Contents

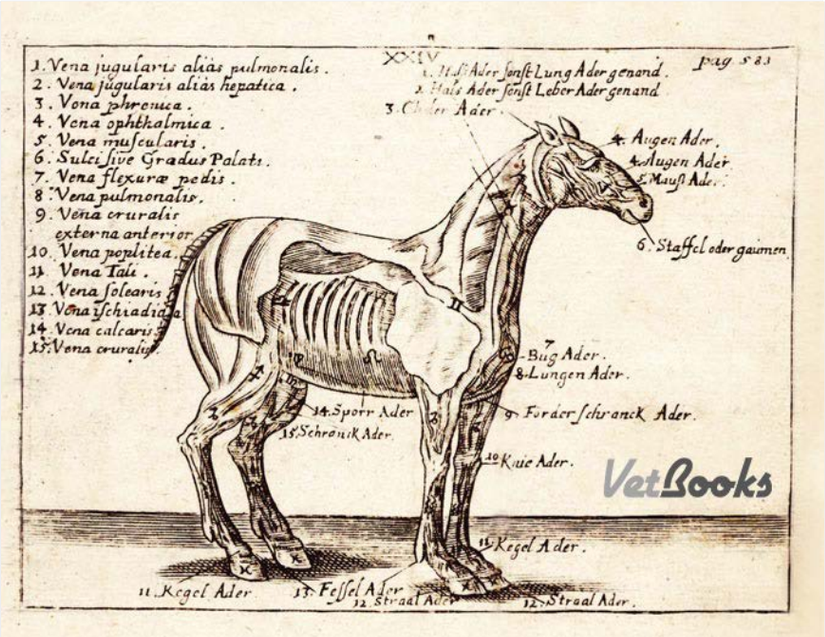

Fig. 1.2 Early illustration of the blood vessels of the horse. (Seifert von Tennecker, pseudonym Valentin Trichter, 1757)

also be found in humans even though now we know it is a typical structure of ruminants. Further, he concluded that humans must have a caecum built like that of herbivores or a uterus with cotyledons.

In the tradition of Galen, an anatomical atlas of the pig (Anatomia porci, written by Copho or Kopho) was published in Salerno around 1100–1150. This was not the first anatomy book in veterinary medicine, but rather was meant as an anatomical teaching tool for students of human medicine. The generally accepted myth then and today – that the pig resembles the human more than any other animal – relies greatly on the similar eating habits and the availability of subject material in those days.

Fig. 1.3 Illustration of the equine musculature. (Dell'Anatomia e dell' Infirmita del Cavallo; Carlo Ruini, Venice, 1598)

During the Renaissance, anatomical studies on human corpses were no longer taboo. With his monumental work on human anatomy (De humani corporis fabrica, 1543), **Andreas Vesalius** marked the hesitant beginning of a revolutionary new attitude toward the human body. Early anatomists still considered themselves naturalists, compiling many fundamental discoveries of morphology through continuing studies of animal anatomy. Vesalius was the first to realize that the Rete mirabile epidurale represented a typical structure of ruminants. Studies of ruminant digestion were advanced by **Johann Conrad Peyer** through his magnificent publication in 1685, Merycologia sive de ruminantibus et ruminatione commentarius (▶ Fig. 1.1). His discovery of lymphatic tissue (Lymphonoduli aggregati) in the intestinal mucosa resulted in the name Peyer's patches. From the beginning, the study of comparative anatomy has remained a domain for research institutes specialising in human anatomy, even more so as zoological research turned away from the study of morphology.

In the last decades of the 20th century, the use of laboratory animals led to the optimizing of therapeutic approaches. The implementation of experimental concepts has been possible only through the application of necessary basic animal morphology, which has largely been provided by physicians. Interestingly, still today animals are chosen as models, not because of their morphological comparability, but rather for their availability.

Veterinary anatomy as a prerequisite for practicing veterinary medicine has developed only in the last few centuries as an independent teaching and research subject. It is evident through ancient and medieval texts for animal caretakers that the anatomical knowledge, especially of horses, was more or less precise (▶ Fig. 1.2). However, the systematic portrayal of the basic morphological associations was nonexistent.

Equerry handbooks created in the tradition of **Jordanus Ruffus** in the late middle ages and early modern age were not systematically organised. They did contain information on equine anatomy, which was often accompanied by ineffectual illustrations. In 1598, **Carlo Ruini** published an at that time exceptional handbook, Dell' Anatomia e dell'Infirmita del Cavallo (▶ Fig. 1.3). Seem-

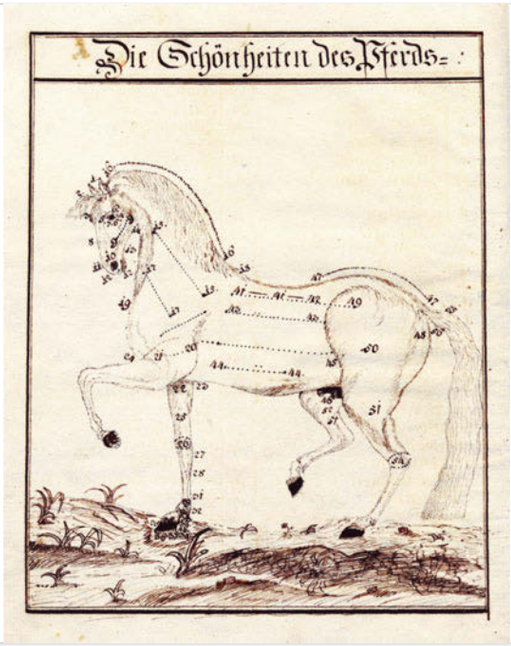

Fig. 1.4 Original drawing showing the body regions of the horse. (from the lecture notes of Ludwig Scotti, School of Horse Cures and Operations, Vienna, 1770)

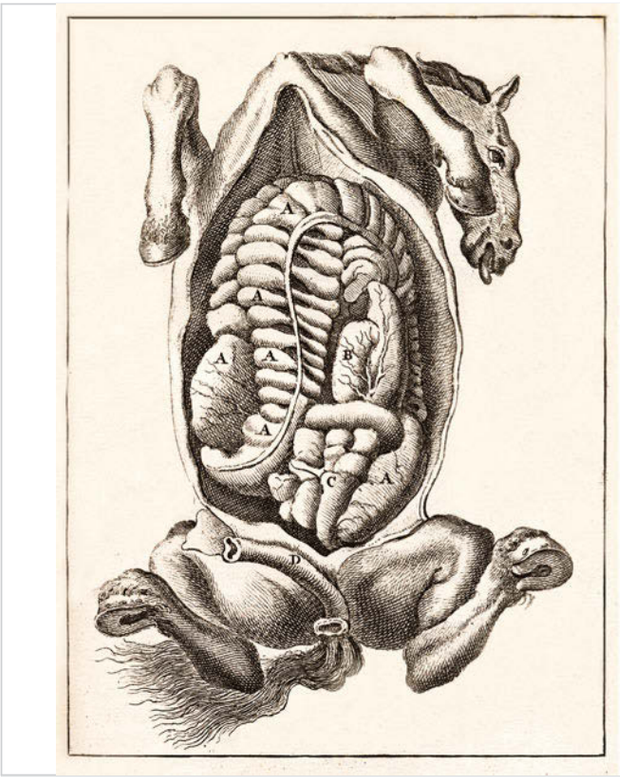

Fig. 1.5 Topography of the horse abdomen. (William Gibson, London, 1754)

ing to appear without a forerunner, this textbook was undoubtedly inspired by Vesalius.

Ruini was born into a prosperous family from Bologna and neither worked as an equerry nor was a member of the university. Through excellent private tutors, he developed a passionate interest in the natural sciences and was an enthusiastic equestrian. Although incomplete and sometimes flawed, his seminal work was nevertheless the first comprehensive and systematic portrayal of equine anatomy. The second half of the book concerning equine diseases was largely an indiscriminate recapitulation of much older literature. The magnificence of this publication lies in its illustrative quality, which rivals that of **Leonardo da Vinci** or **Vesalius**. Ruini's textbook was to be republished, plagiarised and translated many times (▶ Fig. 1.5).

At the beginning of the 17th century, veterinary anatomy was slowly beginning to enter a renaissance. However, it was not to be until about 150 years later that a veterinary academy was created where Ruini's textbook could be used to train animal doctors.

Considered to be the father of veterinary anatomy, **Philippe Etienne Lafosse** opened at his own expense a private veterinary school in Paris in 1767. This endeavour proved unsuccessful, and the school was closed in 1770. Two years later, he published his most successful work, Cours d'Hippiatrique. (A Course on Hippiatry or A Complete Treatise on the Medicine of the Horse). This work was organised according to organ systems, fundamentally resembling the form used today in modern anatomy textbooks. The clinical relevance of a topographical approach was soon integrated into the teaching of anatomy.

One of the earliest topographical illustrations of the horse (▶ Fig. 1.4) is found in the lecture notes recorded and published in 1770 by **Ludwig Scotti**, the first director of the School for Horse Cures and Operations in Vienna. The development of anatomy as an independent discipline at the newly founded European veterinary schools was tentative at best. Consequently, it was not until 1822 that the first comprehensive anatomy text- or handbook was published. The first german comprehensive veterinary anatomy reference was **Konrad Ludwig Schwab's** Anatomy Textbook of Domestic Animals of 1821 (▶ Fig. 1.6), followed closely by **Ernst Friedrich Gurlt's** Handbook of Comparative Anatomy of Domestic Mammals in 1822 (▶ Fig. 1.7). These works represented the beginning of a long German tradition of veterinary anatomical research that quickly gained international recognition and lasted far into the 20th century. Eighteen editions of Gurlt's work were published, with each new edition being revised and improved until the final one was print in 1943. **Wilhelm Ellenberger** and **Hermann Baum** were responsible for the 9th to the 17th editions, creating the style that can still be observed today in this readily available book (▶ Fig. 1.8 and ▶ Fig. 1.9). The sheer volume of publications in veterinary anatomy originating from Germany, Switzerland and Austria in the middle and late 19th century was overwhelming. This reflects the field's significance and the high esteem in which veterinary anatomy was held in those days.

A landmark decision during the modern era of veterinary anatomy was the establishment of the International Committee for Nomenclature in Veterinary Anatomy. Emulating the human medical publication, Nomina Anatomica, the first edition of Nomina Anatomica Veterinaria was published in 1968. This work standardises worldwide anatomical terminology in veterinary medicine, thus providing a useful instrument to maintain the importance of anatomy in a steadily changing medical landscape.

