.2.5 Failed Back Syndrome

Failed back surgery syndrome (FBSS) and post-laminectomy syndrome are terms used to describe a type of a chronic and persistent back and/or leg pain condition that occurs following lumbar spinal surgery. FBSS does not include persistent lower extremity weakness, sensory changes, or reflex abnormalities [13].

Patients with FBS often demonstrate frustration and anger and often have an accompanying diagnosis of depression. These patients frequently require long-term pain management, specifically with narcotic agents. The clinician should be astute to the possibility of malingering for a variety of secondary gain issues which can be found to coexist in patients with FBS.

The causes of FBS include incorrect initial diagnosis; improper preoperative patient selection; continued nerve root compression caused by recurrent disc herniation, scar tissue, pseudomeningocele, hematoma, spinal instability, or stenosis at the surgical or junctional level; permanent nerve injury; technical error during surgery; adhesive arachnoiditis; infection (discitis, osteomyelitis); spondylosis; other non-spinal causes of back pain; and nonanatomic factors/malingering [12].

3.3 Visceral Causes of Back Pain

Occasionally, back pain is the single presenting symptom of a variety of serious medical conditions or possible emergency. Clinicians must be astute to possible medical or visceral causes of back pain when the patient describes severe, refractory, or atypical pain. Examination of the abdomen with palpation of the visceral organs is a necessary step of diagnosis. This chapter will not cover the atypical presentations but will just report a laundry list of differential diagnoses which also may present with back pain: dissecting aortic aneurysm, urinary tract infection, pyelonephritis, prostatitis, pelvic inflammatory disease (PID), endometriosis, ovulation, pregnancy, ectopic pregnancy, acute pancreatitis, duodenal ulcer, cholecystitis, nephrolithiasis, and visceral cancers.

3.4 Non-spinal

3.4.1 Piriformis Syndrome

Piriformis syndrome refers to sciatic symptoms (low back pain radiating in the buttock, thigh, calf, and foot) that do not originate from the lumbosacral plexus and/or from disc herniation but rather by pressure from the piriformis muscle on the sciatic nerve [9]. Pain is made worse with activity such as prolonged sitting and walking.

The piriformis muscle originates at the anterolateral aspect of the sacroiliac region, transverses the sciatic nerve, and inserts on the greater trochanter of the femur. It is innervated by the ventral rami of S1 and S2 and abducts and laterally rotates the femur. The sciatic nerve passes between the two bellies of the piriformis [27]. Trauma or overuse can lead to irritation, inflammation, and spasm of the piriformis, which can compress the transversing sciatic nerve and mimic a herniated lumbar disc or spinal nerve compression.

Performing a straight leg raise (SLR) test can differentiate between piriformis syndrome and sciatica caused by lumbosacral nerve compression. In piriformis syndrome the SLR is only mildly positive or negative unless the examiner flexes, adducts, and internally rotates the proximal leg. Adding these maneuvers places tension on the irritated piriformis and stretches the inflamed nerve root [9].

3.4.2 Bursitis

Trochanteric bursitis and ischiogluteal bursitis are types of pelvic pain that is often misdiagnosed as herniated lumbar disc or sciatica from the lumbosacral spine especially in the elderly patient population. The symptoms of trochanteric bursitis are pain in the hip region with activity and point tenderness over the greater trochanter. Patients will often report that they are unable to lie on the affected side. With ischiogluteal bursitis, pain is localized deep in the center of the buttock. Patients will describe the pain as "unrelenting," aggravated by sitting or walking, and accompanied by radicular leg pain that is unrelieved by rest. Treatments include rest, anti-inflammatory agents, physical therapy, cortisone injections, or in extreme cases bursectomy [28].

3.4.3 Fibromyalgia

Fibromyalgia is a chronic pain syndrome characterized by widespread musculoskeletal pain, fatigue and heightened tenderness to tactile pressure, general fatigue, and sleep disturbance. The most common sites of pain include "tender points" of the neck, back, shoulders, bony pelvis, and hands. Over 6 million Americans are diagnosed yearly, 90 % of which are women between the ages of 20 and 55 years old. Pain is described as a deep ache, sometimes shooting, and burning.

3.4.4 Spasticity

Spasticity is often found in people with cerebral palsy, traumatic brain injury, stroke, multiple sclerosis, and spinal cord injury. Spasticity results from upper motor neuron lesions creating an imbalance of inhibitory influence on alpha and gamma motor neurons. Spasticity is clinically manifested as a hypertonic state of muscles with clonus and involuntary movement. Often painful and debilitating, spasticity creates challenges with self-care, hygiene, posture, and balance. Back pain is a cardinal feature of spasticity [12].

3.4.5 Degenerative Joint Disease (DJD) of the Hip

DJD of the hip is most often caused by osteoarthritis. It is characterized by pain and stiffness from the breakdown of joint surface cartilage. DJD of the hip creates ipsilateral groin and medial thigh pain. At times the pain can radiate to the knee on the same side, creating confusion as to whether the problem is from the hip, from the knee, or from a lumbar radiculopathy. Hip dysplasia and avascular necrosis of the hip can cause these symptoms as well.

When pain originates from the hip, walking and prolonged activity worsen the pain and motion in the joint is limited, often realized when trying to go from sitting or lying to a standing position. Initially, pain is relieved by rest, but once the DJD progresses, minimal activity such as slight movements in bed can worsen the pain. Treatment includes rest, ice, anti-inflammatory agents, cortisone injections, and, if necessary, joint replacement surgery [29].

3.4.6 Leg Length Discrepancy/Pelvic Level/Gait Abnormality

A leg length discrepancy can be due to a mild variation between two sides of the body and is a normal variation when the difference is 3/5 of an inch or less. There are a variety of causes for leg length discrepancy including previous injury or fracture to the leg (especially in children who are fractured at the growth plate), bony diseases, inflammation and osteoarthritis, and neurologic conditions.

The correlation between patients with a clinically significant leg length discrepancy and the incidence of low back pain is controversial. Leg length discrepancy can lead to a pelvic obliquity which changes the coronal balance of the sacrum, leading to a segmental scoliosis and potential for increased low back pain [9].

Leg length discrepancy can lead to gait abnormalities requiring patients to exert more effort with ambulation and hasten degenerative joint disease. Treatment includes orthotics and surgery for inhibiting growth, lengthening, and shortening.

3.4.7 Posture

The position of the body in both the sitting and standing positions can have considerable effect on the development or prevention of lower back pain. Swayback posture (lumbar hyperlordosis) in standing and a slouched or slumped (thoracic hyperkyphosis) posture in sitting can impact the health and function of the muscles of the abdomen and lower back. When daily activities require prolonged sitting or standing and a balanced seated or standing posture is not achieved, the stabilizing muscles of the spine fatigue and lead to pain and stiffness [9].

3.4.8 Obesity

More than half of the adult population of Americans is categorized as being overweight or obese. Overweight and obesity is a contributing factor to back pain and a significant cause for seeking medical care. Being overweight or obese can contribute to the symptoms of osteoporosis, osteoarthritis, degenerative spine disease, and spondylolisthesis. The addition of excess weight and a deconditioned core translate extra strain and stress to the spine, specifically the lower back [30].

