Bone quality, quantity and metabolism in terms of dental implantation

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_Abstract

Bone is the largest calcium storage, forms part of the supporting tissue and displays distinctive plasticity and adaptability. Thus, an adequate, differentiated composition and metabolism are required. The bone matrix consists of organic and inorganic structures. The cells, osteoblasts, osteoclasts, and osteocytes are responsible for bone formation, resorption and metabolism and, thus, for remodeling processes (formation and resorption) which permanently occur in bone tissue. Periosteum and endosteum form a functional unit with bone tissue itself and exercise protective, nutritive and growth functions.

The present paper provides an introduction to regular bone structure in the face area which is considered a precondition of successful implantation. The specific properties of the jaw bones have to be observed in this context.

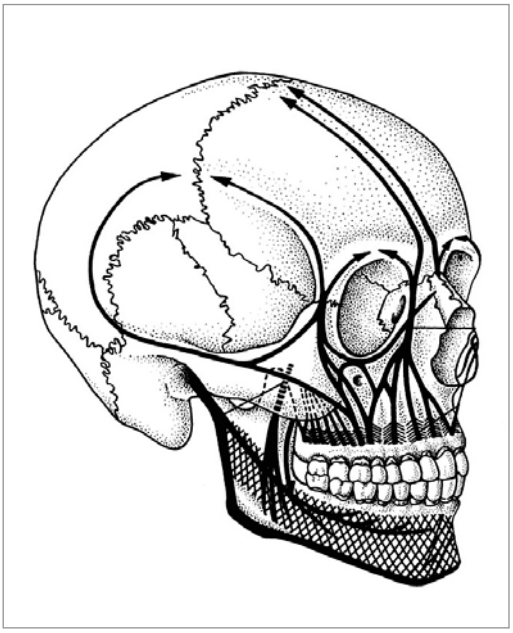

Fig. 1_Trajectorial structure of viscerocranium.

_Introduction

The orofacial or stomatognathic system with its components forms a functional circle representing a biocybernetic system.[11]

A key role is played by bone, particularly the jaw bones. The structure of the osseous viscerocranium is targeted to withstand and divert the chewing pressure.[2,11] This requires a functional composition which is maintained even after osseointegration of bone graft substitutes (Fig. 1).

The periods of function and inactivity occurring in the jaw bones are more clearly noticeable than in any other bone of the body. For instance, the mandible and the maxilla display different atrophy processes.

Continuous remodeling which guarantees adaptation to arising forces requires healthy bone.[8]

Bone composition

Bone is a specific connective tissue which mainly consists of the extracellular substance/bone matrix, cells, blood vessels, and nerves.

Weight distribution (in kilograms) in a 70 kg weighing man shows that bone and bone marrow rank high, as shown by selected examples in table 1.

Table 1_ Weight distribution (in kg) of tissues in a 70 kg weighing man in ranked order.

Muscles	30
fat	10
bone	7
bone marrow	3
blood	3
connective tissue	3
skin	2

Bone matrix

It consists of organic and inorganic material.[9]