Anatomy is the **branch of morphology** dealing with the form, structure, topography and the functional interaction of the tissues and organs that comprise the body. The dissection of dead

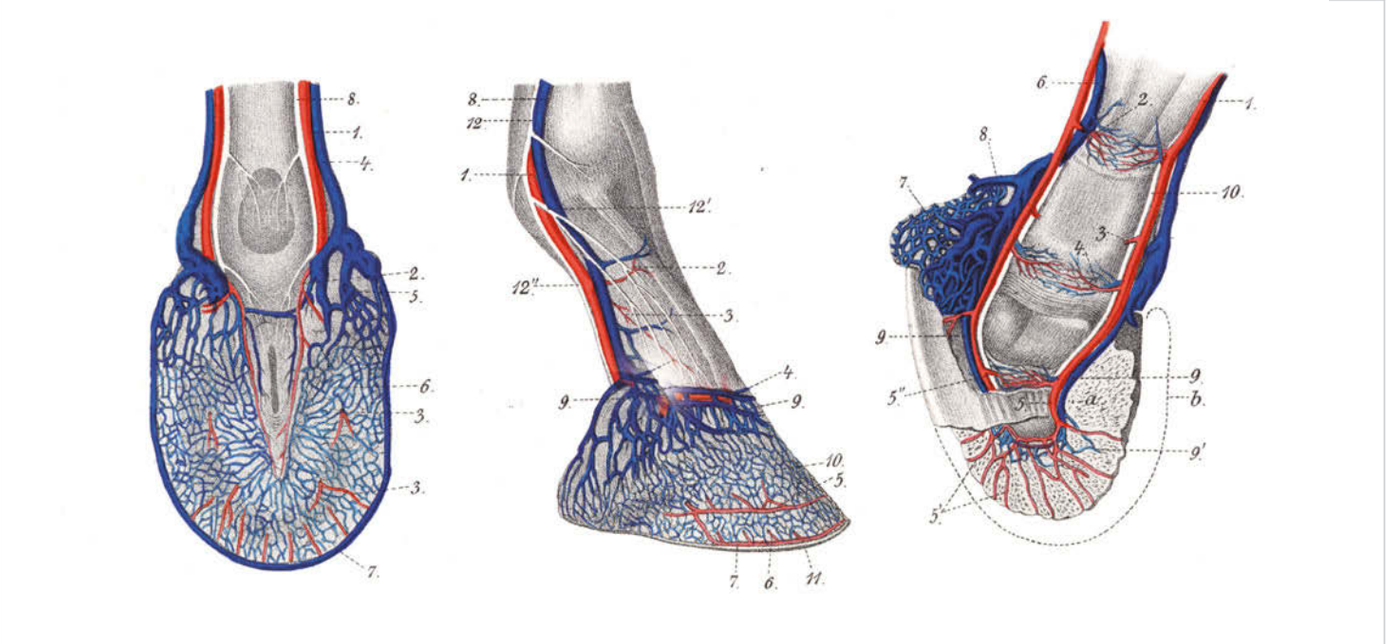

Fig. 1.9 Vascularization of the equine hoof. (from Leisering's Atlas on the Anatomy of Horses and other Domestic Animals; Wilhelm Ellenberger in cooperation with Hermann Baum, Leipzig, 1899)

1.2 Directional terms and planes of the animal body

H.-G. Liebich and H. E. König

Certain descriptive terms are employed to indicate precisely and unambiguously the position or direction of body parts. The most important anatomical terms are illustrated in ▶ Fig. 1.10 and the organ systems are listed with a short explanation in ▶ Table 1.1.

The body of an animal has major divisions which are clearly distinguishable externally: the head (caput), the neck (collum), the trunk (truncus), the tail (cauda) and the limbs (membra). Each one of these sections is in turn divided into regions, which function as descriptive motifs for the topographic anatomy; for more information see Chapter 20 "Topographical-clinical anatomy" (p. 685).

1.3 Division of the animal body in organs and organ systems

H.-G. Liebich and H. E. König

Cells and tissues similar in structure and function are joined together to form individual organs or organ systems. These act synergistically to fulfill functions that define the organism and ensure survival. The individual organ systems are composed of different types of tissue. An individual organ is made up of two types of tissue:

- parenchyma and
- interstitial tissue.

The **cells of the parenchyma** are responsible for the function of the organ (e.g. hepatic cells of the liver, renal cells of the kidneys, glandular cells of the salivary glands). The **interstitial tissue** builds the connective tissue that, for example, either encloses a small functional unit or separates larger areas of an organ into lobules (lobuli) or lobes (lobi). Connective tissue also supports metabolic transport to and from the organs, enclosing not only blood and lymph vessels but also peripheral nerves from the nervous system, all of which supply the organ. Together these structures form an overriding system that greatly influences the structural and functional character of an organ. **Systematic anatomy** examines in detail individual organ systems of the body, which are listed in ▶ Table 1.2.

Veterinary anatomy deals mainly with **domestic mammals**. These are taxonomically classified as Canis lupius f. familiaris (dog), Felis sylvestris f. catus (cat), Sus scrofa f. domestica (pig), Bos primigenius f. taurus (cattle), Ovis ammon f. aries (sheep), Capra aegagrus f. hircus (goat) and Equus przewalskii f. caballus (horse). Also included in the study of veterinary anatomy is poultry, whereby Gallus gallus f. domestica (chicken) is the most common specimen. Poultry is an important field in veterinary medicine and is therefore extensively covered in a separate textbook containing a revised and updated introduction to avian propedeutic and clinical medicine (König HE, Korbel R, Liebich H-G. Anatomie der Vögel. 2. Aufl. Stuttgart: Schattauer; 2009).

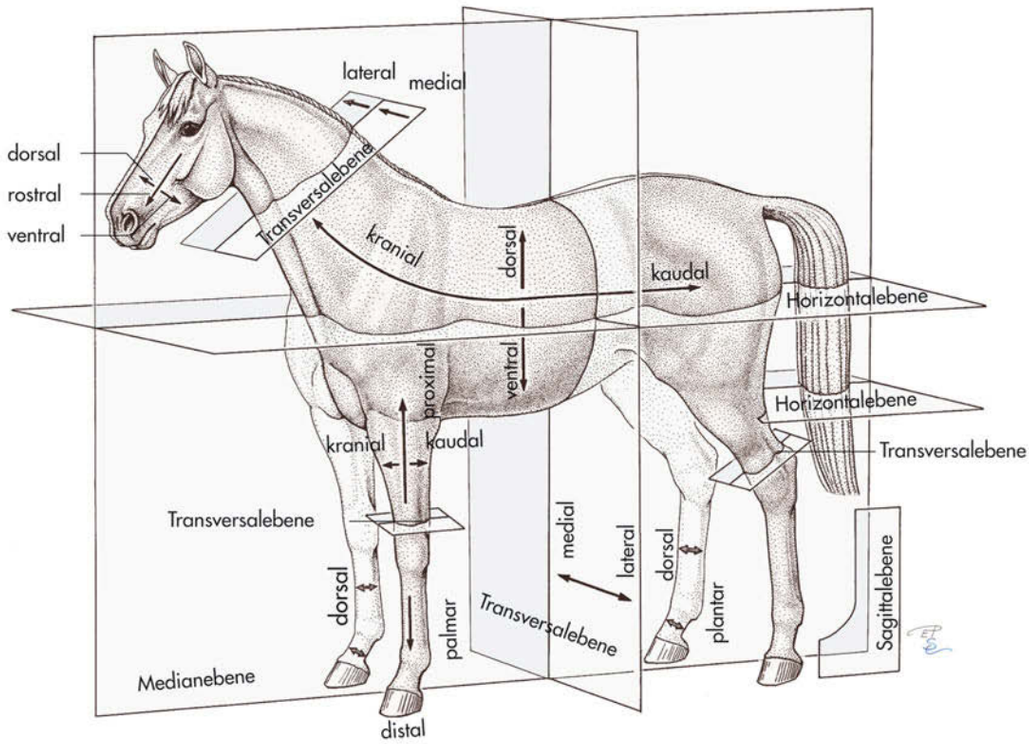

Fig. 1.10 Directional terms and planes of the animal body (schematic); fig. based on data from Dyce, Sack and Wensing, 2002.

1.4 Locomotor apparatus (apparatus locomotorius)

H.-G. Liebich and H. E. König

The locomotor apparatus is a **complex organ system** whose primary function is mechanical. The skeleton and the muscles are the major elements comprising this system, forming and maintaining the individual body shape and providing for the locomotion of body parts or the whole organism.

The **skeleton** is composed of individual elements: the **bones** (ossa), **cartilage** (cartilagines), **ligaments** (ligamenta) and the **joints** (articulationes) that together create the body's framework, the **skeletal system** (systema skeletale).

The **skeletal system** constitutes the **passive part of the locomotor system**, whereas the **musculature** (systema musculare) represents the **active part**. Both parts form a functional unit that is integrated into the body's circulatory, lymphatic and nervous systems.

The system performs many metabolic functions at a cellular level. Hormones regulate a constant process of growth, modification and breakdown. The term "**locomotor system**" does not do justice to this many-facetted system; therefore this system is more appropriately referred to as the system of motion, stability and support.

Malfunctions and diseases of this system are among the most common diagnoses made in clinical veterinary medicine. The importance of basic anatomical knowledge is often greatly underestimated.

1.4.1 Skeletal system (systema skeletale)

Osteology (osteologia)

Osteology is the study of bones (ossa) that combine to form the skeletons of diverse animal species. Bones are composed of:

- **bone tissue** which is sheathed inside and outside by the
- **endosteum** and **periosteum**, respectively, and the
- **bone marrow** (medulla ossium), as well as the
- **blood vessels** and **nerves** supplying these structures.

These components classify bone as an **organ**.

The individual form of each bone is genetically determined and remains even though forces of traction and compression subject the bone to continual adaptation processes. Because of their high **mineral content** (60–70%), bones do not undergo post-mortem changes and are thus useful objects of archaeological study. **Maceration of bone** is the process of removing **organic components** through the use of weak lye. Bones used as teaching objects have usually undergone such treatment. Treating the bones with an **acid** removes the **inorganic** or **mineralised** components.

