Bone: An Architectural Masterpiece

The structure, function, physiology, normal processes of preservation and maintenance of the skeleton, as well as the pathologic processes underlying osteodystrophies are briefly outlined in this chapter.

The skeleton consists of about 220 bones and constitutes approximately 15% of the total body weight.

Bone has five main tasks to fulfill:

- Support and locomotion: of the body as a whole and of its individual components, e.g. from the smallest (the toes) to the largest (the legs and spine).
- Protection: the skeleton protects internal organs from possibly harmful external effects. For example, the ribs shelter the heart and lungs, while the cranial bones protect the brain.
- Storehouse for minerals: The skeleton is the largest depot for minerals in the body. In total, 99% of calcium, 85% of phosphate and 50% of magnesium are stored in the bones. Approximately 1–1.5 kg calcium is built into the skeleton in the form of hydroxyapatite.
- Storehouse for bone matrix proteins: The mineralized bone substance consists of about 50% organic material: 25% matrix (ground substance) and 25% water. The matrix contains 90% collagen type I and 10% other proteins such as glycoprotein, osteocalcin, osteonectin, bone sialoprotein, osteopontin, fibronectin, as well as various proteoglycans. All these proteins are synthesized and secreted by osteoblasts and have a variety of functions, such as seeding crystal formation, binding calcium crystals and serving as sites for the attachment of bone cells. Collagen also has direct effects on important bone cell functions, including apoptosis, cell proliferation and differentiation, which are under complex control from the cell surface to the nucleus. Although collagen may have less effect on bone strength and stiffness than mineral does, it may still have a profound effect on bone fragility. Collagen changes that occur with age and reduce bone toughness or stiffness may be an important factor in the risk of fracture. Bone matrix also contains proteins such as bone morphogenic proteins (BMPs), thrombospondin-2 and metalloproteinases that stimulate or inhibit the actions of bone cells. Some studies have shown that bone also contains growth factors and cytokines, such as transforming growth factor beta 1 (TGF-β1).
- The skeleton participates in the endocrine regulation of energy by means of mechanisms involving leptin and osteocalcin, by which glucose levels in the serum as well as adiposity are both effected. In this context it is clear that the processes involved in energy balance influence many organs and tissues, while imbalance induces adverse effects in the liver, pancreas and skeletal muscle, which in turn affect the bones.
Bone has two mechanical functions to fulfill: weight-bearing and flexibility (Fig. 2.1). Specific structural organizations, from the macroscopic through the microscopic to the molecular, enable bone to perform these functions:

- Configuration and size of bones
- Proportion of compact (cortical) to cancellous (trabecular) bone; adapted to weight-bearing (Fig. 2.2)
- Trabecular bone structure with “nodes” to support weight (a “node” comprises the nodular junction of three or more trabeculae) (Fig. 2.3)
- Lamellar organization of osseous tissue
- Degree of mineralization of osseous tissue
- Arrangement of collagen fibres and filaments, together with non-collagenous matrix proteins (NCPs)
- Cable-like organization of collagen molecules and their “cross-linking”

The elasticity of bone is achieved mainly by a special mixture of its component parts, known as “two-phase components” in the building industry. Bone consists of the matrix (the material laid down by the osteoblasts) made up of layers of collagen molecules between which crystalline calcium and phosphate are deposited (Fig. 2.4). This “passive gradual mineralization” increases density as the bone gets older. The new matrix begins to mineralize after about 5–10 days from the time of deposition (primary mineralization) (Fig. 2.5). On completion of the bone remodelling cycle, a phase of secondary mineralization begins. This process consists of a gradual maturation of the mineral component, including an increase in the amount of crystals and/or an augmentation of crystal size towards its maximum dimension. This secondary mineralization progressively increases the mineral content in

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**Fig. 2.1.** Architectural organization of femoral head, neck and shaft, combining the two principles of construction for maximal weight-bearing: tubular structure illustrated by the television tower and trabecular structure by the crane.

**Fig. 2.2.** Overview of a section of normal bone biopsy from a middle-aged man showing wide cortex and uniform, connected trabeculae. Gomori staining

**Fig. 2.3.** “Node” at the intersection of four trabeculae showing an osteon with concentric lamellae. Gomori staining, polarization