3.4.9 Mood Disorders

Pain, anxiety, and depression are commonly experienced together. In patients with chronic and disabling pain syndromes such as fibromyalgia, low back pain, and nerve pain, this is particularly evident. Patients with diagnosed anxiety and depression report higher incidences and greater severity of pain in addition to increased disability and dysfunction due to pain compared to patients without depression and anxiety [31]. Treatment of both pain and mood disorder is challenging but can be accomplished with a comprehensive plan including cognitive behavioral therapy, relaxation techniques, hypnosis, exercise, antidepressants, and mood stabilizers.

3.4.10 Secondary Gain/Malingering

Secondary gain is an external psychological motivator that may drive a patient to report certain symptoms. If a patient's pain or illness allows them to miss work or gain extra sympathy and attention, these would be examples of secondary gain. With secondary gain, a patient is unconsciously seeking these "rewards." If he or she is deliberately exaggerating symptoms for personal gain, that is, to win a legal dispute, then he or she is malingering [32]. In either case, it is in the patient's best interest to remain debilitated or in pain in order to continue to receive the rewards.

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Radiologic Imaging of the Spine

4

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4.1 Imaging Option Overview

4.1.1 Radiography

4.1.1.1 Physics

Radiography is the first-line technique in the evaluation of the spine. It is relatively inexpensive and widely available. X-rays are produced by rapidly moving streams of electrons from the cathode to the anode. The produced ionizing radiation (photons) penetrates an object and the differences in X-ray attenuation, which depends on differences in tissue density, are registered on a sensor plate. Bones absorb the radiation more than soft tissues; denser tissues attenuate the X-ray beam to a greater degree, lessening the number of X-ray photons sensed on the detector plate. The greater the number of X-ray beams to reach the detector, the darker the image. This is why bones are bright and lungs are dark on a conventional radiograph.

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4.1.1.2 Radiography as a Screening Tool in Spine Trauma

The standard method of screening the cervical spine is a conventional radiographic series, which typically includes lateral, anteroposterior, and odontoid views. Other views include swimmers lateral (to clear the shoulders and allow visualization of the cervical thoracic junction), oblique views, and flexion/extension views in the lateral projection. Particular difficulty in positioning high-mechanism, poly-trauma patients may lead to a large number of inadequate radiographic examinations.

Cervical spine radiography, although relatively cheap, adds substantially to health-care costs because of the high volume of its use. Emergency departments annually treat millions of patients with trauma who are at risk for cervical spine injury, and the total cost of cervical spine radiography is therefore substantial and judicious use of cervical spine radiography in the emergency trauma is necessary.

Several decision algorithms have been developed. The Canadian C-spine Rule (CCR) [1] and the National Emergency X-Radiography Utilization Study (NEXUS) low-risk criteria (NLC) [2] were developed independently. Both rules are sensitive for detecting acute C-spine injury which allows the emergency department physicians to be more selective in the use of radiography in alert and stable trauma patients [3].

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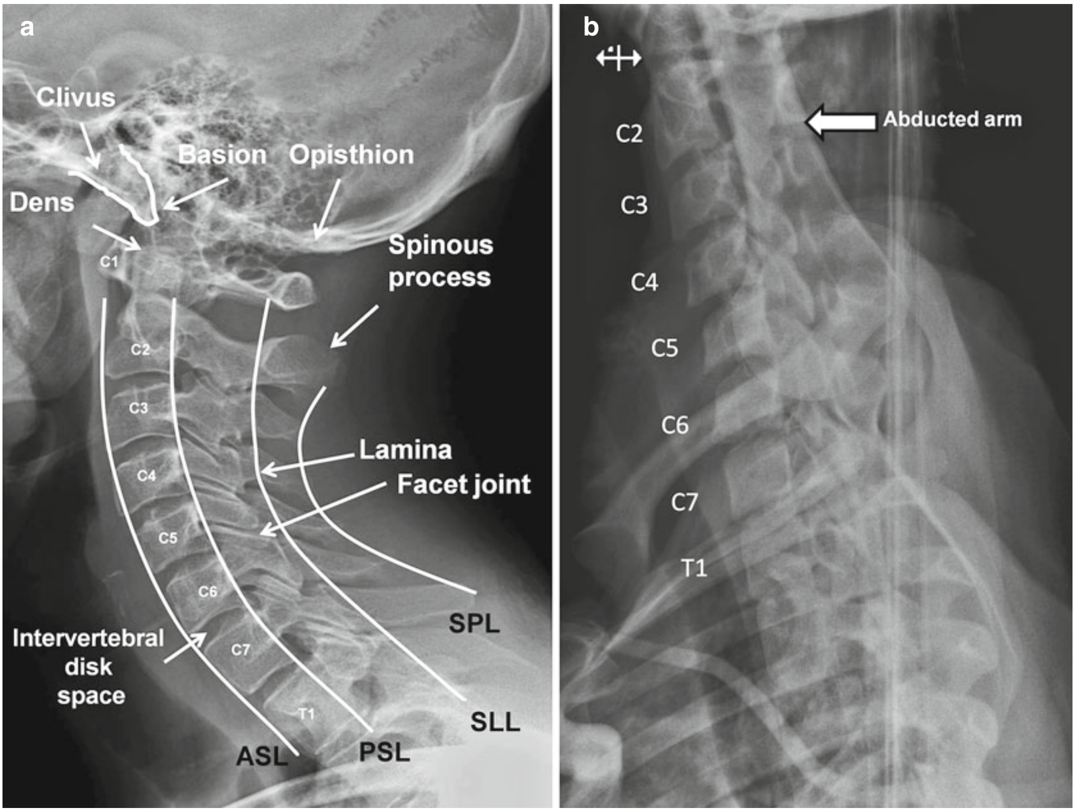

Fig. 4.1 Normal lateral (**a**) and swimmer's lateral (**b**) projections of the cervical spine with labeled pertinent anatomy. Anterior spinal line (*ASL*), posterior spinal line (*PSL*), spinolaminar line (*SLL*), and spinous process line (*SPL*)

4.1.1.3 Normal Radiographic Anatomy of the Spine

When evaluating spinal radiographs, a firm understanding of normal anatomy is necessary to allow one to detect pathology.

Cervical Spine

Radiographic assessment of the cervical spine requires adequately exposed images to allow visualization of the bone trabeculae, as well as adequate patient positioning. On a true lateral radiograph of the cervical spine, the facet joints are superimposed on each other. A frontal view of the cervical spine should have similar coverage as a lateral view. On a true frontal view, the spinous processes are midline. Open-mouth odontoid view should be centered on the C1–C2 articulation and the teeth and occiput should not be superimposed over the area of interest.

Lateral View (Fig. 4.1)

The lateral view (Fig. 4.1a) is the most important view in the routine trauma series. The lateral view must include all seven cervical vertebrae, as well as the C7–T1 intervertebral space. Several methods have been used to include the vertebral bodies and posterior elements of the cervical thoracic junction. On a swimmers view (Fig. 4.1b), one of the arms is raised above the head to avoid superimposition of the shoulders over the cervical thoracic junction. Disadvantages to the swimmers view include higher radiation dose, high scatter, and difficult positioning. Although bony details are usually suboptimal on the swimmer's lateral view, gross alignment can be confirmed.

