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MATERIALS AND BIOLOGICAL ISSUES

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Dental Implants and Bone Grafts: Materials and Biological Issues

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Introduction

Healthy teeth are supported with bone tissue in the maxilla and mandible called alveolar bone, which is subjected to remodeling associated with the functional demands of mastication [1]. However, teeth loss and alveolar bony defects are common and pose a significant health problem in dental clinics. Reconstruction of alveolar bone and replacement of missing teeth using dental implants and bone grafts greatly enhances treatment success and patient satisfaction [2]. Currently, the potential market in dental implants and bone grafts is great and includes virtually every dental treatment plan in some way.

Worldwide, the market size for dental implants is estimated to reach nearly $5 billion in 2023 (BCC research report 2018–23) [3]. Dental implants show many advantages over the conventional prostheses, including high patient acceptance, natural appearance, and less requirement of maintenance. Indeed, dental implants have played a major role in oral rehabilitation in recent decades. Based on the National Center for Health Statistics, more than 90% of adults in the United States have untreated dental caries, and 69% show at least one missing tooth [4]. Moreover, more than 24% of adults aged 74 years and older are completely edentulous [4]. Also, nearly 10 million patients per year have dental injuries due to road accidents and sport injuries [3]. Therefore millions of patients need replacements for their missing teeth, hence facilitating extensive demand for dental implants. In 2016, Europe and Asia dominated the dental implant market due to an increase in the edentulous population [5]. By 2020, it has been estimated that 25% of Europeans will be older than 60 years. In addition, increased oral-care awareness in developed countries is anticipated to drive the market growth of dental implants [5].

There are many patients that require alveolar bone reconstruction prior to placement of dental implants. This is the reason for the demand and market for bone substitutes. Recently, the global market for bone substitutes was valued at more than $2.4 billion [6]. In addition, new products in a variety of shapes and sizes are providing excellent biological and clinical properties, thereby increasing the demand for bone substitutes. Bone grafts are widely used in orthopedic and maxillofacial surgeries for numerous applications. They can be categorized into natural and synthetic grafts, with natural bone grafts harvested from patients themselves or donors, and synthetic grafts being of artificial origin. Because natural bone grafts have several clinical limitations, synthetic grafts are nowadays leading the global market [6].

Interestingly, the acceptance and utilization of dental implants and bone grafts by dental practitioners are increasing. This means that the science and techniques of dental implants and bone grafts should take their rightful place in the armamentarium of the dental health professional. Therefore clinicians and

dental scientists should always gain a thorough knowledge of science related to materials and biological issues of dental implants and bone grafts.

The focus of this book is on the optimization of science and application of dental implants and bone grafts. In order to understand the principles of dental implants and bone grafts, we must first understand alveolar bone, as it part of a more specialized and complex system compared to other skeletal bone tissues. As discussed in Chapter 1, the alveolar process is a major component of the tooth-supporting apparatus and is comprised of alveolar bone proper, cortical alveolar bone, alveolar crest, and trabecular bone. The alveolar process develops along with the dentition and undergoes resorption following extraction of teeth. With the advent of dental implant-supported rehabilitation, understanding and preserving the alveolar bone has become more imperative than ever before. In order to achieve the same, knowledge about applied biology, composition, microstructure and anatomic, clinical, and radiographic features of alveolar bone is essential. Hence, the aim of Chapter 1 is to provide the reader with a thorough knowledge of alveolar bone characteristics and its applied biology in relation to dental implant therapy.

Chapters 2 and 3 highlight the clinical application and procedures of alveolar bone reconstruction as well as implant osseointegration. In particular, Chapter 2 focuses on edentulism. Whether partial or complete, toothlessness has always posed great challenges to clinicians. Among the multitude of available replacement options, dental implants have currently gained importance due to well-established and standard protocols. A systematic approach to diagnosis and treatment planning is fundamental to the success of dental implants and their long-term functionality. The success of dental implants treatment is owed to their longevity and biocompatibility. Furthermore innovative implant designs can cater to a multitude of patient needs. Thus understanding the clinical indications can be regarded as the deciding factor for the success of osseointegrated dental implants.

Bone grafts are used as scaffolds to replace the missing bone and assist in new bone formation and healing. These materials can be derived from a patient's own body (i.e., natural substitutes) or can be of a synthetic origin. Chapter 3 discusses the most commonly used bone graft materials for bone regeneration. It has been estimated that more than 2 million alveolar bone-grafting procedures are carried out yearly worldwide. Usually they involve replacing missing bone tissue with a suitable bone substitute that has the ability to trigger bone regeneration. This provides adequate tooth support and allows successful implant placement and osseointegration.