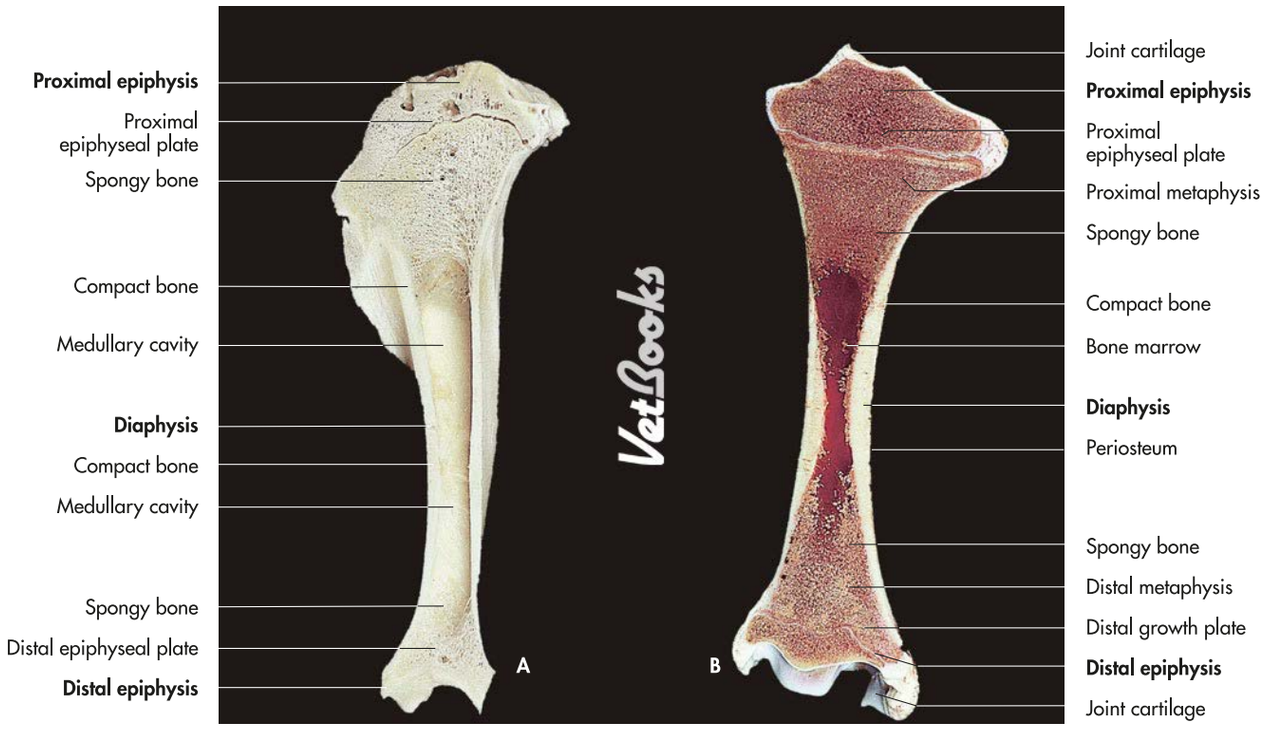

Fig. 1.12 Sagittal section of a long bone after maceration **(A)**, and sagittal section of an untreated long bone including joint cartilage and red bone marrow **(B)**.

Long bones form the basis of the limbs, i.e. upper arm (humerus), shin bone (tibia), or the metacarpal bones (ossa metacarpalia).

Short bones can have different forms: cylindrical, cubic or round. Such bones contain an extensive latticework of spongiosa in which haemoreticular tissue is present. Examples of short bones are those of the vertebral column and the hock joint.

Flat and **wide bones** consist of two layers of compact bone (tabulae) surrounding either spongy bone (diploe) or air (sinus). This group contains for example the scapula, the iliac bone or the ribs. Some bones of the skull are flat bones surrounding **cavities of air** (ossa pneumatica). These bones have formed through the subsequent resorption of bone substance and are lined with mucosa. Examples are the maxilla or the ethmoid bone.

Examples of irregular bones are the wedge-shaped bones of the skull: the sphenoid, presphenoid and basisphenoid bones. **Sesamoid bones** (ossa sesamoidea) are found close to the joints (i.e. the foot joints) and either lie beneath or are embedded in (i.e. patella) a tendon (▶ Fig. 1.33).

An **apophysis** is a bony protuberance that developed from an independent ossification centre. These structures provide attachment sites for muscles and ligaments. An example is a vertebral spinous process or the trochanter major on the femur. **Bones of the organs** are not related to the locomotor system. Such bones are found in the penis of male cats and dogs or in the bovine heart.

▶ Fig. 1.25, ▶ Fig. 1.26, ▶ Fig. 1.27, ▶ Fig. 1.28 and ▶ Fig. 1.29 schematically show the skeletons of the domestic animals covered in this textbook: cat, dog, pig, ox and horse. These illustrations provide a general overview of the topography of the bones, enabling a comparison between the species. The individual bones are described in detail in later chapters.

Architecture of bone

The high stability of bone is created through the bone tissue. Bone tissue is not massive and homogenous, but rather each individual bone has a specific architecture which is influenced by the:

- structure of the **compact bone** (substantia compacta),
- arrangement of the **spongy bone** (substantia spongiosa),
- form of the **central medullary cavity** (cavum medullare),
- **principles of tensile** (traction) and **compressive stress** (pressure),
- formation of **stress trajectories** and
- **flexure** (shear stress) demands on the entire bone.

The bone surface is constructed of **compact lamellae** which form the basis of the compact substance of bone. This solid layer surrounds the spongiosa, a delicate latticework of bone trabeculae and lamellae. Trabeculae and lamellae are arranged in a **pattern of stress lines** that have formed in response to external mechanical factors, the maximal tensile and compressive forces acting on the bone. The stress lines are either tensile or compressive trajectories. The family of curves that are tensile trajectories run parallel to one another just as the compressive trajectories run parallel to each other. These two types of stress trajectories always cross at right angles to each other **(trajectorial construction)**. One can distinguish between:

- tubules of bone (substantia tubulosa),
- trabeculae of bone (substantia trabeculosa) and
- lamellae of bone (substantia lamellosa, ▶ Fig. 1.13 and ▶ Fig. 1.14).

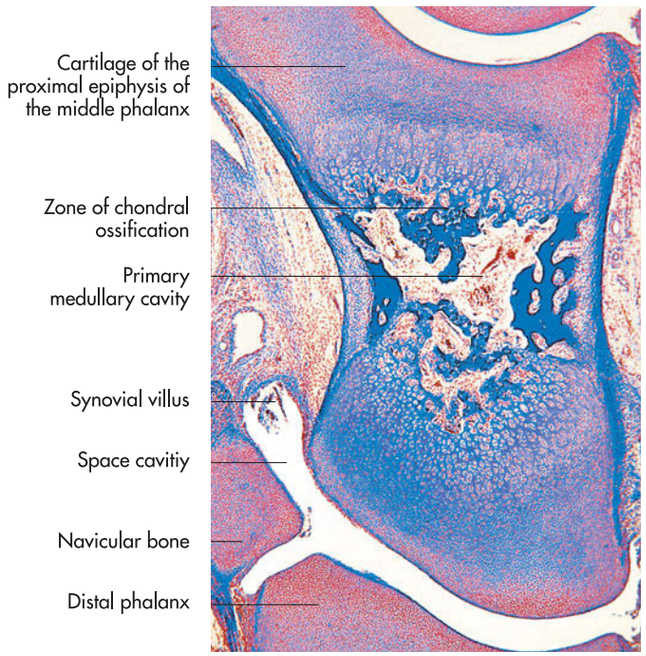

Fig. 1.15 Middle phalanx of a horse embryo (histological section, Azan staining).

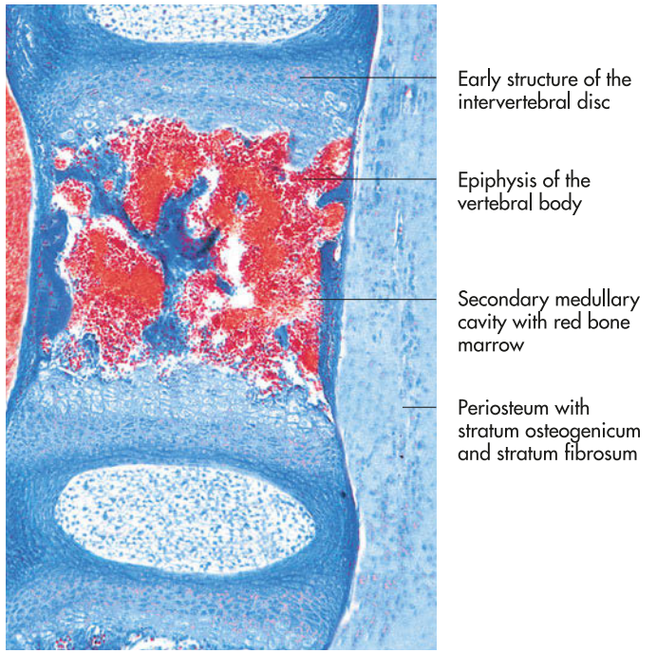

Fig. 1.16 Embryonic vertebrae (histological section, Azan staining).

tum osteogenicum forms the **cartilage callus** and **bone callus**, and prolonged mechanical stimulus of the periosteum can lead to the formation of **osseous bulges** (exostoses or splints).

Dense connective tissue interwoven with elastic fibers makes up the outer layer, the **stratum fibrosum** (▶ Fig. 1.16 and ▶ Fig. 1.17), which is very resistant to tensile forces. Collagen fibre bundles originating in this layer (**perforating fibres**) bind it to the surface lamella of the bone matrix (**Sharpey fibres**). These fibres firmly anchor the periosteum to the bone surface. The **stratum fibrosum** is also responsible for the attachment of muscles, tendons and ligaments to bone. At the site of attachment, fibres from the tendon or ligament branch out into the stratum fibrosum and, continuing as Sharpey fibres, strongly attach to the bone.

The **endosteum** (▶ Fig. 1.17) consists of a single layer of flattened, inactive osteoprogenitor (bone-lining) cells. They can differentiate into either **bone-forming cells** (osteoblasts) or **bone-resorbing cells** (osteoclasts). The endosteum borders the capillary network of the bone marrow and like the periosteum, is **capable of producing bone tissue (osteogenic potential)**.

Bone regeneration

Osteoprogenitor cells in the periosteum and endosteum are responsible for regeneration processes of the bone tissue. Regeneration is only possible when two conditions are met: 1. **mesenchyme cells** are available and 2. **osteoblast precursor cells** can proliferate. New tissue bridges the gap in the bone resulting from fracture.

Primary fracture healing occurs when motion between the two fracture pieces is negligible and they are separated by only small gaps. Lamellar bone forms directly in the fracture gap, reuniting the two ends of the bone. When the edges are too far apart, then **secondary fracture healing** occurs. Fibrous connective tissue initially bridges the fracture gap forming a soft callus. The **callus ossifies** through mineralisation until, after a long reorganisation process, compact bone is formed.

Supply of blood vessels and nerves to the bone

Bone is an extremely well vascularised tissue, and this underscores its metabolic importance. A dense network of blood vessels supplies not only bone tissue, but also bone marrow, the periosteum and the endosteum. Bone trauma or fracture can interrupt the vascularisation, leading in extreme cases to tissue death (**bone necrosis**).