Lateral view of the cervical spine allows evaluation of the vertebral bodies and intervertebral disks height, as well as the cervical spine alignment which physiologically has a gentle lordotic

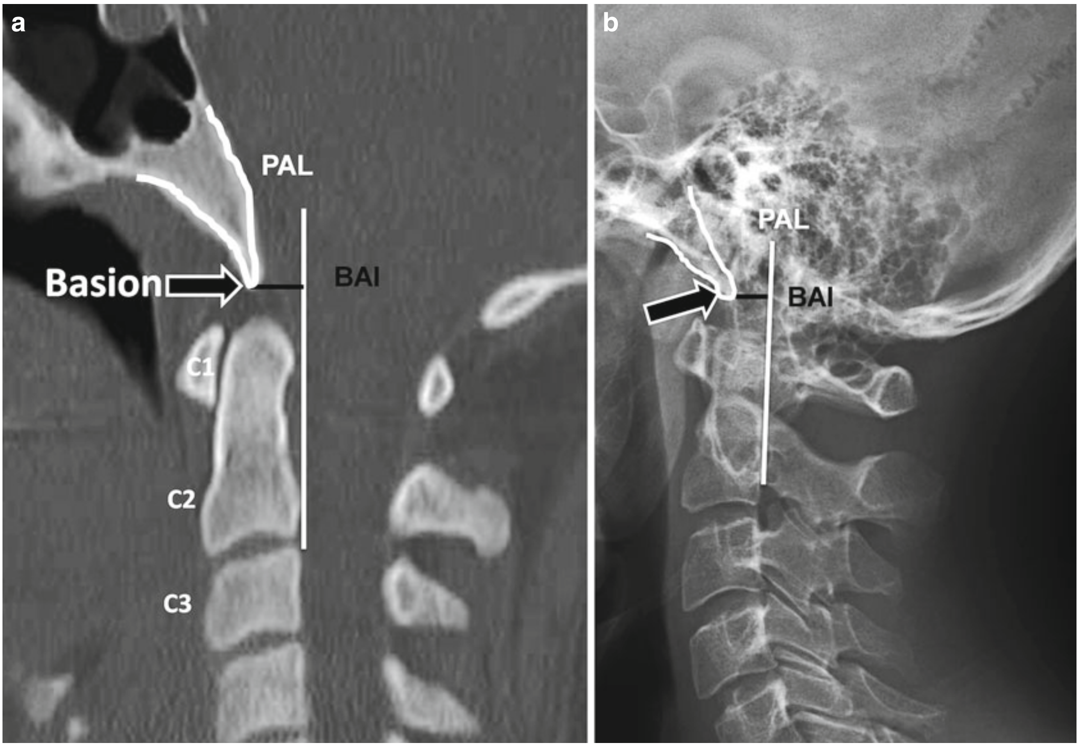

Fig. 4.2 Sagittal CT reconstruction (**a**) and lateral cervical spine radiograph (**b**) demonstrating the basion-axial interval (*BAI*). Basion-axial interval is the distance between basion (*black arrows*) and a line extending superiorly, tangential to the posterior cortex of the C2 vertebral body, the posterior axial line (*PAL*)

curve. Vertebral bodies should be rectangular in shape and similar in size to the adjacent ones.

The articular facets connect the posterolateral aspect of vertebral bodies and combine to form the facet joints. On the lateral view, the lateral masses appear as rhomboid-shaped structures projecting posteroinferiorly.

The anterior longitudinal ligament (ALL) and the posterior longitudinal ligament (PLL) are major stabilizers of the intervertebral joints, helping to maintain the vertebral body alignment [4]. When assessing spinal alignment, it is helpful to evaluate the integrity of the anterior spinal line (Fig. 4.1a, ASL) which extends along the anterior margin of the vertebral bodies; the posterior spinal line (Fig. 4.1a, PSL) along the posterior margin of the vertebral bodies; the spinolaminar line (Fig. 4.1a, SLL) along the posterior margin of spinal canal; and a line connecting the tips of C2–C7 spinous processes, the spinous process line (Fig. 4.1a, SPL). Misalignment of ASL, PSL, SLL, or SPL can suggest ligamentous injury or occult fracture. Although any spinal offset should be scrutinized, there are common nonpathologic reasons for minimal offset including pseudosubluxation of C2 in the pediatric population [5] and the slight offset of the SLL between the posterior elements of C1 and C2.

Radiographic assessment of the craniocervical and atlantoaxial articulations is difficult but crucial (Figs. 4.2, 4.3, and 4.4). Craniocervical and atlantoaxial biomechanical continuity depends on the integrity of the skull base (occipital condyles), atlas (C1), and axis (C2) and their stabilizing ligaments. On lateral view, the craniocervical relationship can be assessed visually by several methods. The basion is the caudal tip of the clivus and can be a critical bony landmark for assessment of the craniocervical relationship. Harris et al. [6, 7] described a simple and reliable method that used the basion-axial interval (BAI) and basion-dens interval (BDI) for accurate assessment of occipitovertebral relationships on initial lateral radiographs in the supine position.

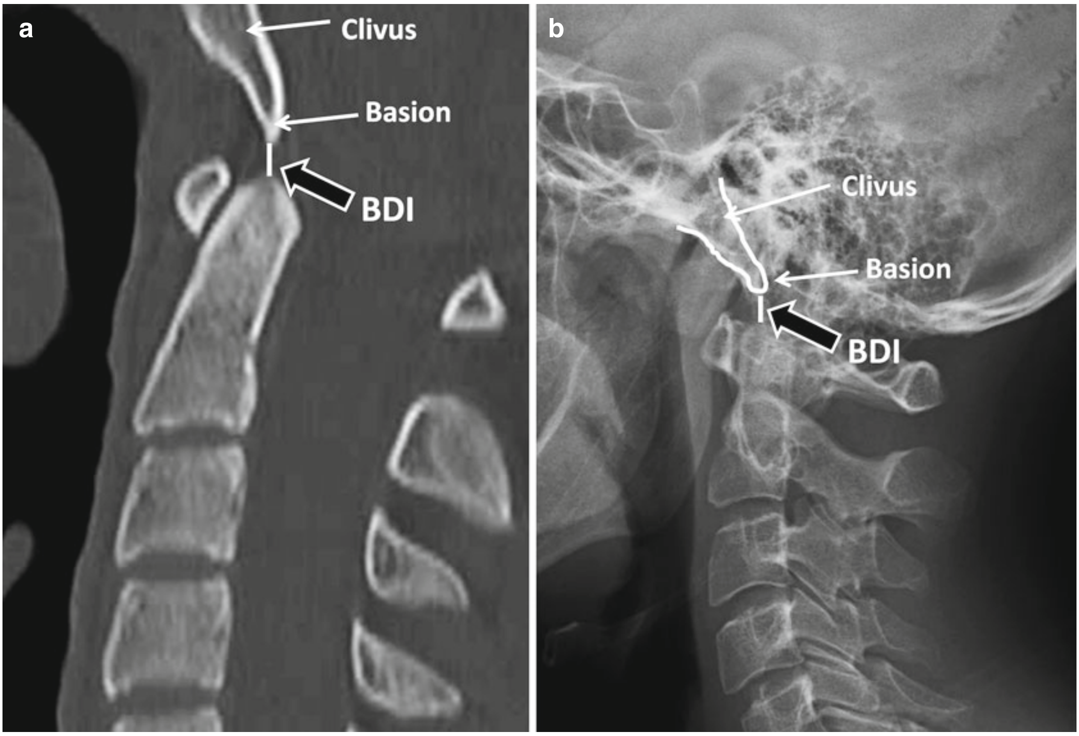

Fig. 4.3 Sagittal CT reconstruction (**a**) and lateral cervical spine radiograph (**b**) demonstrating the basion-dens interval (*BDI*). The BDI is the distance from most inferior portion of basion to closest point of superior aspect of dens

The BAI (Fig. 4.2a, b) is the distance between the basion and a line extending superiorly from the posterior cortical margin of the body of the axis, that is, the posterior axial line (PAL). The BAI should not exceed 12 mm [7].

