### Skeleton

The spinal column is normally composed of 24 individual vertebrae divided into three regions, **cervical**, **thoracic** and **lumbar**. These articulate caudally with five fused vertebrae forming the sacrum, which in turn articulate with three to five fused small vertebrae forming the coccyx. All vertebrae develop from the same three elements, which form within the sclerotome at each level (see page 77). These are the **centra** (forming most of the vertebral body), the **neural arch** and the **costal process**. However, the contribution of each of these elements will differ in the formation of the adult vertebra at each level within the spinal column.

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**MUSCULOSKELETAL SYSTEM**

A 60-year-old woman attended her family doctor because she had persistent pain and pins and needles along the ulnar border of her left forearm. When examined by her doctor, he noticed:

1. She had some decreased sensation on the medial aspect of her forearm, where she had noticed the discomfort.

2. The small muscles of her left hand, particularly the thenar eminence, were wasted compared to the left.

3. The left radial pulse was more difficult to palpate than the stronger right radial pulse.

4. There was no abnormality when examining her neck.

This combination of symptoms suggested compression of the lower roots of the brachial plexus and the main arterial supply to the limb, the subclavian artery. When x-rayed, her neck clearly demonstrated a cervical rib attached to the seventh cervical vertebra (Fig. 3.1). This rib appears to be articulating with the first thoracic rib.

The clinical findings are explained by the rib pressing on the lowest trunk of the brachial plexus, carrying the C8 and T1 roots, namely decreased sensation on the ulnar border of the forearm and wasting of the small muscles of the hand. Cervical ribs occur in less than 1% of the population. The subsequent angiogram confirmed that there was compression of the subclavian artery as it passed over the cervical rib (Fig. 3.2), especially when the arms were elevated.

A vascular surgeon excised the cervical rib. After some months the nerve function in the T1 root gradually recovered. The abnormality of the pulse recovered almost immediately.
Vertebrae

Each vertebra has a body anteriorly (Fig. 3.3). Passing posteriorly from the body are two pedicles, one each side of the spinal canal. Posteriorly each pedicle is united to the other through a lamina, passing medially from the pedicle to meet the lamina from the opposite side in the midline. In addition to the lamina passing medially, there is a transverse process passing laterally from the posterior end of each pedicle.

Where both laminae meet in the midline, they form a posterior projection, the spinous process. The space surrounded by this complete ring of bone is known as the vertebral foramen or canal. The bony ring surrounds and protects key elements of the central nervous system, the spinal cord and its roots, while acting as key points for the attachment of the spinal musculature.

Those components projecting posteriorly from the vertebral body, the pedicles, lamina, transverse and spinous processes, are collectively known as the neural arch. Vertebrae articulate with each other through several articular surfaces. Anteriorly intervertebral discs (secondary cartilaginous joints) join the vertebral body to the next vertebral body superiorly and inferiorly. Posteriorly there
are the posterior articular facets (synovial joints), two projecting superiorly and another two projecting inferiorly, located at the junction of each lamina and pedicle. When a vertebra is viewed laterally due to the presence of the inferior articular processes, a notch is observed inferior to the pedicle, the vertebral notch, which is converted into the **intervertebral foramen** when articulated with the vertebra below. The spinal nerves pass from the vertebral canal through the intervertebral foramen.

**Cervical vertebrae**

Each of the seven cervical vertebrae is typified by the presence of two foramina transversaria, located laterally where the transverse process joins the pedicle (Figs. 3.3a, 3.5). These two foramina transmit the vertebral arteries (see below) and are formed developmentally between the neural arch element and the costal element.

The five typical cervical vertebrae each have a small body, a relatively large vertebral canal and a spinous process with a bifid tip. Posterior articular facets project superiorly and inferiorly. The spinous process of the seventh cervical vertebra, known as **vertebra prominens**, is particularly prominent and is a very useful surface anatomical landmark.

A 24-year-old man was involved in a road traffic accident. He came off his motorbike at high speed. He immediately complained of a painful neck. On examination he had no definite neurological abnormality. However, he complained of an unusual ‘pins and needles’ sensation in both arms and feet. He had no other injury.

An X-ray was performed (Fig. 3.4) in the casualty department, which demonstrated a fracture through the posterior elements of the second cervical vertebra. This is called a ‘hangman’s fracture’ and is a highly unstable injury that requires speedy recognition and treatment. Alignment was satisfactory. The patient had an emergency operation to stabilise the posterior elements with metal plates and made a full recovery. His unusual sensation resolved before he left the hospital.