The inorganic material which determines bone

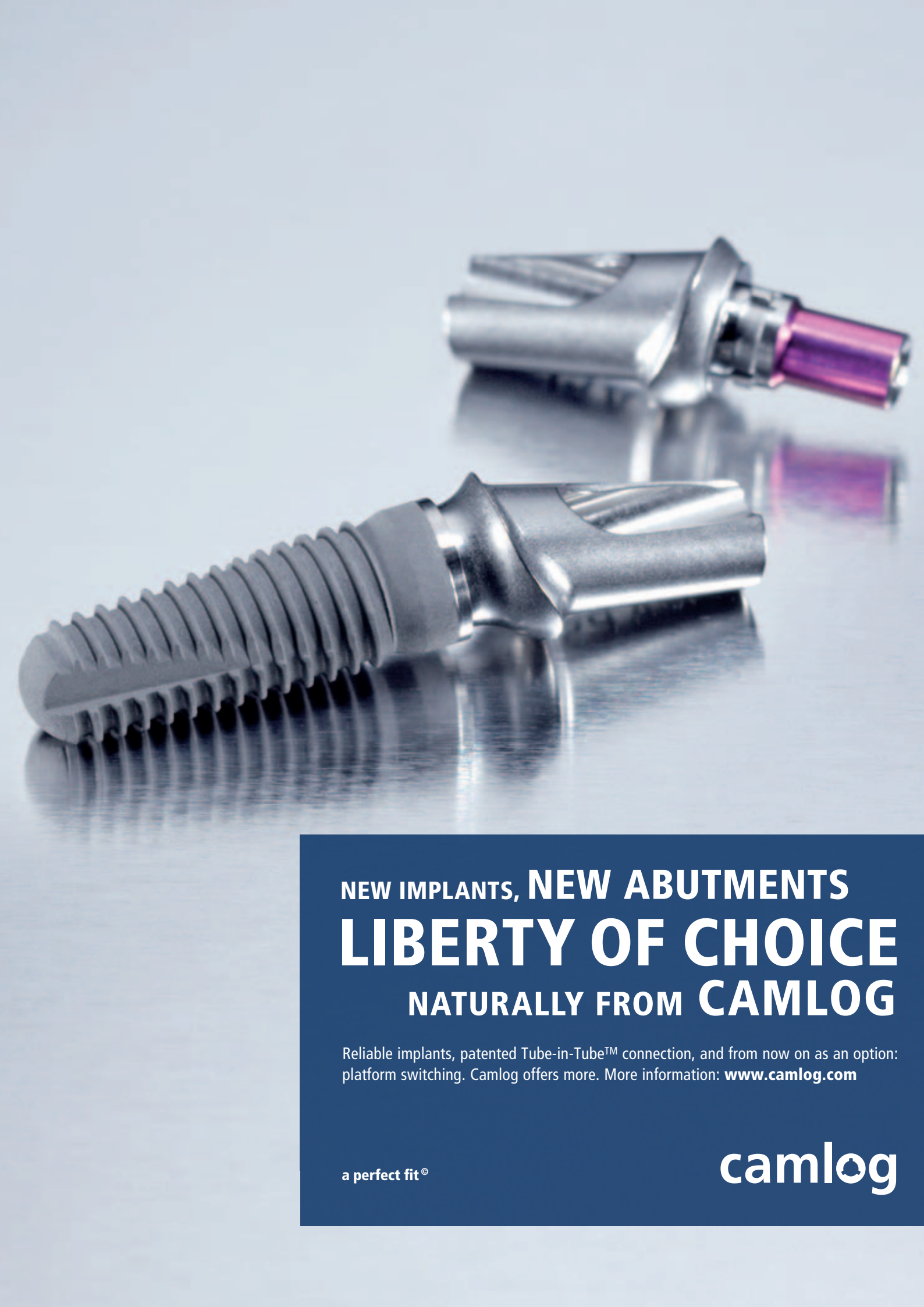

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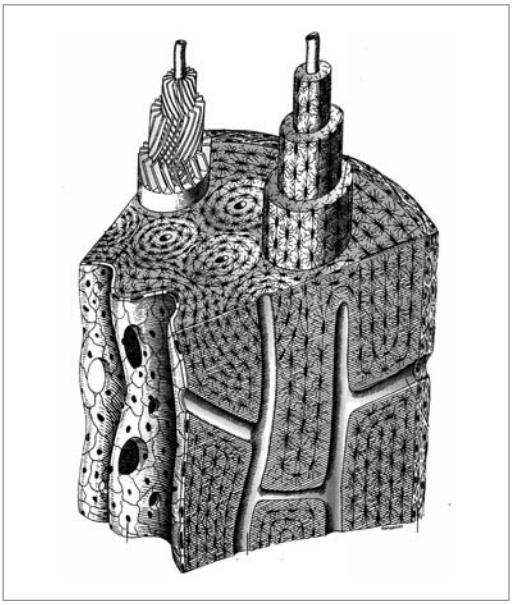
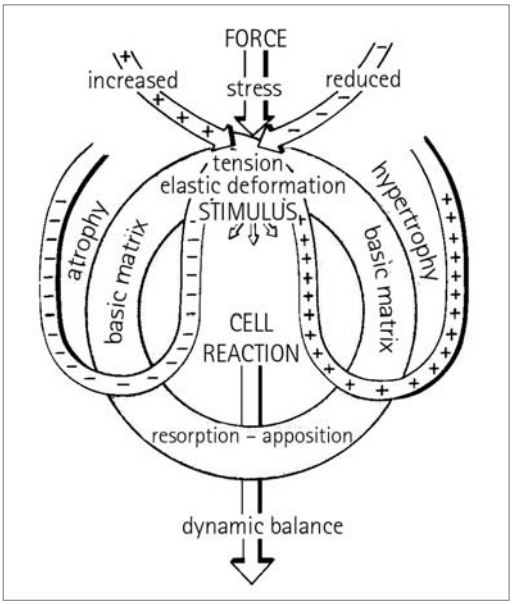
Fig. 2_Osseous lamella.
Fig. 3_Functional composition of bone and dynamic equilibrium.





stiffness, constitutes about half of the matrix. The major part (50 per cent) is composed by calcium and phosphate in the form of hydroxyapatite crystals. Additionally, non-crystalline calcium phosphate, citrate, hydrogen carbonate, and furthermore, magnesium, potassium, and sodium salts are found. The apatite crystals are surrounded by matrix substance and lie along the collagen fibrilles. A so-called hydration cover facilitates ion exchange between crystal and body fluids. The water content of the bone matrix amounts to 10–20 per cent. The water-free matrix contains 70 per cent inorganic and 30 per cent organic substance.