The basion-dens interval (BDI) (Fig. 4.3) is the distance between the basion and the tip of the dens and should not exceed 12 mm [6]. Abnormal increase in this distance can indicate craniocervical dissociation. An inverted BDI where the tip of the dens is superior to the basion indicates cranial settling/basilar invagination.

The atlantodental interval (ADI) (Fig. 4.4) is a measurement used to evaluate the atlantoaxial relationship. This distance, described by Hinck et al., is considered normal when it is less than 3 mm [8].

The prevertebral soft tissue thickness (Fig. 4.5) should be measured at C3 and should be ≤7 mm in adults [9]. Below C4 the thickness is variable related to variable location of the esophageal takeoff. The neck position in children is pivotal in the assessment of prevertebral soft tissue to prevent false-positive findings.

The facet joints are normally symmetric and uniformly superimposed, with minimal physiologic movement during flexion and extension. The supraspinous and interspinous ligaments, the ligamentum flavum, and the facet joint capsule maintain this anatomic relationship. In the cervical region, the articular facets are small, flat, coronally oriented, and angled approximately 45° from the horizontal plane. This alignment helps to prevent excessive anterior vertebral body translation and is important in weight bearing. This orientation explains the great degree of motion allowed, as well as the relative ease with which cervical facets sublux, dislocate, and lock [10].

Anteroposterior (AP) and Open-Mouth Views

As previously discussed, patient's position is important when evaluating the cervical spine radiograph. On AP view (Fig. 4.6a), the spinous processes should be midline to accurately assess alignment. It is important to make sure all pedicles are present and equidistant from the vertebral body margins. The intervertebral disk spaces

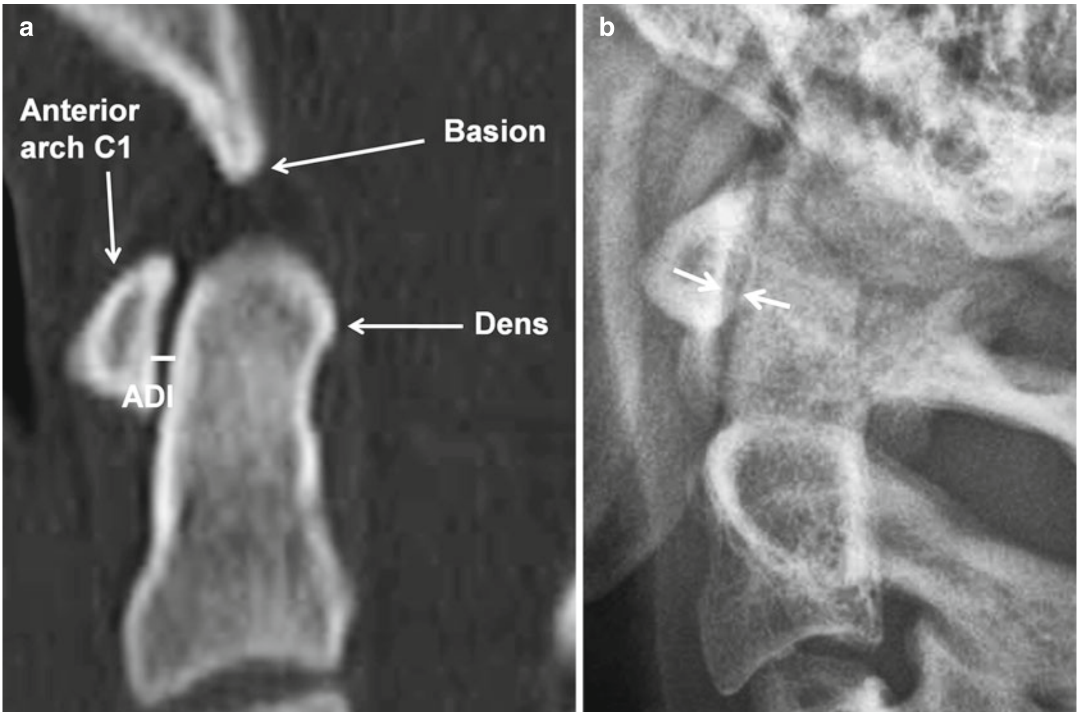

Fig. 4.4 Sagittal CT reconstruction (**a**) and lateral cervical spine radiograph (**b**) demonstrating the atlantodental interval (*ADI*). The atlantodental interval is the distance from the posterior aspect of anterior arch of the C1 vertebra to the anterior aspect of dens

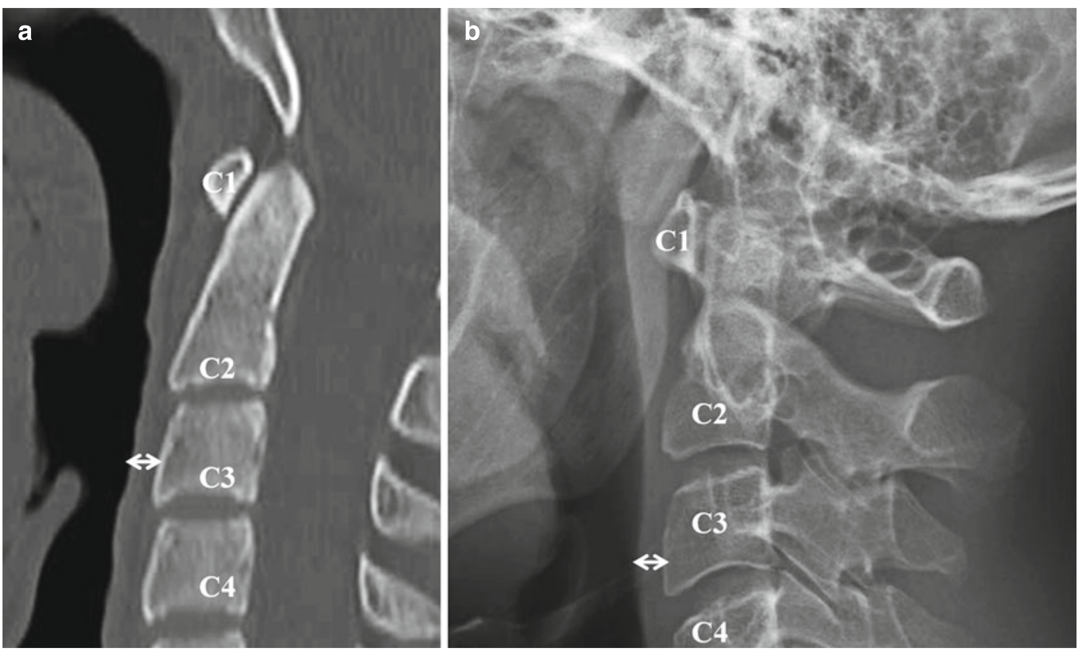

Fig. 4.5 Sagittal CT reconstruction (**a**) and lateral cervical spine radiograph (**b**) demonstrating normal prevertebral soft tissue (*PVST*) thickness. PVST thickness should be measured at C3 and should be ≤7 mm in adults