The vascularisation of bone is achieved through a unique, systematic distribution of blood vessels. **Nutrient arteries** (aa. nutriciae) branch off from the larger limb arteries and enter the long bones through openings (**foramina nutritia**) in the diaphysis. These vessels reach the medullary cavity after passing through the stratum compactum. Here they divide into several ascending and descending branches supplying the proximal and distal epi- and metaphyses (▶ Fig. 1.23). At the epiphyses, the vessels form **looped-ending arteries** that reach through the epiphyseal subchondral bone to supply the calcified zone of the joint cartilage. From the medullary cavity, the blood vessels supply the compact substance of bone through the Volkmann's canals (see below). The spongy bone does not contain blood vessels but is supplied through diffusion from the bone marrow. The venous return occurs through the axial system of the bone marrow.

Bone tissue does not contain lymphatic vessels. A dense network of lymphatic vessels is present only in the periosteum. Bone

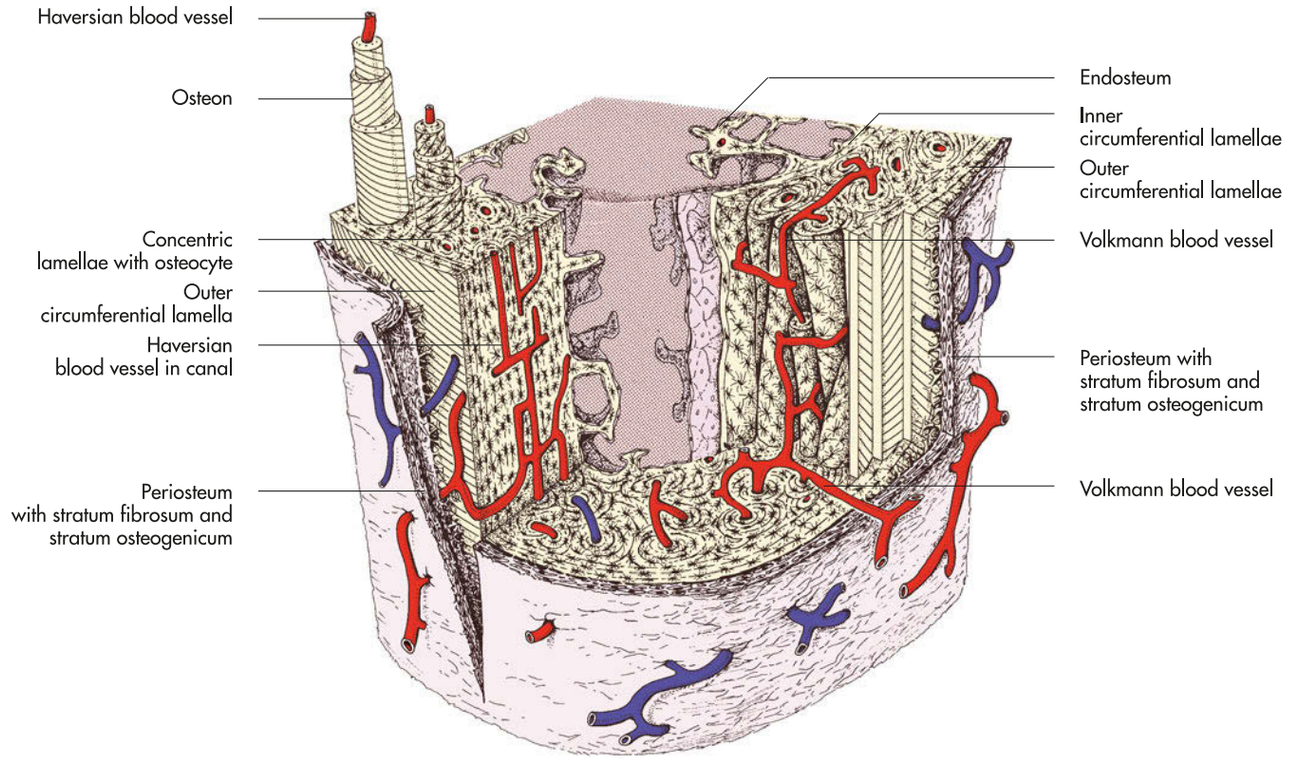

Fig. 1.17 Section of compact bone from the diaphysis (schematic).

tissue itself is not sensitive to pain. Alone vegetative nerve fibres follow the path of the blood vessels within the Haversian canals.

Bone as an organ

Bone constitutes an organ-like system composed of:
- ossified elements,
- joint cartilage (when present),
- periosteum and endosteum,
- bone marrow and
- nerve tracts.

Bone architecture and its extracellular matrix (organic and inorganic material) provide the stabilising components of the passive system of motion, stability and support. The organization of collagen I fibres, the mineralised interfibrillary matrix and the structure of bone tissue all play a large role in stabilisation.

A bone can withstand the application of mechanical stress, body weight, muscle strength or acceleration. These forces work as compression, traction, loading, torque and shear, and do not result in fracture when they are within certain limits. As opposed to the intermittent application of force, bone that experiences a continuous loading force atrophies. On the other hand, bone experiencing constant tensile force hypertrophies.

The architecture of bone tissue is governed lifelong by functional demand. Compact and spongy bone structures are continuously adapting to changes in biomechanical forces. The endosteum is responsible for inducing these structural changes which occur following the physiological principles of bone formation and resorption, for more information see Chapter "Osteogenesis" (p. 32).

Osteogenesis

During foetal development, a **precursor skeleton of cartilage** is formed, providing support and shape (**primordial skeleton**) for the growing foetus. Until ossification, this primordial skeleton undergoes quick successions of mitotic division, eventually determining the growth and form of the entire organism. In most cases, each piece of the primordial skeleton acts as a space saver for the bone tissue that will eventually replace the cartilage. Positively influencing bone tissue formation are **inductive mediators** (i.e. bone morphogenetic protein, mitogenic factors). At a certain developmental stage, the cartilage of the primordial skeleton slowly undergoes remodelling. The cartilage is slowly resorbed and eventually **replaced by bone**. This process is **chondral** or **indirect ossification**. New, foetal bone is referred to as **immature** or **woven bone** due to the random honeycomb architecture of the trabeculae. Eventually, resorbed and woven bone is replaced with **mature lamellar bone**. The majority of adult bones (i.e. the vertebrae and limb bones) are formed through **chondral ossification**.

The replacement of cartilage through bone begins during the middle foetal period at sites referred to as **primary ossification centres**. In some bones this process is completed only when the animal has reached physical maturation. Radiographs of adolescent animals often show remaining cartilage that has not yet ossified, which can lead to false diagnoses should this fact be disregarded.

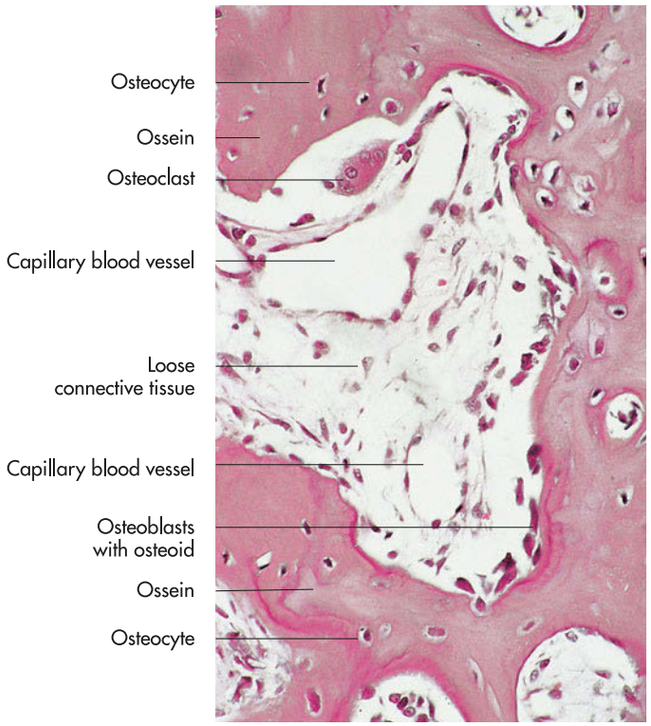

Fig. 1.20 Intramembranous ossification with central capillary in loose connective tissue including osteoblasts and osteocytes (histological section, hematoxylin and eosin staining).

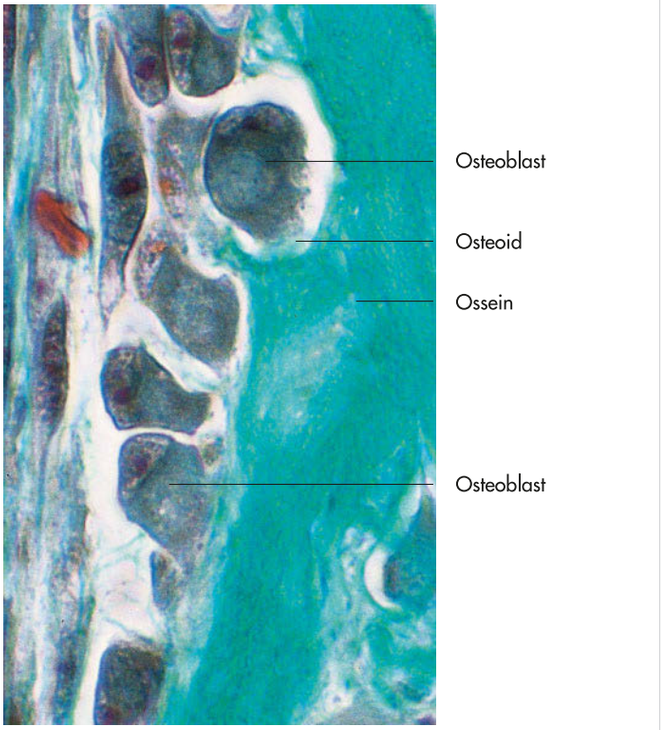

Fig. 1.21 Intramembranous ossification with osteoblasts, osteoid and ossein (histological section, Goldner staining).

dle of the diaphysis and results in the formation of a bony sheath, the **periosteal collar**. The ossification of the perichondrium progresses towards each bone extremity, the **epiphyses**. Thus, the perichondrium becomes the **periosteum**. Perichondral ossification leads to the development of the periosteum of the long bones.

The formation of the periosteum mechanically inhibits the metabolism of the hyaline cartilage, essentially forcing **calcification of the cartilage matrix**. At the same time, blood vessels burrow through the periosteal collar and invade the calcified cartilage. Cells that remove existing cartilage, the **chondroclasts**, enter the calcified matrix through the proliferating blood vessels, and resorption of the remaining cartilage follows. The chondroclasts leave behind empty spaces that soon become filled with connective tissue and capillaries, which deliver not only nutrients but also substances necessary to build new bone tissue. **Osteoblasts** also reach the medulla cavity through these blood vessels and begin from the inside to build bony tissue (**endochondral ossification**). The continuous process of bone resorption and replacement of the matrix results in the development of the primary medullary cavity, which is filled with a fine latticework resembling a partly ossified sponge (**development of the substantia spongiosa**).