The non-calcified organic matrix is referred to as osteoid and provides the bone with the required elasticity. It mainly consists of collagen.

Bone cells

Cells are indispensable for regular osseointegration processes.[1,2]

_ *Osteoblasts:* These mononuclear and nearly cubic shaped cells produce all essential organic matrix components of bone (osteoid). They are located exclusively at the surface of spongious trabecles, and synthesize and secrete collagen I, proteoglycans and glycoproteins. As they activity fades, the cells become increasingly flatter and form processes. The newly produced matrix proteins are released towards the surface of the existing bone matrix. The organic material enabling bone elasticity constitutes about 20 per cent. Finally, water amounts to about 10 per cent of the matrix substance.

The osteoblasts are activated by cytokines, growth factors and vitamin D3 and thereby enabled to induce osteoclast proliferation and differentiation.

_ Osteoclasts are multinucleate, large mobile cells resorbing mineralized bone and derived from the mononuclear phagocyte system. One surface of resorbing osteoclasts is facing the mineralized bone tissue. The surface periphery is closely connected with the matrix by a sealing zone. The area surrounded by this zone displays numerous folds ("ruffled border"). Between the „ruffled border" and the bone matrix, there is an extracellular space, the so-called resorption lacuna where bone resorption occurs. The osteoclast secretes H^+ ions to the lacuna by means of a vacuolar ATPase located in the folded membrane, and the matrix minerals are dissolved in the acid milieu. The release of lysosomal enzymes leads to decomposition of the collagen fibrilles.

_ Osteocytes develop from osteoblasts and represent metabolic centres of the bone. These cells predominate in bone. Their cell bodies are located in the lacunae. With their processes, they are interconnected by nexuses. The processes permit intercellular substance transport and enable the coordination of metabolic activities. An exchange of compounds among osteocytes, mineralized matrix and blood vessel also occurs in the gap system between cells and calcified bone matrix.

The osteocytes respond to mechanical stress exerted on the bone and sustain the extracellular matrix. After their death, the matrix undergoes resorption.

The jaw area is very likely to exhibit a population of bone cells different from cells from other regions in terms of their origin, their involvement in specific local developmental and bone formation processes and their specific adaptation to local biomechanics. At the moment, it may be merely speculated whether the activity of such neuroectodermally derived "jaw osteoblasts" essentially contribute to perfect dental implant treatment outcomes.[5]

Periosteum and endosteum

Their main functions are protection and nutrition as well as the continuing supply of osteoblasts for

thickness growth and successful defect repair.[1,2] The outer periosteum consists of fibroblasts, collagenous and elastic fibres (stratum fibrosum). The inner layer (stratum germinativum) is formed by divisible cells ("lining cells") which can differentiate into osteoblasts. The stem cells play an important role for bone growth and repair. Sharpey's fibres are bundles of collagenous fibres connecting the periosteum with the bone substance.

The endosteum fills the inner cavities of bone, is thinner than the periosteum, consists of progenitor cells and comprises only a slight amount of connective tissue. The endosteal border cells are resting osteoblasts forming a continuous cell assembly on the inner cortical surface and the Haversian canal walls

Bone types

Woven bone and lamellar bone are distinguished according to the arrangement of osteocytes and collagen fibres.

_ Woven bone (also "primary bone") is found only during bone development and repair processes, and, therefore, also in osseointegration. Its mineral content (higher radiolucency!) is lower. The collagen fibrils run irregularly rather than in lamellar form. This type of bone is replaced by lamellar bone except for suture areas.

_ Lamellar bone (Fig. 2): The collagen fibres and other matrix components form lamellae of 3–7 µm thickness which are arranged in concentric layers around a central channel (Haversian canal).[6] This structure is referred to as Haversian system or osteon. Between the lamellae, the cell bodies of the osteocytes are located with processes running in respective channels (see above). Each channel harbors nutritive vessels, nerve fibres, and loose connective tissue. The canals communicate with the bone marrow cavity, the periosteum and with each other. Larger channels are Volkmann's canals which also run outward. The entire channel system reflects a complex and delicate microcirculation.[4]

Each osteon is surrounded by mineralized matrix with few collagen fibres (cementum). Immediately beneath the periosteum and around the marrow cavity lie more outer and fewer inner general lamellae. Between outer and inner general lamellae, the so-called osteons and the often irregularly shaped intermediate lamellae are located. The latter are residual lamellae of a Haversian system which was degraded during a remodeling process.