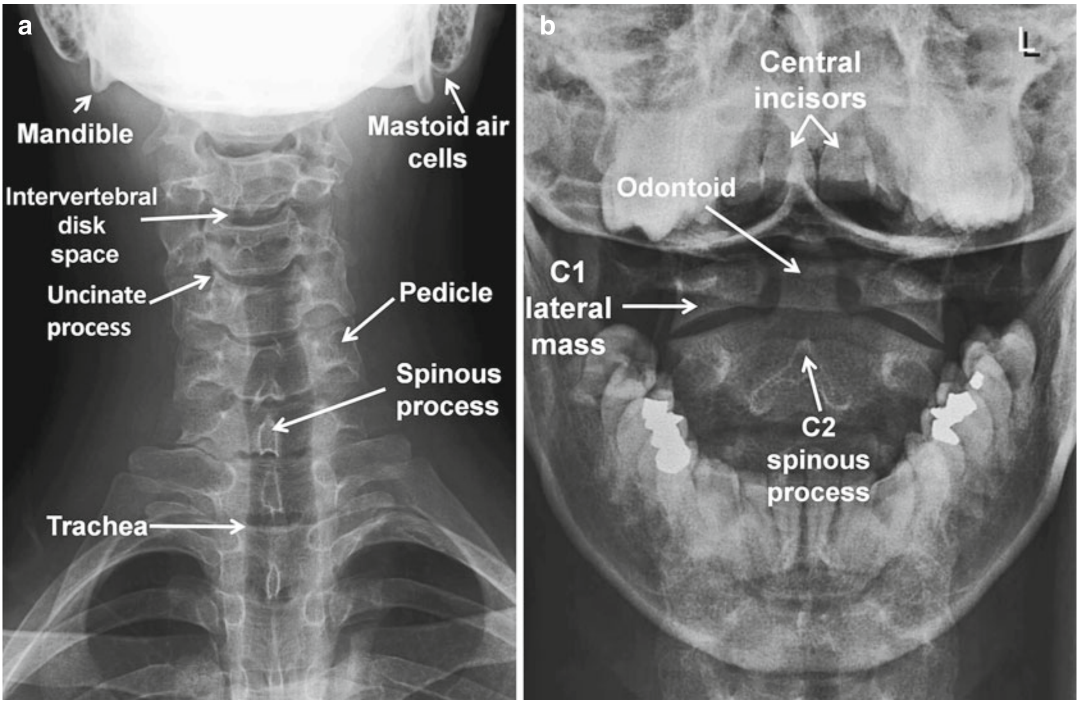

Fig. 4.6 Normal radiographic anatomy on AP cervical spine (**a**) and open-mouth odontoid (**b**) radiographs with labeled pertinent anatomy

should be maintained. Tracheal morphology and lung apices should be assessed for abnormality.

The AP "open mouth" or "odontoid" (Fig. 4.6b) is a coned-down view of the craniocervical junction, obtained with the X-ray beam directed through the patient's open mouth. True AP positioning is necessary as rotation can simulate C1–2 misalignment. On an optimal open-mouth view, the central incisors and occiput are not superimposed over the dens. The lateral margins of the C1 ring should align exactly with the lateral masses of C2 when degenerative spurring is ignored [11]. Displacement of C1 lateral masses by more than 2 mm laterally is abnormal. The open-mouth view is also helpful when evaluating an odontoid fracture or incomplete fusion of the dental ossification center to the C2 vertebral body, an os odontoideum.

Oblique Views

On the oblique projection (Fig. 4.7), the patient's neck is 45° angle relative to the detector plate. The oblique views are typically obtained bilaterally and profile the neural foramina to evaluate bony foramina encroachment. Oblique views can also be useful to confirm appropriate alignment of the facet articular processes.

It is important to identify which neural foramina are being profiled, as oblique projections can be obtained in both AP and PA views. The film should be clearly labeled and the visualized neural foramina are contralateral to the direction the mandible is turned. For example, if the patient's chin is turned to the left, the right neural foramina are profiled.

Flexion/Extension Views

Flexion/extension radiographs can theoretically be diagnostic of ligamentous injury in the acute setting, although muscle spasm commonly stabilizes an otherwise unstable spine resulting in false-negative flexion/extension radiography. Delayed radiographs after a period of time in a soft collar, allowing resolution of muscle spasm, have been shown to unmask an otherwise occult ligamentous instability [12].

In nontraumatic situations, flexion/extension radiographs are used to assess the degree of

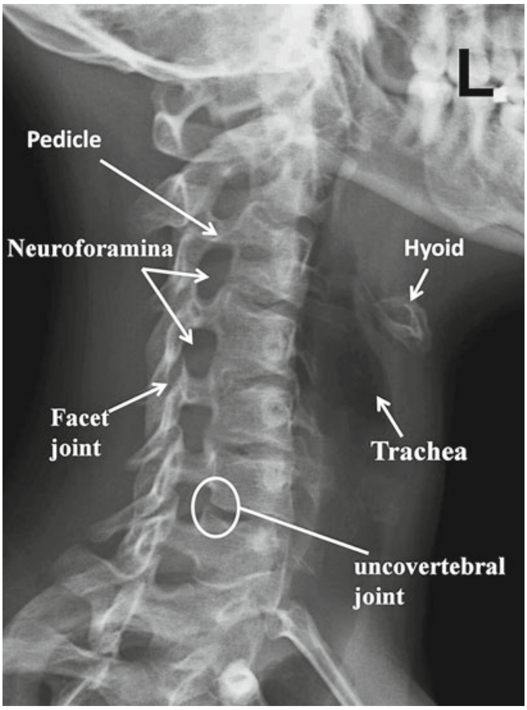

Fig. 4.7 Radiographic anatomy of an oblique projection of the cervical spine. Note that the right neural foramen is profiled as the mandible is turned toward the patient's left (*L*)

instability associated with ligamentous laxity (inflammatory arthropathies, Down's syndrome) or degenerative spondylolisthesis. This can provide valuable information to guide surgical management of chronic cervical spine conditions.

Thoracic Spine

Evaluation of the thoracic spine with radiography allows the assessment of vertebral height, alignment, intervertebral disk spaces, and the presence of fracture and swelling of soft tissues.

Lateral View

The lateral view of the thoracic spine (Fig. 4.8a) should include the seventh cervical vertebra to evaluate the cervicothoracic junction and the first lumbar vertebra to assess the thoracolumbar junction. Evaluation of the high thoracic vertebral bodies commonly requires a swimmer's lateral projection identical to the technique used in complete evaluation of the cervical spine.

On lateral view of the thoracic spine, the anterior margin of the vertebral bodies is slightly concave and the posterior height of the vertebral bodies is greater than the anterior height resulting in a physiologic thoracic kyphosis. The thoracic facets are more vertically oriented in the coronal plane than the cervical facets.

In the traumatic setting, Denis [13] and McAfee et al. [14] independently developed a three-column classification system used to explain the radiographic pattern of injury and subsequent surgical treatment (Fig. 4.9). The system is based on radiographic evaluation of the anterior column (the anterior two-thirds of the vertebral body and intervertebral disk), the middle column (the posterior one-third of the vertebral body and intervertebral disk, as well as the posterior longitudinal ligament), and the posterior column (the osseous neural arch, the facet joints and capsules, the ligamentum flavum, and the supraspinous and interspinous ligaments). Traumatic injury to more than one column of the spine has implications to spinal stability and treatment algorithms.

It is important to evaluate the intervertebral disk spaces in conjunction with the adjacent vertebral endplates. The endplates should be well corticated and distinct (Fig. 4.8). Disk height loss with associated endplate destruction suggests diskitis with associated osteomyelitis, while the association of intervertebral disk height loss with disk vacuum phenomenon, endplate sclerosis, and productive changes is most consistent with common degenerative spondylosis.