![Fig. 3.4 Lateral cervical spine radiograph demonstrating a hangman’s fracture (→←); note the fracture through the posterior elements of the C2 vertebra.](image)

![Fig. 3.5 Relationship of the atlas and the axis: (a) posterior view of vertebral bodies, (b) superior view of atlas sitting superior to axis, (c) AP radiograph through the oral cavity demonstrating the atlas, axis, and clearly demonstrating the dens.](image)
from which spinous processes can be counted superiorly and inferiorly.

In the cervical region there are two atypical vertebrae, the first and second. The first cervical vertebra articulates superiorly with the occipital condyles on the base of the skull and is easily identified, as it has apparently no vertebral body (Figs. 3.5, 3.6), just a ‘thin’ ring of bone. An alternative name for this vertebra is the atlas (after the mythical Atlas holding up the world, the skull). Developmentally the centrum of C1 fuses with the centrum of the second cervical vertebra to form the odontoid peg (Fig. 3.5), which sits within the ring of bone anteriorly where the vertebral body of C1 should be located. Superiorly the laminae have an impression due to the vertebral artery passing across their cranial surface before entering the cranial cavity. The spinous process is rather rudimentary and presents more of a swelling or tubercle than a process. Movement between the skull and atlas is that of ‘nodding’ and is reflected in the shape of the superior articular facets.

The second cervical vertebra, also known as the axis, is typified by the superiorly projecting odontoid process or peg. This peg provides the axis for the ‘rotational’ movement facilitated through the shape of the superior articular facets of C2 and the inferior facets on C1.

**Thoracic vertebrae**

There are twelve thoracic vertebrae with heart-shaped vertebral bodies. Developmentally the rib element remains separate from the vertebra forming the ribs. The second to tenth thoracic vertebrae all show the features of the typical vertebra with very long-drawn-out inferiorly (caudally) projecting spinous processes (Fig. 3.3b). Classically these spinous processes project inferiorly as far as the lower border of the next inferior vertebral body (see Fig. 4.13). The posterior articular facets are rather flat in the coronal plane, and project anteriorly and posteriorly. Each thoracic vertebra has three additional facets on each side for articulation with the ribs. One facet (for the tubercle of the rib) is located on the transverse process and the other two (hemifacets) are located either side of the pedicle where it arises from the vertebral body. The head of a rib normally articulates with the lower facet and transverse process of its own level and the superior facet on the vertebra below.

Exceptions to this typical thoracic vertebra occur at the first (T1), the eleventh (T11) and twelfth (T12). At T1 there is just one articular facet where the pedicle and vertebral body meet inferiorly for articulation with the head of the first rib. The eleventh and twelfth thoracic vertebrae start to take on features of the lumbar vertebrae. The vertebral body becomes more oval and larger; there is a single articular facet at the base of the pedicle for articulation with the head of the 11th or 12th rib as appropriate. There is (a) no articular facet on the transverse process as the ribs at this level are missing a tubercle and ‘float’, and (b) the spinous processes become shorter and heavier in construct. The posterior articular facets change their orientation to be more like those of lumbar vertebrae.

In the early embryo starting in week 3, paired and segmented condensations of the paraxial mesoderm, known as somites, develop lying parallel to the developing neural tube. By the end of the fifth week there will be around 42 somite pairs. It is at this stage that each somite pair will gain a pair of nerves (one on each side) passing from the developing central nervous system. No matter where the structures formed by a particular somite migrate to, they will retain this connection to the central nervous system. The cellular elements within a somite then give rise to three subdivisions.
referred to as the dermatome forming skin structures, the myotome forming muscles and the sclerotome forming the bone and cartilage element. Sclerotome cells migrate initially to surround the developing neural tube and will form the vertebral column and associated ribs. Each vertebra as seen in the adult is formed by the fusion of the caudal half of one pair of somites with the cranial half of the subjacent pair of somites.

In the fetus, these fused components contribute to the formation of the neural arch and vertebral body, with ossification centres appearing within each component. Failure of fusion of adjacent somites can lead to anomalies such as hemivertebrae, congenital scoliosis and other abnormalities. A common presentation of such anomalies is spina bifida, where the posterior elements of the neural arch fail to form leaving the vertebral canal contents potentially exposed (Fig. 3.7).

A mother, aged 45 years, who had been unable to conceive was delighted to be pregnant. The pregnancy proceeded initially uneventfully. During her pregnancy her doctor offered her the possibility of having amniocentesis (withdrawal of fluid from the amniotic sac via percutaneous puncture under ultrasound guidance) to test the amniotic fluid. The doctor explained that this could detect spina bifida, which is one of the risks of pregnancy in an ‘elderly’ mother. The mother said that, irrespective of whether the baby had spina bifida or not, she wanted to have the baby and would not entertain a termination under any circumstance. The procedure was not performed.