Principles of bone structure

_ *Substantia compacta, Substantia spongiosa of the bones*

The outer compact bone layer is referred to as substantia compacta, while the inner layer which possesses numerous interconnected cavities is termed substantia spongiosa. The latter represents a spongy

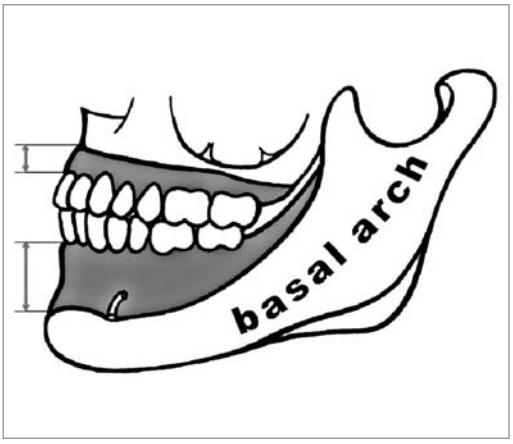


Fig. 4_Vertical atrophy of the mandible.

trabecular framework. However, both structures show a lamellar bone composition. Spongiosa prevails in the maxilla, whereas the mandible is predominated by compacta.

Bone shape and composition are adjusted to its mechanical function. According to its trajectorial architecture, structure conforms to tension and strain trajectories. Bone substance is arranged in such a way that best possible absorption and transmission is achieved with minimum expense of material in the loaded area. The trajectorial construction, e.g., of the mandible, permits selective material usage in the loaded area.[2] This lightweight construction saves muscular strength for motor activity. Bone morphology is genetically determined and modified by external influences through differentiation. Bone is solid by virtue of its inorganic components and elastic due to its organic components. Thus, bone substance features a dynamic equilibrium of adaptation.[2, 3, 8] Figure 3 shows the oscillation between atrophy and hypertrophy, resorption and apposition.

Special properties of the jaw bones

The jaw bones as well as the tooth germs (except the enamel organ and enamel) develop from the neural crest cells which are preprogrammed for the facial region where to migrate.[5] Development of cartilage, bone and teeth, however, requires numerous interactions between the mesectodermal cells, the ectoderm and the inner body surface. Almost all jaw bones (including the alveolar process) develop to woven bone by desmal osteogenesis. The osteoblast progenitor cells are derived from neural crest cells. Ossification of the alveolar processes is closely associated with tooth germ development. Desmal ossification is recapitulated in reparative processes. Similarly, osseointegration of dental implants follows this principle.[2]

Jaw atrophy

Jaw atrophy is a major field of implantology. Such inactivity atrophy results from a lack of strain stimuli and reflects complex atrophic and resorptive processes. Resorption of the (edentulous) alveolar processes is multifactorial and cannot be attributed to altered loading alone. Mechanical factors, biological and metabolic factors, and inflammatory causes are distinguished.

Mandibular involution is primarily vertical. The alveolar process is smaller than the basal arch which represents the constant part (Fig. 4). At old age, the mandible shows increased prominence.[3] Vertical bone resorption is increased compared to the maxilla. These changes are even more marked in females. The mandibular basal arch is more extended than the maxillary one: by up to ca. 3 mm during the first three years after tooth loss, and by 0.3 to 0.4 mm p.a. during the following years. This difference is compensated by alveolar process inclination resulting in oral inclination of the mandibular alveolar process and vestibular inclination of the maxillary one.

Besides the basal arch which may also exhibit resorption during old age, there are structures that are not subject to atrophic changes, such as linea mylohyoidea, linea obliqua, spina mentalis, tori mandibulares, and trigona retromolaria.[3]

The basal arch as well as the alveolar walls show a trajectorially oriented arrangement.