Anteroposterior (AP) View

As described on AP view of the cervical spine, adequate patient's position is crucial to the thoracic AP radiograph (Fig. 4.8b). To reduce the radiation dose, collimation is used, although the entire transverse processes and a small portion of the medial ribs should be included.

Thoracic spine AP radiograph is useful for evaluating vertebral body height and alignment. The spinous processes should be aligned and midline. The presence and integrity of the vertebral pedicles is evaluated in the thoracic spine. The interpedicular distance is between the pedicles on AP view and is increased in the setting of a burst fracture relative to adjacent levels. Osseous metastatic disease to the spine commonly involves

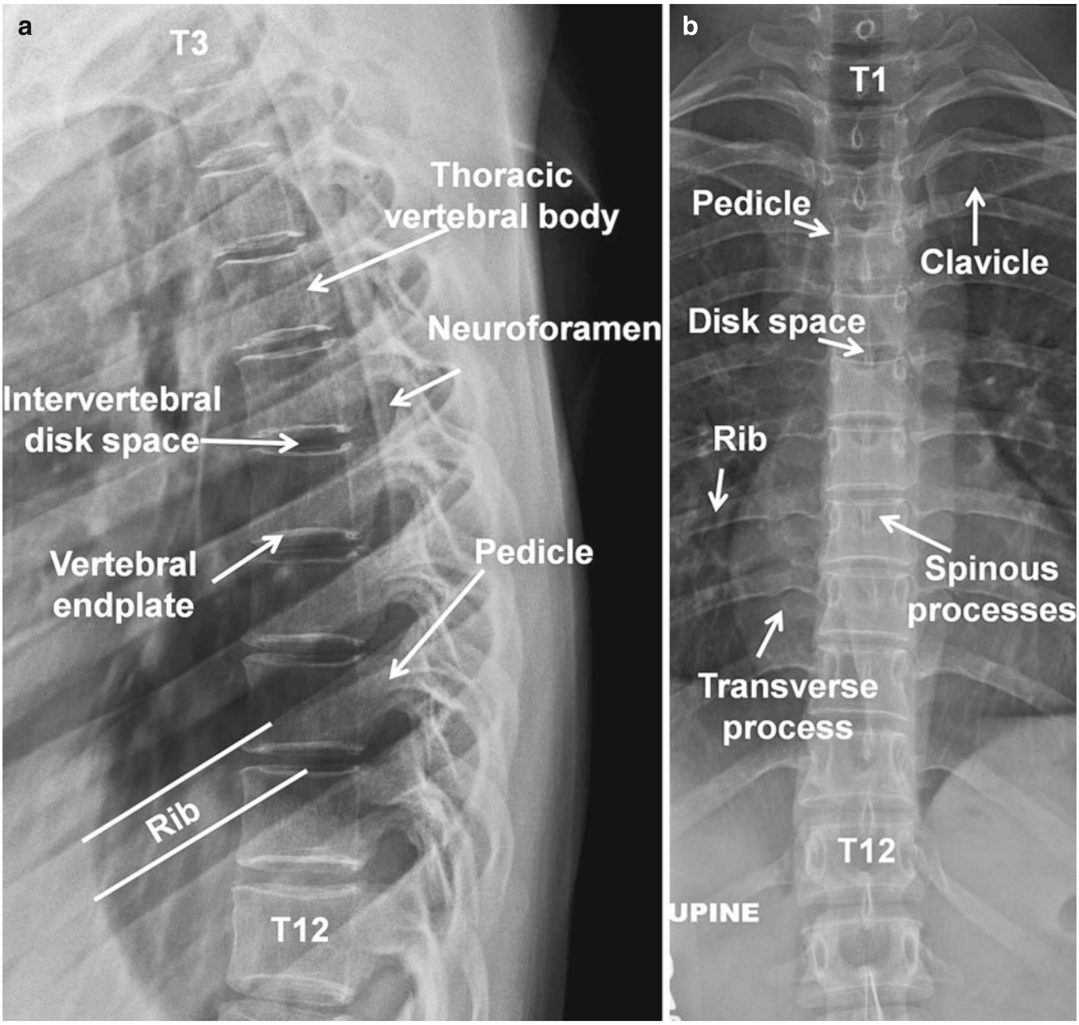

Fig. 4.8 Lateral (**a**) and frontal (**b**) views of the thoracic spine, with pertinent labeled normal radiographic anatomy

the pedicle and can result in an absent pedicle if lytic or a sclerotic pedicle if blastic.

Lumbar Spine

Lateral View

On a lateral view, the lumbar spine characteristically demonstrates a smooth lordotic curvature (Fig. 4.10a). The combination of the thoracic spine kyphosis and lumbar spine lordosis maintains the center of gravity at the central sacrum. The intervertebral disk spaces should appear open, with the L4–L5 disk space typically being of greatest caliber. The neural foramina can be visualized, from T12 through S1. Facet joint orientation transitions to a more sagittal plane in the lumbar spine and allows more flexion and extension than in the thoracic spine but remains limited compared to the cervical spine. A spot film may be used to include the entire sacrum and coccyx for trauma imaging or coned to the lumbosacral junction for routine imaging.

Anteroposterior (AP) View

Optimal radiographic technique for the AP view of the lumbar spine (Fig. 4.10b) is crucial to penetrate the abdominal soft tissues appropriately to obtain adequate exposure and

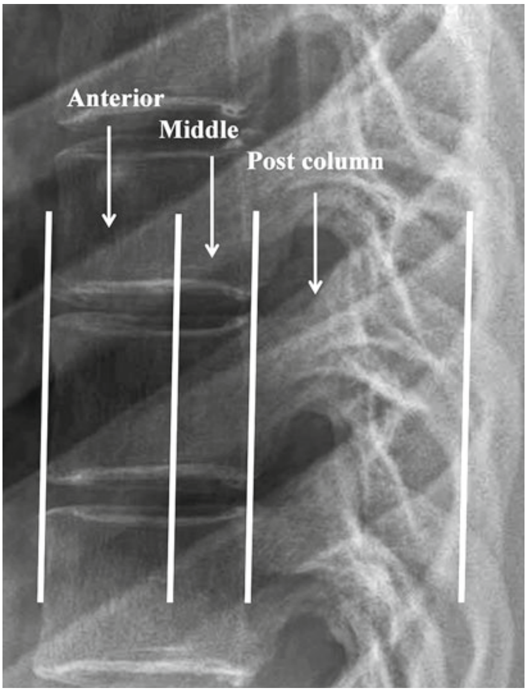

Fig. 4.9 Magnified lateral view of the thoracolumbar junction with lines demarcating the 3-column theory of spinal division. Disruption of more than one column can indicate instability and has implications with regard to treatment

demonstrate vertebral bodies, facet joints, and the spinous processes. An AP radiograph of the lumbar spine should include from the thoracolumbar junction to the coccyx.

The number of non-rib-bearing vertebral bodies should be counted, as transitional and additional vertebral bodies are common at the thoracolumbar and lumbosacral junctions. The most common transitional vertebral body consists of sacralization of the fifth lumbar vertebral body, consisting of a partial or solid, unilateral or bilateral, bony union between an abnormally large L5 transverse process and the sacrum [15]. The spinous processes should be midline of the vertebral bodies and equidistant relative to the pedicles.