The multi-chambered **secondary medullary cavity** (cellulae medullares, ▶ Fig. 1.16) is formed when connective tissue in the primary medullary cavity differentiates into hemo-reticular tissue responsible for the production of blood cells (**hematopoiesis**). This occurs during the later stages of foetal development, and the newly formed hemoreticular tissue is called **red bone marrow** (medulla ossium rubra).

The **bone marrow** (medulla ossium) located in the medullary cavities of both epiphyses and between the spongiosa trabeculae remains lifelong a **hemopoietic organ** (▶ Fig. 1.12). In adults the red bone marrow of the diaphysis is gradually replaced by **fat** (medulla ossium flava), which is again transformed into **gelatinous marrow** (medulla ossium gelatinosa) in senile animals or can prematurely form in diseased animals.

Endochondral ossification

Between the diaphysis and each epiphysis of a long bone, an area of calcified cartilage persists as the **proximal** and **distal metaphyses**. The two metaphyses border on each end of the bone an area of distinct endochondral ossification called the **epiphyseal growth plates** (cartilago epiphysialis) (▶ Fig. 1.12). The epiphyseal plates are of great importance because they are responsible for the **longitudinal growth of a bone**.

The periosteal collar encloses the bone and, in the area of the **metaphysis**, inhibits radial growth of the cartilage. The chondrocytes proliferate through mitotic division and hypertrophy, organising themselves in columns reflecting their **progressive development** (▶ Fig. 1.22 and ▶ Fig. 1.24). This organisation is the basis for the **longitudinal growth of cartilage**, which is necessary for bone growth.

The endochondral ossification of the metaphyseal cartilage occurs in **several zones** (▶ Fig. 1.22 and ▶ Fig. 1.24). The chondrocytes juxtaposed to the epiphyseal plates are diffusely located throughout the hyaline cartilage and do not divide (**zone of resting chondrocytes**) (▶ Fig. 1.22). Neighboring this zone, in the direction of the medullary cavity, is the wide **zone of proliferation**, where the chondrocytes actively divide. Mechanical influence of

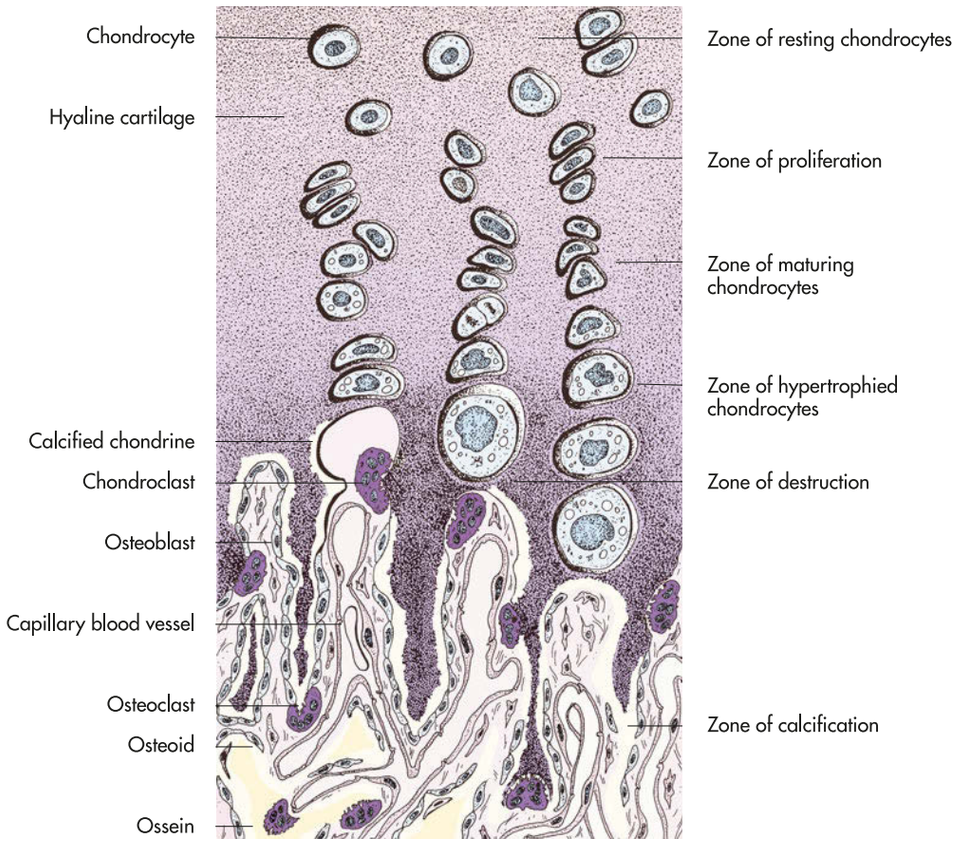

Fig. 1.22 Structural remodelling during chondral ossification in a long bone (schematic).

the periosteal collar forces the maturing chondrocytes in the following zone (**zone of maturing chondrocytes**) to form obvious columns. The chondrocytes begin to degenerate. This is a process characterised by an increase in volume due to water uptake and the calcification of the intercellular substance (**zone of hypertrophied chondrocytes**).

As calcification continues, chondroclasts enzymatically erode the remaining calcified cartilage (**zone of destruction**), (▶ Fig. 1.22 and ▶ Fig. 1.24). The chondroclasts enter this zone through capillaries and connective tissue from the medullary cavity, reaching as far as the zone of calcification. At the demarcation between the zones of destruction and calcification, the process of cartilage resorption is complete. In the final zone, the intercellular matrix becomes saturated with minerals and ossification is complete (**zone of calcification**).

Invading blood vessels also allow secondary osteoblasts to enter the zone of destruction. These cells produce new **matrix** (osteoid) through intramembranous ossification. Eventually, the young woven bone is replaced by mature lamellar bone (see below).

Types of bone tissues

There are two types of bone tissue: **woven bone** (os membranaceum reticulofibrosum) and **lamellar bone** (os membranaceum lamellosum) From an evolutionary point of view, woven (fibrous, immature) bone is regarded as the first and therefore phylogenetically oldest form of bone, often being classified as ossified connective tissue. During foetal development, each bone initially consists of woven bone, and only after birth this is bone slowly replaced by the more complex lamellar bone. However, some woven bone persists throughout life. For example the osseus labyrinth of the ear, the external acoustic meatus, and muscle attachment sites on long bones remain as woven bone.

Lamellar (mature) bone is characterised by the arrangement of strictly parallel or concentric layers of collagen fibres, called lamellae. Most bones of the adult animal consist of lamellar bone, which forms the long bones as well as the short and flat bones. The structural unit of lamellar bone is the **osteon** (**Haversian system**).

Each **osteon** (▶ Fig. 1.17) is a series of concentric rings made up of layers of bone matrix around a **central canal** (Haversian canal) through which a **blood vessel** (Haversian blood vessel), **lymphatic vessels** and **nerves** travel. The collagen fibres in the matrix of each layer are helically arranged and orientated at the opposite angle to those of the previous layer. Osteons are connected through transverse bony structures, creating a construction which enables bone to resist tensile and compression forces (▶ Fig. 1.17, ▶ Fig. 1.18 and ▶ Fig. 1.19). Bone cells (osteocytes) lie between the **concentric lamellae** (Haversian lamellae) (▶ Fig. 1.18) surrounding the Haversian canal. Cell-to-cell-contact is preserved through long, radiating processes of the cell plasma that anastomose within **bony channels** (canaliculi ossei) with processes of neighbouring cells (▶ Fig. 1.18).

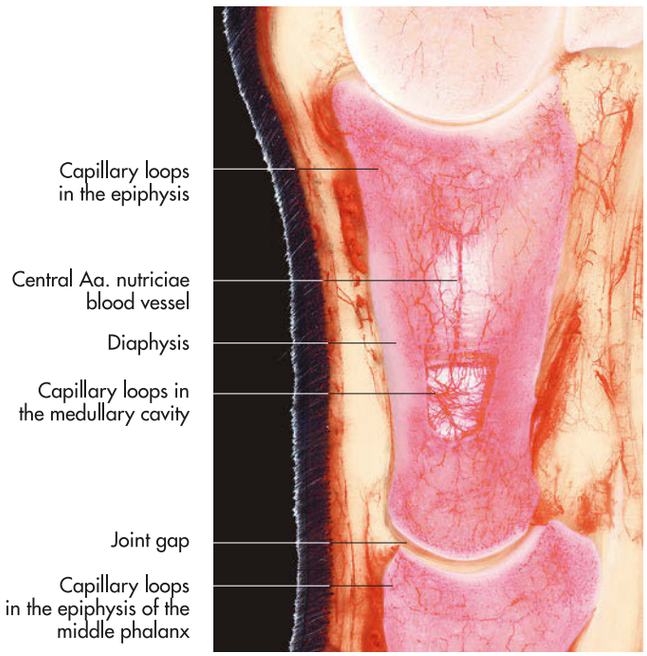

Fig. 1.23 Vascularisation of a long bone, here the first phalanx of the horse (injected plastination). (source: courtesy of H. Obermayer, Munich)

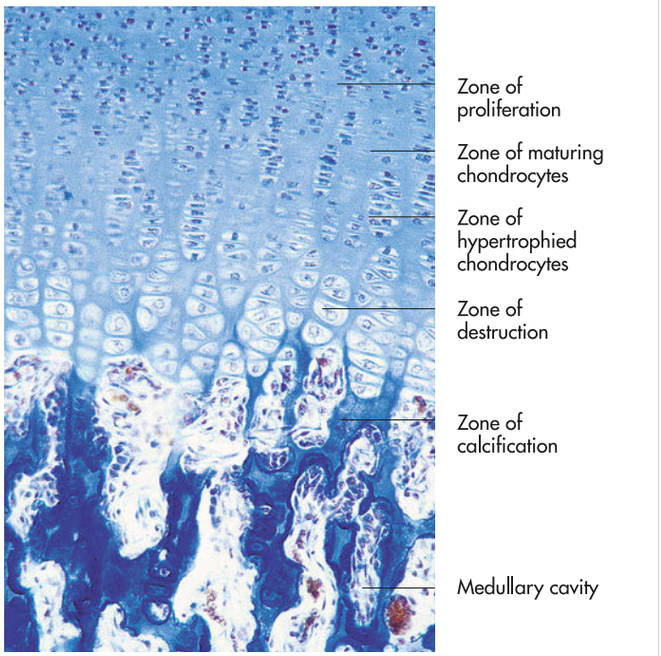

Fig. 1.24 Histological section through the epiphysis of a long bone demonstrating chondral ossification (Azan staining).