Alveolar process atrophy also leads to an altered mandibular angle. This angle amounts to 150° in newborns and to 120° in adults. At old age, the angle tends to return to childhood values and may even exceed 160°. These angular changes also exert an effect on the trigonum retromolare sinking down in atrophic bone and, thus, assuming an almost topographical relation to the pars obliqua of the mandibular canal. In atrophic bone, therefore, the trigonum retromolare fails to serve as an implant abutment site.[10]

Maxillary atrophy primarily occurs horizontally and only slightly in vertical direction. The alveolar process which provides only little space for the tooth roots, is larger in relation to the corpus maxillae.[3] Thus, the maxillary arch becomes more reduced. Due to resorption, its size decreases relative to the mandible. With increasing maxillary atrophy, the alveolar midcrest is displaced palatally (centripetally). Atrophy of the hard palate proceeds anteroposteriorly (Fig. 5) and may be of such an extent as to cause bone perforation and contact between oral and nasal cavity mucosa.

The alveolar process ends with the tuber retromolare behind the last molar. Before seven years of age, the tuber does not exist but as a rudiment. The alveolar canals for the nn. alveolares superiores posteriores develop from primordial alveolar sulci. Beyond 20 years of age, the tuber is fully differentiated, and alveolar canals are found. After 50 years of age, involution of the tuber occurs, and the alveolar canals reopen into alveolar sulci. These changes show that the tuber retromolare is not suitable as an implant abutment

site.[10] The anterior maxilla shows numerous channels harboring blood vessels and nerves which also present as sulci and open toward the maxillary sinus.[7] The torus palatinus, the crista zygomatico, and the spina nasalis anterior do not reveal any atrophic alterations. The chewing pressure abutments of the maxilla are not subject to atrophic processes and, hence, preserved.

Blood vessel supply

Blood vessel supply is a prerequisite of regular bone growth and metabolism. It is effected by means of the vasa nutricia which run without contortions through the corticalis into the medullary cavity (Fig. 2). Diaphyseal arteries branch out to marrow arteries. Several small arteries supply the metaphysis and epiphysis. The epiphyseal vessels display only few anastomoses with the metaphyseal and diaphyseal vessels. The corticalis is supplied from within and outside. The outer cortical sections are supplied directly by the periosteal vessels. Perfusion is increased in high-density bones compared to low-densitiy bones. This should be considered for implantation.

Bone tissue lacks lymphatic vessels which occur only in the periosteum.[1]

Nerve supply

Nerves are indispensable for bone tissue viability as well. With the bllod vessels, the nerves enter the bone, run in Volkmann's and Haversian canals (Fig. 2) and also reach the spongiosa. The nerve fibres are largely unmyelinated. The periosteum is innervated abundantly. There has been evidence of numerous transmitters (e.g., norepinephrine, neuropeptide Y).[1]

Bone function

Bone function is manifold and plays an important role for osseointegration.[2, 3]

Supportive function

The bones make up the skeleton which determines skull weight and shape. Additionally, the skeleton provides the origin and attachment of the muscles which in turn influence cranial morphology. Owing to its biological plasticity, bone is capable of adaptation to stress.

Protective function

The cranial bones protect the central nervous system, the sense organs, and the bone marrow.

Development of masticatory pressure pillars in the viscerocranium serves for diversion of the chewing pressure and the trajectorial structure of the mandible (Fig. 1).

Calcium storage

About 99 per cent of the body's calcium is stored in the skeleton. The stored calcium is mobilized, when

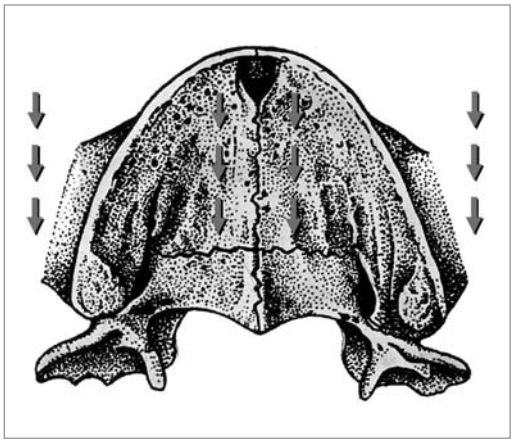


Fig. 5_Horizontal atrophy of the maxilla.

blood calcium concentration declines. Calcium is mainly released from hydroxyapatite crystals in the spongy substance.[1] Acting as a calcium storage, bone tissue plays an important role in regulating calcium homeostasis.

Hormone and vitamin metabolism

Bone is related to hormone and vitamin metabolism. The osteoblasts possess receptors for parathyroid hormone, vitamin D3, cytokines and growth factors. They produce factors that increase osteoclast proliferation and differentiation. Calcitonin exerts a receptor-mediated inhibiting effect on osteoclast activity. Both androgens and estrogens generally stimulate bone anabolism and accelerate epiphyseal gap and suture closure. They facilitate mineralization and bone formation. Opposite effects are exerted by cortisol.

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The Literature list can be requested from the editorial office.

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