Oblique Views

Oblique projections of the lumbar spine are infrequently performed as their utility is controversial and the radiation dose to the patient is significant. However, in young patients with back pain, oblique views can be helpful to confirm the presence of spondylolysis (pars defects) [16]. There is usually no need for routine oblique views in older adults as spondylolysis is much less important in this age group, and there is doubt as to whether it is a significant cause of symptoms in older individuals [17]. Oblique views may be safely omitted in the initial examination for low back pain in the typical patient.

Flexion/Extension Views

Flexion/extension views of the lumbar spine are uncommonly of significant utility in the acute traumatic setting. However, these significantly affect treatment planning with regard to surgical intervention of more chronic back pain. Significant translation (≥3 mm) between flexion and extension can exclude particular treatments related to lumbar stenosis and can shed light on the etiology behind dynamic lumbar radiculopathy.

Whole-Spine Imaging

A brief mention is necessary related to large-format radiography and its use in the spine. Large-format radiography can be performed manually in the absence of digital radiography (radiographic hard copy films shot at different stations and manually connected to include the entire spine). Digital radiography has made large-format imaging much easier with fiducial markers allowing accurate synthesis of multiple acquisitions. The benefit is an overall impression of the spinal balance (Fig. 4.11). In addition, lateral bending, traction, and bolstered films can give further information about the flexibility (and by extension, correctibility) of the curvature, all critical to the surgical management of spinal deformity. Detailed explanation of the evaluation of scoliosis radiographs is, unfortunately, beyond the scope of this chapter.

4.1.2 Computed Tomography (CT)

4.1.2.1 Background and Physics

Computed tomography, which is available since the early 1970s, utilizes an X-ray beam spinning in a circle within a gantry. The detectors, which

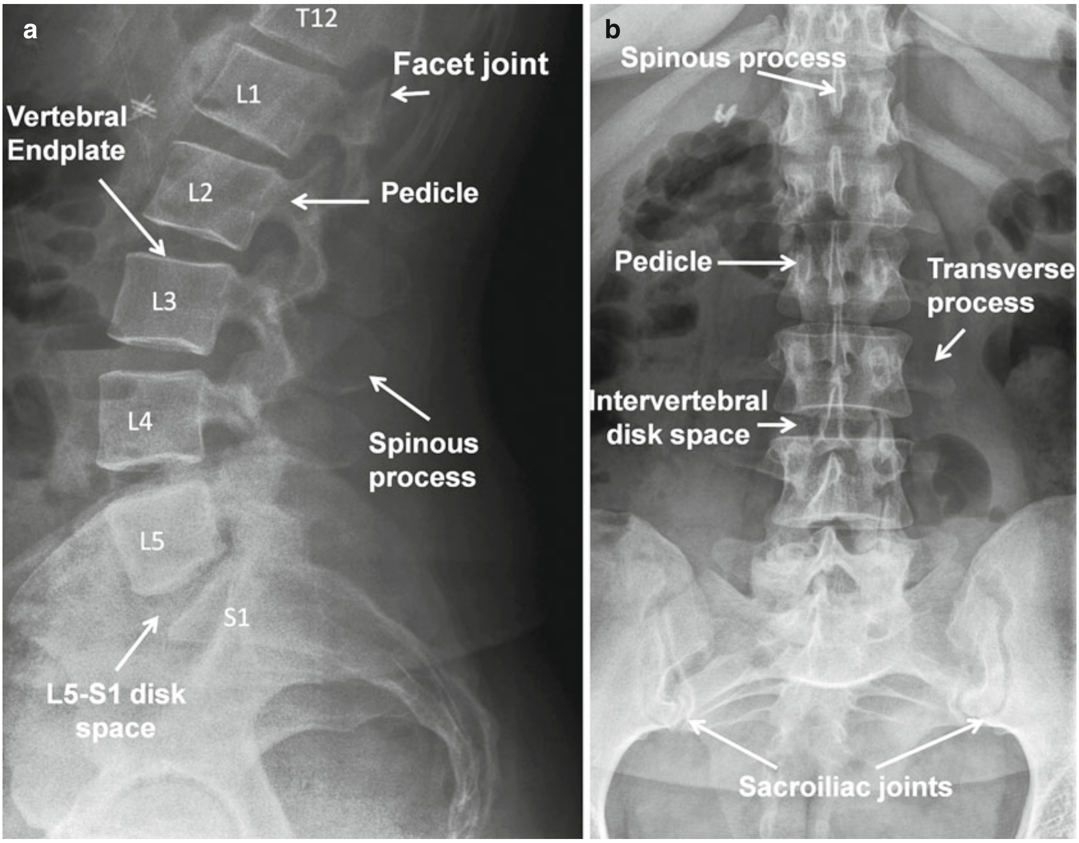

Fig. 4.10 Lateral (**a**) and frontal (**b**) radiographs of the lumbar spine with pertinent radiographic anatomy labeled

are opposite in position relative to the X-ray source, record the strength of the exiting X-ray after passing through the patient; this information is then processed by a computer to produce a detailed two-dimensional cross-sectional image of the body. Early CT scanners had a single X-ray source and single detector. This required a full 360° acquisition followed by the table moving to a new position, where the process was repeated. Early scanners required 30 min or more to do a single CT of the brain. With current technology there are scanners that contain 256 (or more) individual detectors, allowing the table to move quickly through the X-ray beam. This enables acquisition of a tremendous amount of data, resulting in higher-quality images that are easily reconstructed into various multiple planes, thought to be more useful clinically than axial images alone. We can now scan an entire body in a few seconds!

Computed tomography is a noninvasive, painless, and fast imaging diagnostic technique and is the modality of choice for imaging bony detail. Because of the accuracy and ease of CT, there has been a marked increase in usage in the last 30 years. It is estimated that more than 62 million CT scans are currently obtained each year in the USA, as compared with 3 million in 1980, over a 20-fold increase [18]. While CT is a widely used diagnostic technique, several disadvantages need to be considered, such as higher direct medical costs, ionizing radiation, and availability. It is estimated that medical CT scanning contributes approximately 45 % of the US population's collective radiation dose from all medical X-ray examinations [19] and must be used judiciously.

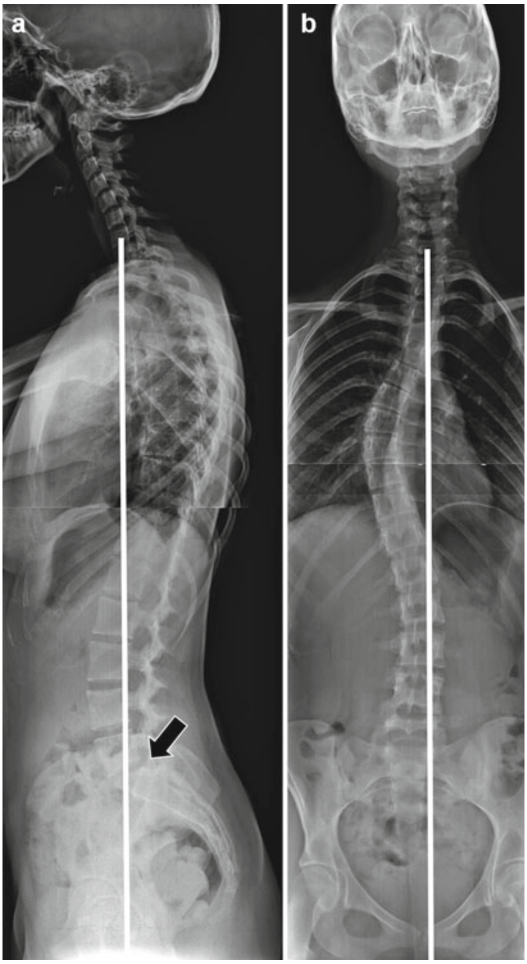

Fig. 4.11 A 19-year-old female with idiopathic scoliosis. Large-format scoliosis radiographs in lateral (**a**) and frontal (**b**) projections. These large-format views allow for evaluation of the overall sagittal balance (**a**, *white line*) and coronal balance (**b**, *white line*). Appropriate sagittal balance is a plumb line that extends from the center of the C7 vertebral body inferiorly to intersect the dorsal margin of the S1 endplate (**a**, *arrow*). Coronal balance is measured with a plumb line that extends from the C7 spinous process inferiorly through the pubic symphysis/mid-sacrum. This patient demonstrates minimal anterior and left coronal imbalances of a degree that would not likely be considered clinically significant