This system allows the transport of substances between the blood vessels of the Haversian canal and the bone matrix, essential for the nutrition of the osteocytes. The central blood vessels in the osteons communicate with the periosteum, the endosteum and the medullary cavity through transverse **Volkmann vessels** (▶ Fig. 1.17). By means of this dense network of blood vessels, bone becomes a heavily vascularised tissue.

Bone reacts to changes in static and mechanical forces through adaptation of its internal architecture. Superfluous osteons are destroyed and their remaining fragments form interstitial bone or lamellae (▶ Fig. 1.17).

Layers of lamellae form the outer circumference of the bone directly beneath the periosteum (**outer circumferential lamellae**). The **inner circumferential lamellae** border the medullary cavity, and the endosteum covers the innermost layer (▶ Fig. 1.17). **Collagen fibres** (**Sharpey fibres**, **fibrae perforantes**) anchor the periosteum to the outer circumferential lamellae. These collagenous fibres originate in tendons attaching muscle to bone and are essential for transmitting forces generated by the muscle to the bone.

Bone functions

Bone and cartilage form the supporting and protective framework of the body. Not only do they ensure locomotion, but also protect the soft tissue organs of the thoracic and pelvic regions and the central nervous system. Bone contains the red bone marrow responsible for building blood components (**hematopoiesis**) and stores **calcium** and **phosphate** (▶ Fig. 1.12). Thus the three major functions of the skeleton are **support**, **protection** and **metabolism**. These functions together influence the structure of every skeletal bone and thus the **architecture of the entire body**. The bone structure adapts to mechanical demands through changes in metabolism. This adaptation process involves the continuous resorption and deposition of osseous material.

Every bone is subjected to these **adaptive changes throughout life**. Changes in the physiological compressive, tensile and shear forces lead quickly to remodelling processes. The limbs, the vertebrae or the pelvic bones experience more intensive structural changes compared to, for example, the bones of the skull.

Compact bone develops in a direct relation to the amount of physiological stress it must endure. The cortex (Substantia corticalis) of long bones is thickest at the diaphysis because here the greatest forces are effective. The epiphyses are not subjected to great force and here the cortex becomes progressively thinner (▶ Fig. 1.12). Physiologically, permanent traction forces lead to thickening of the bone where they are most experienced, for example, at the point where tendons attach to bone.

Another important function of bone is to **store calcium** and **phosphate**. Spongy bone (substantia spongiosa) stores depots of calcium that can quickly be mobilised into the blood stream to maintain necessary vital functions. The metabolism of calcium and phosphorus is regulated by **endogenous** and **exogenous mechanisms**.

The **parathyroid hormone** excreted by the parathyroid gland **activates the osteoclasts**, thus increasing the amount of calcium in the blood while at the same time reducing calcium excretion by the kidneys. Together with **vitamin D_3** (**1,25-dihydroxycholecalciferol**), the parathyroid hormone enhances the **resorption of calcium** in the intestines. The **C cells of the thyroid gland** produce a hormone, **calcitonin**, that activates the osteoblasts and **antagonises parathyroid hormone**. The osteoblasts form bone, thus automatically storing calcium and reducing the amount circulating in the body. The **growth of bone** is also positively influenced by the somatotropic hormone (STH), the adrenocorticotropic hormone (ACTH) and the thyrotropic hormone (TSH), as well as by male and female sex hormones.

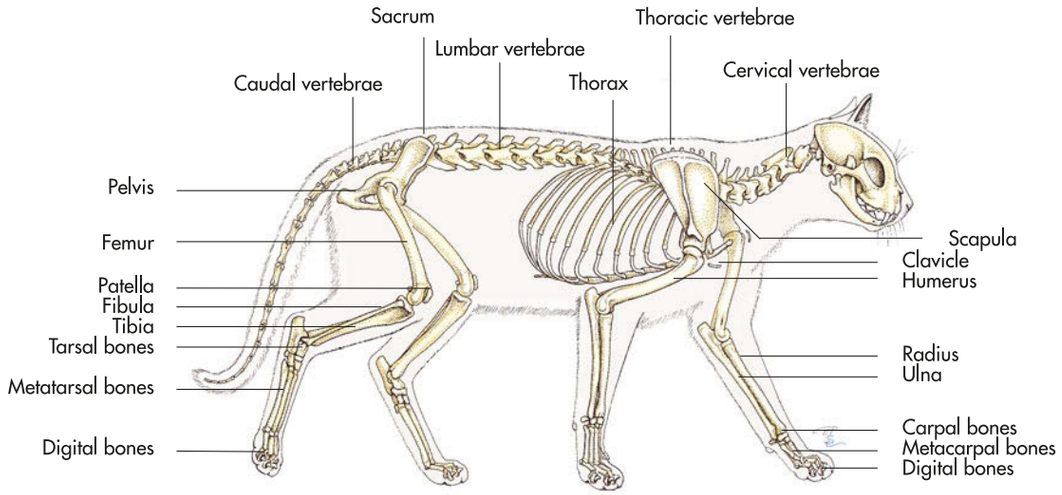

Fig. 1.25 Skeleton of the cat (schematic).

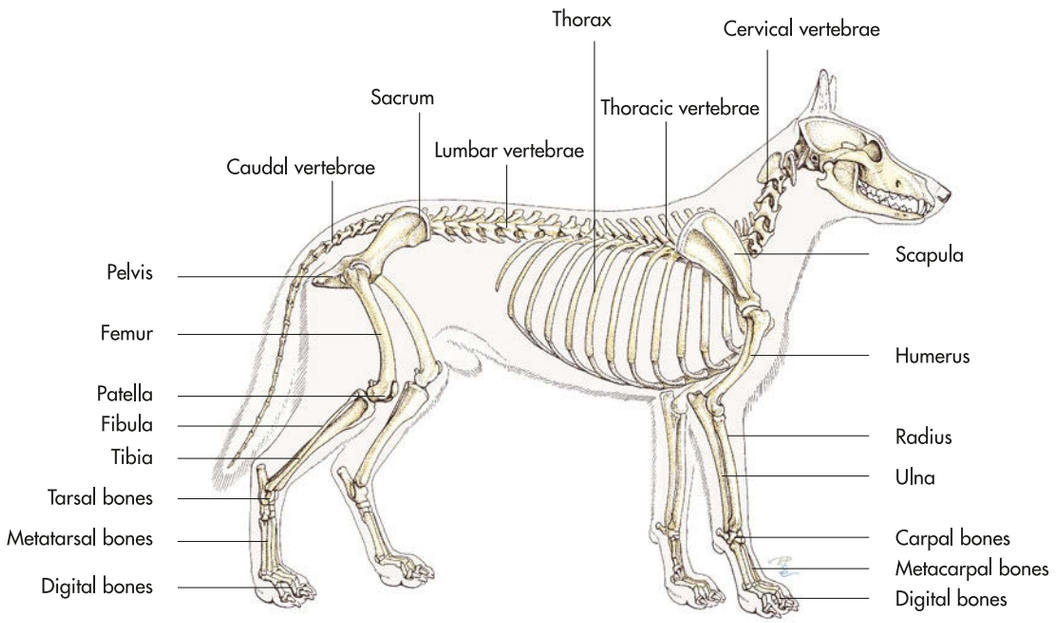

Fig. 1.26 Skeleton of the dog (schematic).

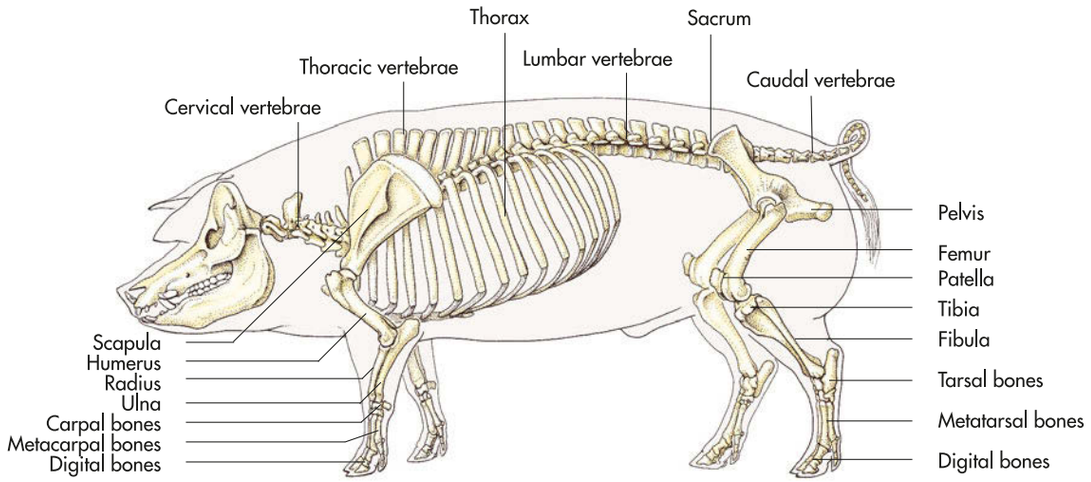

Fig. 1.27 Skeleton of the pig (schematic).

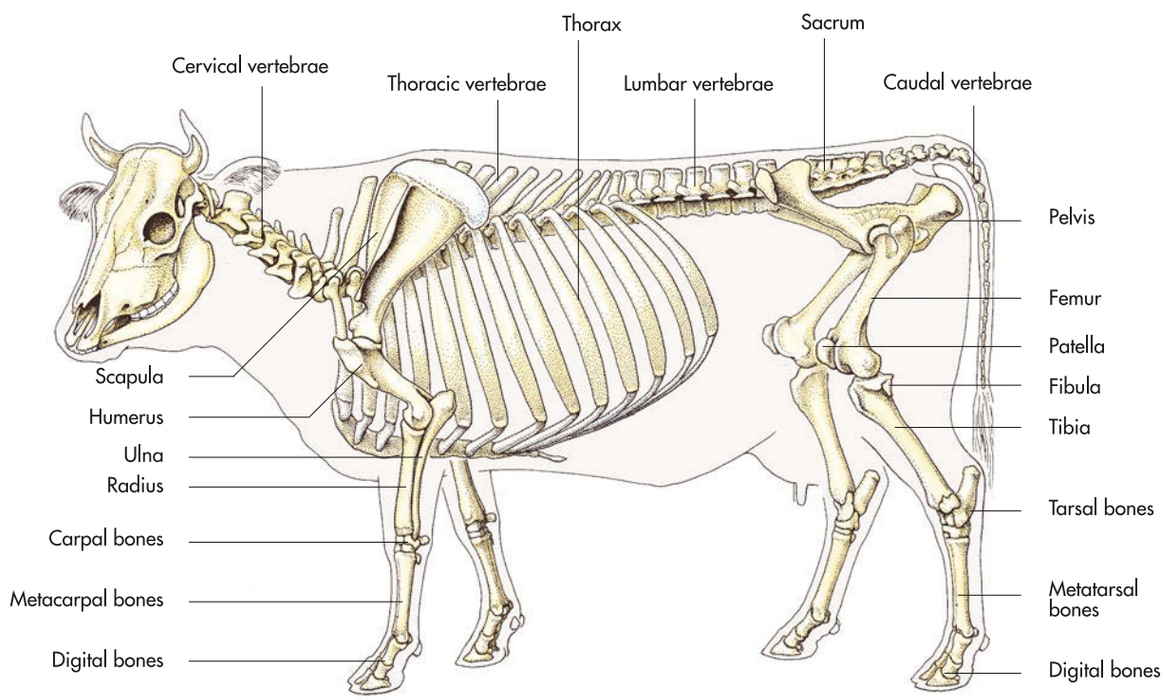

Fig. 1.28 Skeleton of the cow (schematic).