At the time of birth the baby was noted to have another type of abnormality in its lower spine where a large cystic structure was seen overlying the lumbar vertebrae. The baby underwent surgery with a neonatal surgeon to obtain cover over the spinal nerve roots. Unfortunately the nerve roots supplying the lower limbs did not develop adequately and the patient suffered paralysis of the lower limbs. The patient was also incontinent of urine and required a permanent catheter initially and later diversion of the ureters on to the abdominal wall (urostomy).

**Lumbar vertebrae**

Normally there are five lumbar vertebrae, each demonstrating all the features of a typical vertebra (Fig. 3.3c). Each has a large oval-shaped vertebral body, which increases in size inferiorly, and thin, flat, laterally projecting transverse processes. The spinous processes are very sturdy, squat and square in shape for muscle attachment (see below). Seen most clearly on lateral X-rays of the vertebral column (Fig. 3.8), superiorly the posterior articular facets project anterolaterally and inferiorly they project posteromedially. Also at this point, but passing laterally, are the thin trans-
verse processes, which are clearly demonstrated on the normal AP abdominal X-ray. Developmentally the transverse process is formed by the rib element. It is of note that the lumbar posterior articular facets normally project medially and laterally (compared to those of the thoracic spine, which project in an anterior–posterior plane).

**Sacrum**

Normally five vertebrae fuse to form the wedge-shaped ‘flat’ sacrum with calcification of the intervertebral joints. Broadest superiorly, the sacrum articulates with the fifth lumbar vertebra (see Figs. 3.8, 7.1), whilst inferiorly (caudally) it narrows to articulate with the coccyx. The first sacral vertebra may not fuse with the second, in which case there is said to be lumbarisation of S1 and the patient appears to have six lumbar vertebrae. The converse can also occur, known as sacralisation of L5, where the individual appears to have four lumbar vertebrae.

The anterior sacral surface, when viewed from the side, is in the form of a concave curvature, especially in the male. In the female it is considerably flatter, with the curvature limited to its inferior tip. Lateral to the vertebral bodies is the ala of the sacrum. Prominent on both the anterior and on the convex posterior surface of the ala are two vertical columns of foramina, the sacral foramina. Passing through these foramina are the right and left primary rami of the sacral spinal nerves. The smaller posterior primary rami pass through the posterior foramina and the larger anterior rami through the anterior foramina. Posteriorly and inferiorly the lamina of the sacral vertebra do not always fuse, leaving the vertebral canal open posteriorly. This is known as the sacral hiatus. In some individuals this can be quite extensive over two or more of the lower sacral vertebrae. The more extensive the hiatus, the greater is the risk that the meninges can result in neurological damage to the pelvic structures and lower limb and is known as spina bifida (see case above) (see Fig. 3.7).

**Coccyx**

The coccyx, the most inferior (caudal) point of the vertebral column, is triangular in shape and composed of a variable number of fused vertebrae. It articulates with the caudal aspect of the sacrum and projects anteriorly towards the anal canal.

A 72-year-old man presented with a 3-week history of back pain. The pain was constant in nature and unrelated to movement. His temperature and white cell count were normal. He had a past medical history of renal cell carcinoma, for which he underwent a right nephrectomy 2 years earlier. Clinical examination was unremarkable, as were plain films; these showed only degenerative changes, consistent with his age. The orthopaedic surgeon was concerned given the nature and severity of the back pain and the history of renal cell carcinoma and requested an MRI of the spine.

The MR images were very abnormal. Several vertebral bodies had an altered signal within them, indicating the replacement of the normal vertebral fatty marrow with tumour material. The changes were consistent with metastatic disease. There was no evidence of the spinal cord being compromised, or of a vertebral fracture. The patient was referred to the oncology service for palliative treatment.

**Articular elements**

Viewed as a whole from the anterior aspect the vertebral column appears to be straight. However, when viewed from the side it is obvious that the vertebral column is normally curved. In the newborn child it has a concave curvature anteriorly, a kyphosis, as in the fetal position (Fig. 3.9). When the infant learns to lift its head up and look around, the neck effectively extends and anteriorly the cervical spine takes on a convex curvature, a lordosis. Likewise, as the infant learns to sit up a similar process occurs in the lumbar spine, which like the cervical region becomes convex anteriorly with the development of the lumbar lordosis. Throughout life the thoracic region maintains a slight kyphosis (see Fig. 4.2). These curvatures are important in maintaining good posture and balance. Muscle action is central to maintaining the normal lumbar and cervical curvatures. An abnormality that seems to preferentially afflict the young female is the development of a lateral curvature, particularly of the thoracic component of the spine. This is known as a scoliosis (Fig. 3.10). It is interesting to note that in the newborn child the spinal processes, especially those in the lumbar region, are very short compared with the adult. They continue to elongate posteriorly throughout childhood.

Fig. 3.9 The development of spinal curvature: (a) fetal spine, (b) first month, (c) child/adult.