4.1.2.2 CT for Spine Evaluation

CT demonstrates exquisite bony detail and spatial resolution. The current technology allows reformation of the data in multiple planes. The bony anatomy visible is identical to that seen on radiograph, but the tomographic depiction allows much improved visualization of fractures and bony lesions as discussed above (Fig. 4.12a, b).

CT is commonly used for evaluation of the spine following trauma. Care should be taken to select patients carefully, to minimize radiation dose and medical cost. However, the cost of any diagnostic test needs to be considered with regard to the diagnostic efficacy, the appropriate and rapid work-up of trauma patients, and the risk of misdiagnosis. When considering these factors in the setting of acute cervical spine trauma, C. Craig Blackmore et al.'s cost-effective analysis indicated that screening CT of the cervical spine should be adopted for the initial evaluation of *high-risk* patients [20]. The sensitivity of screening cervical spine CT is higher than that of radiography [21] for fractures of all types. Several other studies have shown CT to be far superior in evaluation of cervical spine trauma [22–25].

The 2007 American College of Radiology Appropriateness Criteria emphasizes this and recommends that "thin-section CT, and not radiography, is the primary screening study for suspected cervical spine injury" [26].

CT is excellent for accurate bony evaluation and is commonly used for assessment of primary or metastatic neoplasms involving the spine. In the evaluation of diskitis and osteomyelitis, CT allows excellent visualization of the characteristic endplate destructive changes (Fig. 4.13a, b).

Radiographic evaluation of the postoperative spine can be challenging. Although the effectiveness of conventional CT can be limited by severe beam-hardening artifacts, the evolution of multichannel CT has made available new techniques that can help minimize these artifacts [27]. Postoperative imaging is typically performed to assess the progress of osseous fusion, to confirm the correct positioning and the integrity of instrumentation, to detect suspected complications (infection, non-union, or hardware loosening), and to detect

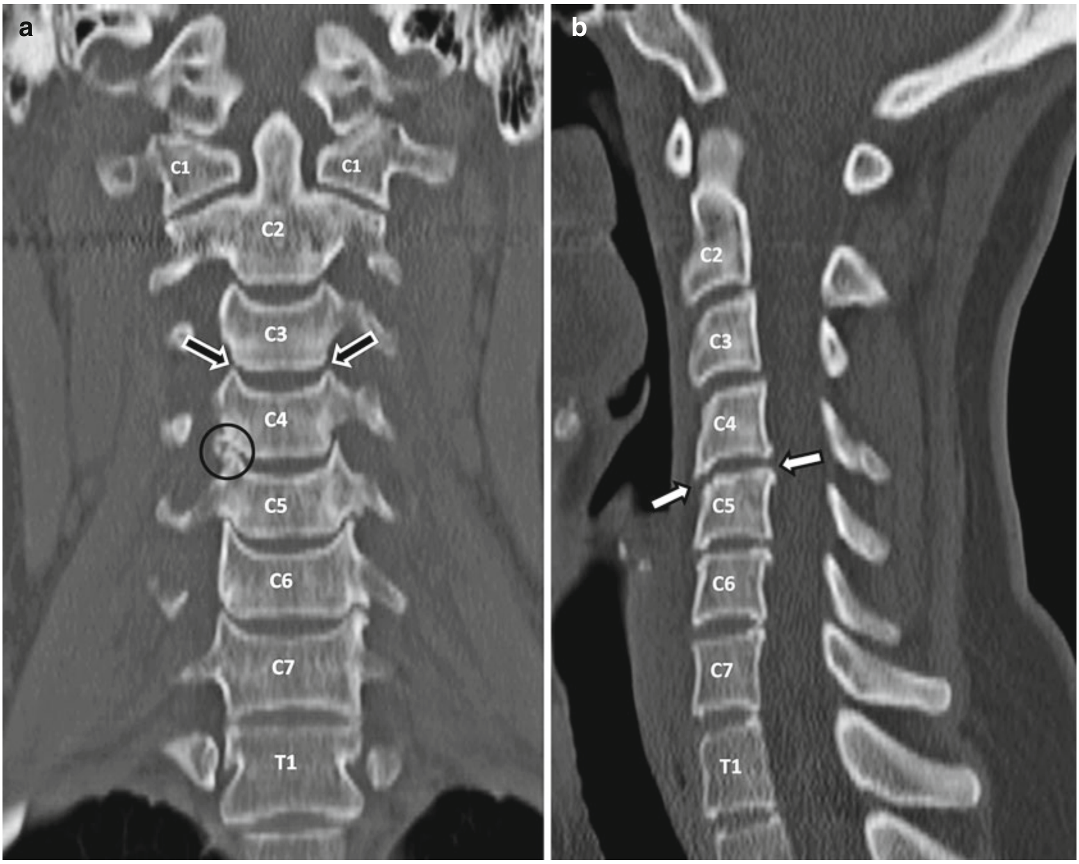

Fig. 4.12 CT coronal (**a**) and sagittal (**b**) reconstructions of a 43-year-old female with chronic neck pain demonstrate the tomographic anatomy afforded by current CT techniques. Coronal reconstruction (**a**) shows normal uncovertebral joints (*black arrows*) at C3–4, with typically degenerative appearance to the C4–5 uncovertebral joints, right greater than left (*circle*). Sagittal reconstruction (**b**) shows great bony detail and in this patient shows degenerative disk disease with endplate productive change greatest at C4–5 (*white arrows*)

new disease or disease progression (Fig. 4.14) [28]. Radiography is the noninvasive modality most commonly used for the assessment of fusion, although CT has been reported to be more accurate [29].

Evaluation of the intraspinal soft tissues in patients who are unable to undergo MRI can be challenging. CT myelography can be used in these situations for the evaluation of nerve root impingement-related spinal degenerative disease. Following the injection of iodinated myelographic contrast material into the thecal sac, CT is performed. The opacification of the thecal sac filled with contrast affords more accurate evaluation of central spinal canal and neural foraminal narrowing.

4.1.3 Magnetic Resonance

4.1.3.1 Background and Physics

MR uses a powerful static magnetic field (commonly referred to as the field strength of the magnet, measured in Tesla (T)) to align the magnetization of atoms in the body. Current clinical MRI systems range from 0.2 to 3.0 T. Once the patient has been placed in this powerful static magnetic field, radio-frequency pulses systematically alter the alignment of these magnetized protons. The frequency at which the protons realign along the static magnetic field is tissue specific, and this information is used to construct an image of the scanned area of the body. A more extensive