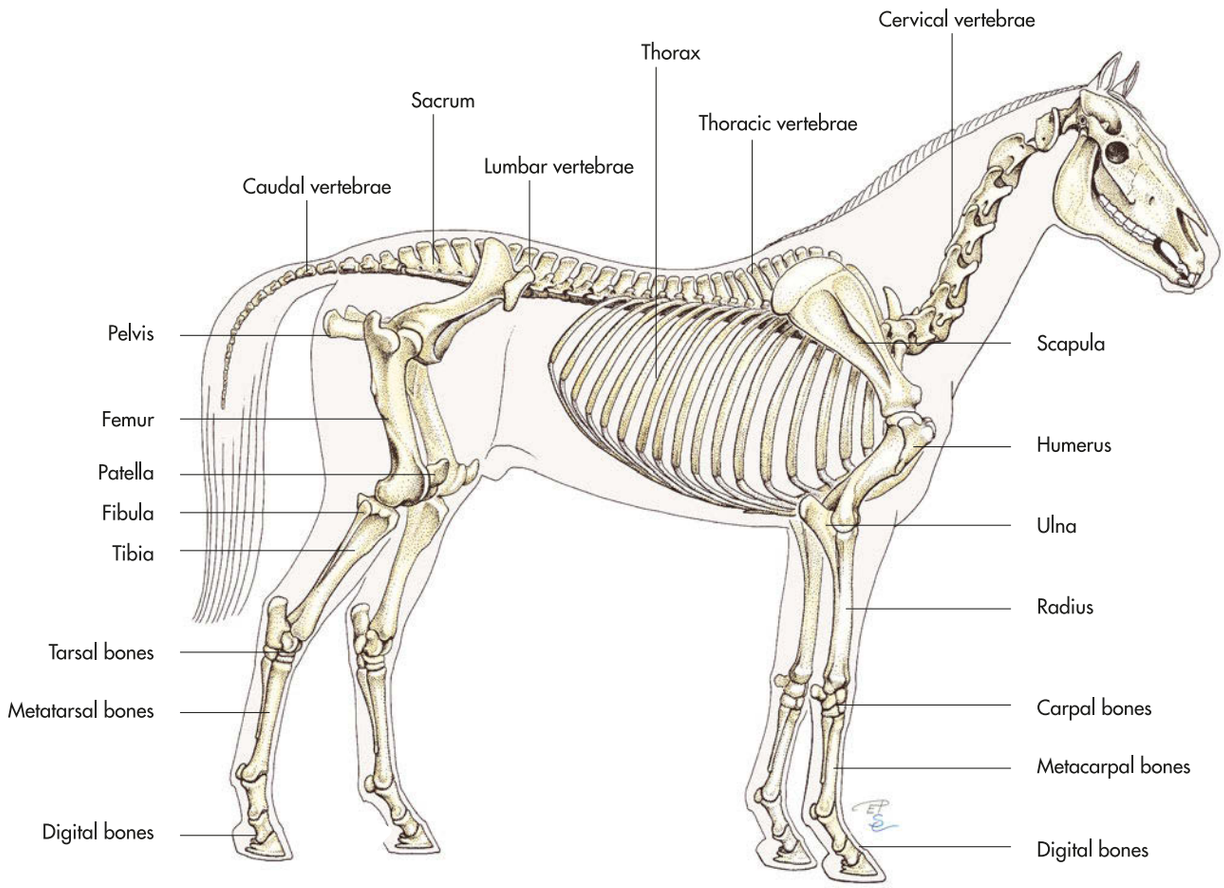

Fig. 1.29 Skeleton of the horse (schematic).

Beneath the joint cartilage is a **subchondral bone plate** that includes parts of the calcified joint cartilage as well as a layer of lamellar bone (▶ Fig. 1.33). This plate (corticalis) supports dynamic functions of the joint, acts as a cushion protecting the cartilage from axial forces and promotes the metabolic supply of the deeper layers of cartilage.

The metabolism of joint cartilage is **anaerobic**. The cartilage is supplied with nutrients, for the most part, **bradytropically** through diffusion. To a lesser degree, nutrients can also reach the cartilage from the joint synovia or through the blood vessels of the bone marrow. The high proteoglycan content lends a high capacity for binding water molecules, which facilitates the intrachondral transport of metabolites.

Joints are strengthened by intracapsular, capsular or extracapsular joint **ligaments** (ligamenta articularia). Some joints contain **fibrocartilagenous structures** (menisci articulares in the knee joint, disci articulares in the jaw joint) that serve to stabilise the joint or to compensate for **incongruent joint surfaces**. Fat tissue can also build intra-articular depots providing additional cushioning. Synovial joints can be classified according to different characteristics:

Number of bones forming the joint:
- **simple joints** (articulatio simplex), involving only two bones (e.g. shoulder joint), and
- **composite joints** (articulatio composita), involving more than two bones (e.g. the wrist joint).

Type of movement allowed by the joint (▶ Fig. 1.34):
- **uniaxial joints** with:
  - **hinge joint** (ginglymus): the joint axis is perpendicular to the long axis of the bones (e.g. elbow or tibiotarsal joint), and
  - **pivot joint** (articulatio trochoidea): the joint axis is parallel to the long axis of the bones (e.g. atlantoaxial joint between the 1st and 2nd cervical vertebrae);
- **biaxial joints** with:
  - **saddle joint** (articulatio sellaris): e.g. between the interphalangeal joints, and
  - **ellipsoidal joint** (articulatio ellipsoidea): e.g. atlanto-occipital joint between the occipital bone and the 1st cervical vertebra;
- **multiaxial joints** with:
  - **spheroidal** or **ball-and-socket joint** (articulatio sphaeroidea): e.g. shoulder joint or hip joint, and
- **tight joints** (amphiarthroses): e.g. sacroiliac joint.

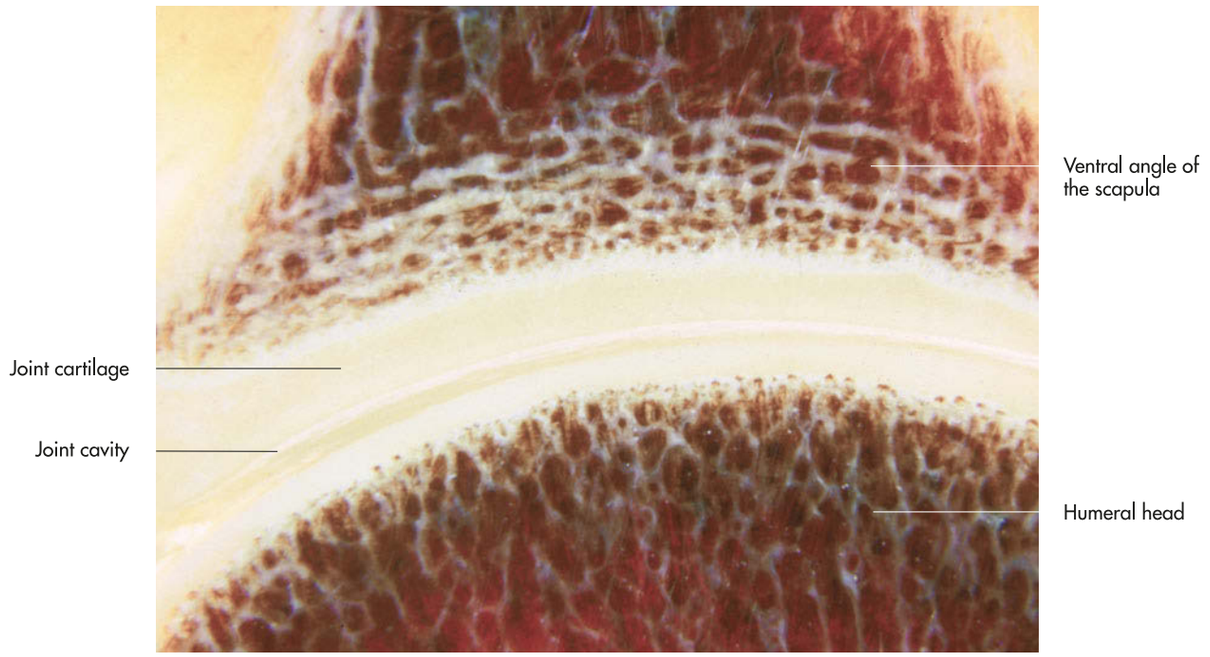

Fig. 1.30 Joint gap formed by the ends of the scapula and humerus in the dog (longitudinal section, plastination).

Form of the articular surfaces:
- **spheroidal** or **ball-and-socket joint** (articulatio sphaeroidea): e.g. shoulder joint or hip joint,
- **cotyloid joint** (articulatio cotylica): a spheroidal joint where the glenoid cavity (socket) covers more than half of the joint sphere (ball), e.g. the aviary hip joint,
- **ellipsoidal joint** (articulatio ellipsoidea), e.g. between the occipital bone and the 1st cervical vertebra,
- **saddle joint** (articulatio sellaris), e.g. the interphalangeal joints, and
- **condylar joint** (articulatio condylaris), e.g. the femorotibial joint.

Joints are also classified according to their **functional characteristics**:
- **hinge joint** (ginglymus): e.g. fetlock joint,
- **cochlear joint** (articulatio cochlearis): e.g. hock joint of the horse,
- **spring** or **snap joint**: a suspension joint as well as a hinge and cochlear joint, where the collateral ligaments attach eccentrically to the axis of rotation and proximal to the joint axis (in the neutral position of the joint, the collateral ligaments are under the greatest amount of tension; during extension or flexion, the tension in the ligaments decreases, causing the joint to spring into a position other than the neutral position, e.g. the elbow joint of the horse),
- **sledge** or **gliding joint** (articulatio delabens): e.g. femoropatellar joint,
- **spiral joint** (articulatio spiralis): the collateral ligaments attach eccentrically, distal to the axis of rotation (the ligaments are shortest in the neutral position; during extension or flexion, the tension in the ligaments increases, slowly braking the motion, e.g. the stifle joint of the horse),
- **plane joints** (articulationes planae): a gliding joint, e.g. the joints between the articular processes of the vertebrae, and
- **incongruent joints**: joints where the articular surfaces do not correspond, as seen in the femorotibial joint or in the temporomandibular joint; the joint surfaces are rendered congruent through fibrous discs, the menisci in the femorotibial joint and the articular disc in the temporomandibular joint.

Clinical note

A reduction in the passive range of movement of a joint is referred to as **joint contracture**. Causes of joint contracture include extended immobilisation or lack of use of the joint. Severe pain associated with joint effusion or free bone fragments (joint mice) can bring about a sudden decrease in joint mobility. Sprains and luxations may result in excessive stretching and rupture of ligaments, leading to joint instability.

A **marked increase in the volume of synovial fluid** (joint effusion) manifests as swelling of the joint. The associated pain is caused by stretching of the joint capsule, which stimulates pain receptors in the capsule wall.

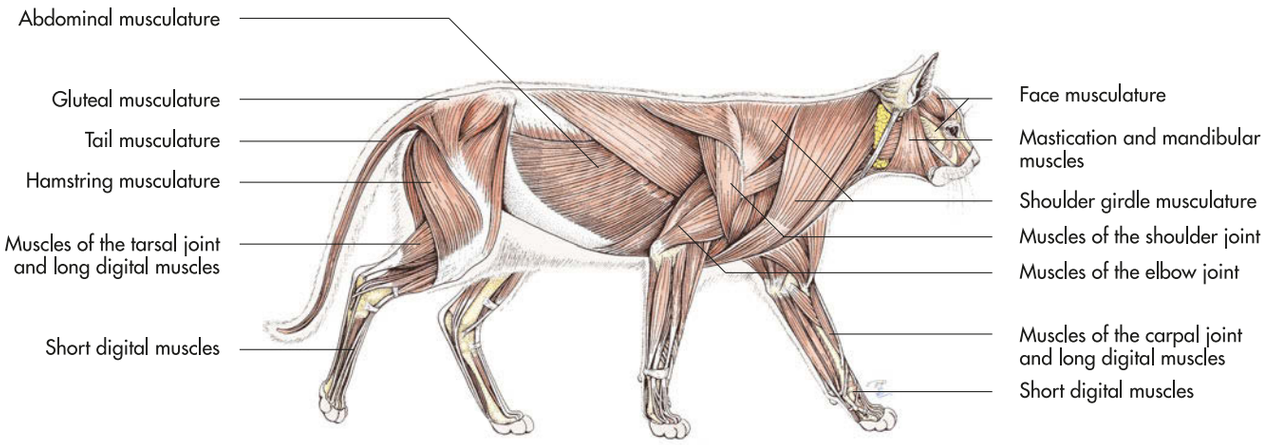

Fig. 1.40 Superficial muscle groups of the cat (schematic).

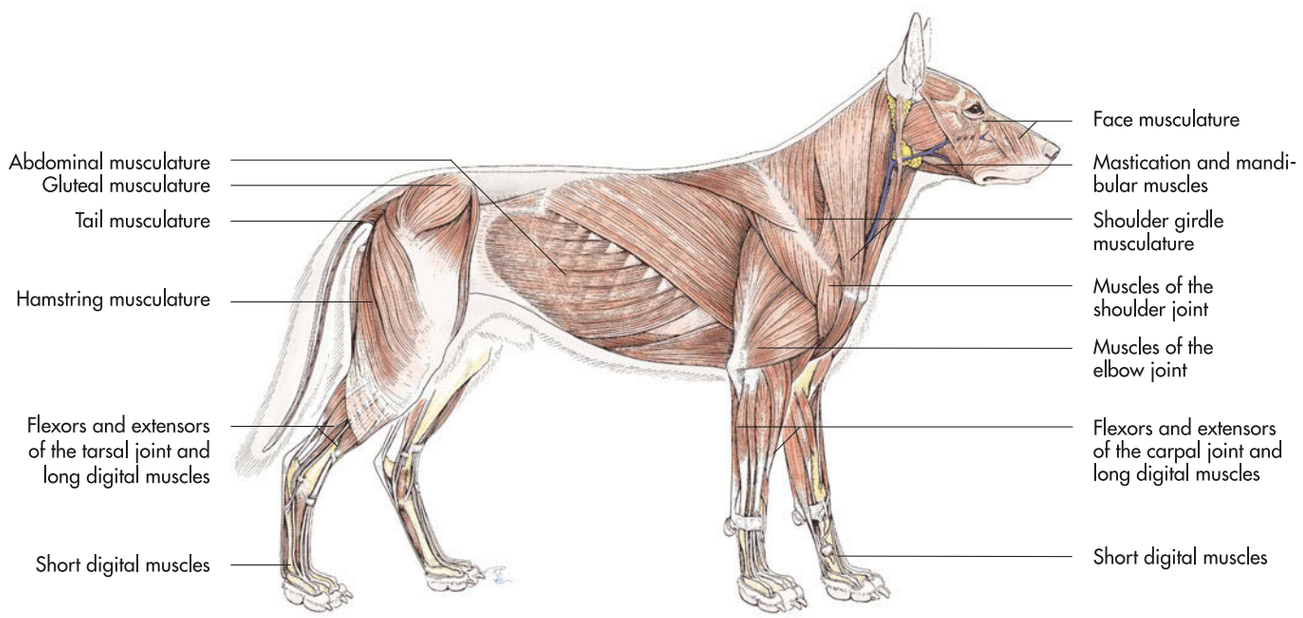

Fig. 1.41 Superficial muscle groups of the dog (schematic).

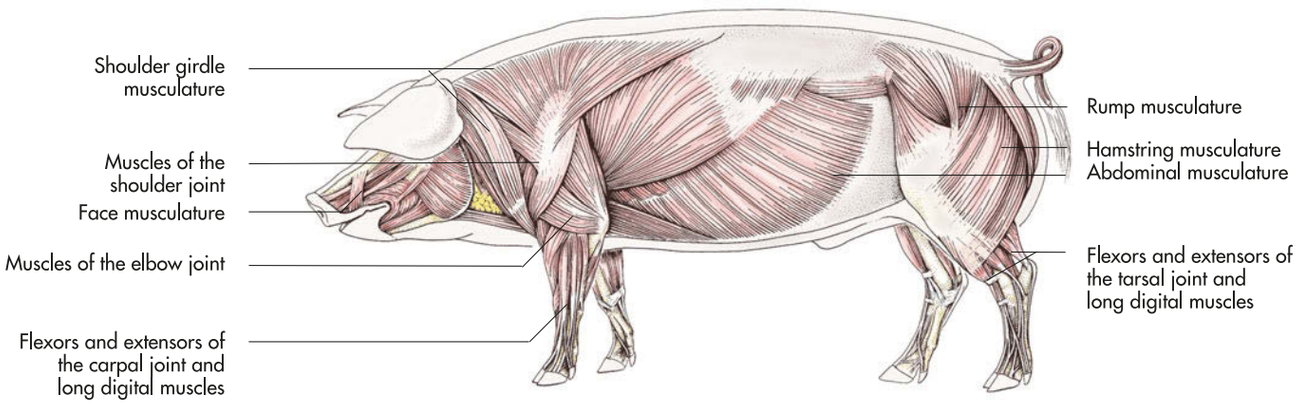

Fig. 1.42 Superficial muscle groups of the pig (schematic).

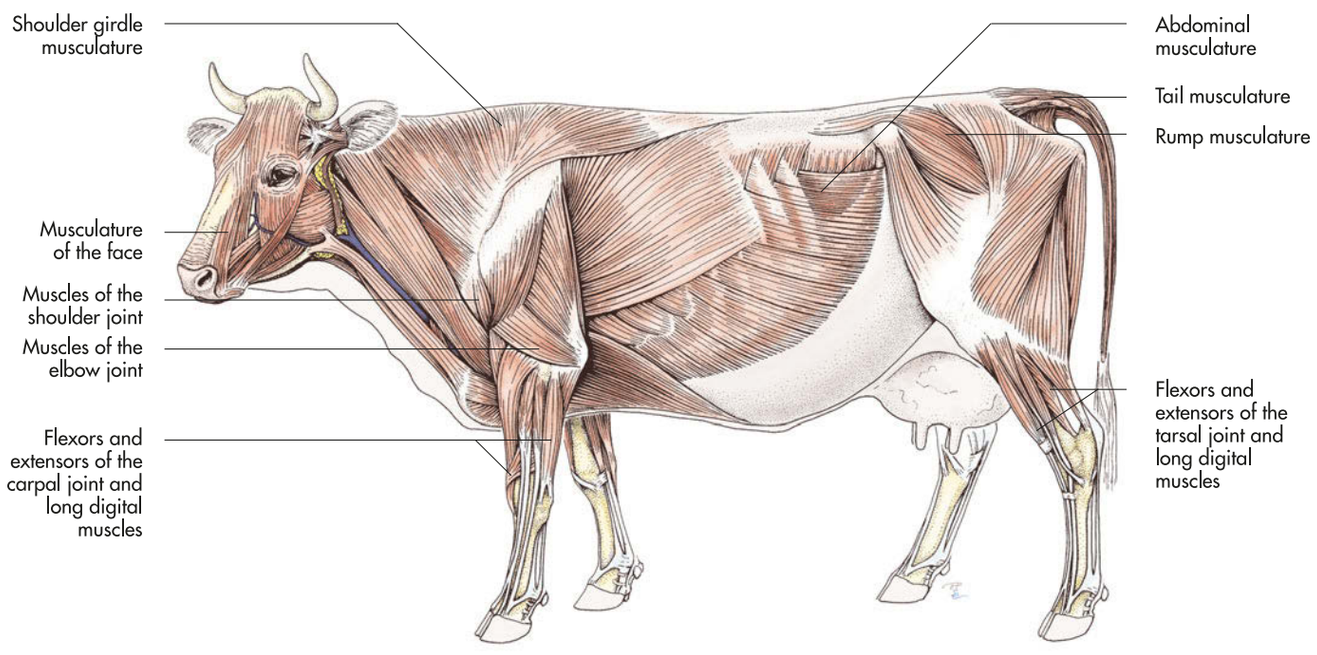

Fig. 1.43 Superficial muscle groups of the cow (schematic).