Chapter 4 explores dental implant design and surface modification as an important means to improving osseointegration. It discusses new developments in implant surface modifications that are critical for bone healing. Introduction of nanostructural features into implant surfaces accompanied by defined modification of the inorganic chemical status of the surfaces, including the release of ions, shows a great potential for addressing and improving implant osseointegration and antibacterial properties. These surfaces might be further

improved by immobilization of peptide sequences addressing both subprofiles (i.e., improved osseointegration and long-term antimicrobial properties). In many, though not all, studies the early stages of tissue regeneration and antimicrobial properties appear to be improved by organic surface modifications. However, it should be kept in mind that due to heterogeneity in study design, interstudy comparability is complicated. Therefore long-term clinical studies are still necessary to validate long-term success. Future directions could include the development of electrochemical treatments to remove biofilm contaminations from inserted implants, as it has been found that both anodic or cathodic polarization will increase pH, reduce pO_2, and generate reactive oxygen species (ROS) as well as reactive chlorine species (RCS), all of which are discussed as active agents against bacteria. Unlike conventional chairside treatment methods, here the application of a current to electrically conductive implants would result in an attack of the bacterial biofilm directly from the implant surface. For organic coatings, a promising strategy appears to be multifunctional coatings that address multiple aspects simultaneously, such as promoting bone and soft tissue regeneration as well as reducing bacterial adhesion and biofilm formation.

Chapter 5 proceeds with the science of materials related to synthetic bone grafts. This chapter describes the main characteristics and the potential of synthetic bone graft substitutes based on calcium for dental applications. It reviews aspects such as the composition, the structure, and the processing routes of the different families of materials to give the reader a general overview of the different materials. Particular attention is given to calcium phosphates due to the close chemical resemblance of these materials to the mineral phase of bone. Other families such as calcium sulfates, calcium carbonates, and calcium-containing bioactive glasses are also discussed. The chapter places particular attention on the current and novel strategies based on ion doping (to mimic mineral bone composition), surface functionalization (to mimic extracellular matrix), and additive manufacturing (to make highly porous yet mechanically stable scaffolds) in the fabrication of the next generation of materials to help accelerate tissue healing and improve bone growth at impaired sites.

Chapter 6 focuses on tissue-engineering techniques for bone grafts. In recent years, bone tissue-engineering techniques have shown great promise for generation of dental bone grafts with highly biomimetic properties. Alveolar bone tissue engineering uses a combination of scaffolds, cells, and/or bioactive factors to generate new bone tissue and, occasionally, other related and interfacial tissue types relevant to the periodontal unit. Given the highly complex environment of the periodontium in which alveolar bone resides, composite scaffold design has been instrumental in producing truly biomimetic scaffolds that can recapitulate the heterogeneous chemical, physical, and biological properties of dental bone. One important aspect of composite scaffold design has been utilizing novel material combinations and composite materials from multiple classes—including synthetic polymers, natural polymers, and ceramics—to provide a myriad of biomimetic features. Building upon this, the emergence of high-fidelity scaffold

fabrication techniques in rapid prototyping have enabled the production of complex, spatially defined architectures from these composite materials. Furthermore tissue engineers have utilized multiphasic and gradient scaffold design to directly address the heterogeneity of alveolar bone and its surrounding periodontium. Thus more biomimetic scaffolds and dental bone grafts have been produced by combining composite material selection, high-fidelity 3D scaffold fabrication, and multiphasic scaffold design. Further improvements to dental bone graft engineering can be explored through the development of more precise mechanical, physical, and biological gradients that mimic the periodontal unit.

The chapters in the second part of the book focus on the biological interaction and biocompatibility of dental implants and bone grafts. Chapter 7 highlights the importance of cellular and molecular interaction. It provides an overview of the cellular interactions and the genetic regulations at the bone-implant interface, based on experimental in vivo studies and available studies in humans. The first section discusses the current knowledge on the cellular and molecular events governing the initial cell recruitment, early inflammation, and the transition from inflammation to bone formation and remodeling during the phases of osseointegration. The modulation of these events, by different implant surfaces, and their relationship with the structural and functional development of the interface are emphasized. A subsequent section focuses on selected key biological factors potentially involved in the osteogenic differentiation of mesenchymal stem cells (MSCs) or in coupling of bone formation and remodeling at the interface. Further, the chapter discusses possible phenotypic polarizations of macrophages at the interface, in vivo. Finally, it provides some insights into possible dysregulations of the molecular activities at the interface, under selected bone-compromising conditions.

Chapter 8 reviews bone regenerative issues related to bone grafting biomaterials. Tens of millions of European citizens are partially edentulous and lack sufficient bone for placement of dental implants. This chapter reviews the different options used by oral surgeons for guided bone regeneration (GBR) prior to dental implant placement. Autologous bone grafting is the gold standard but requires a second surgery, induces pain, and the quantity is limited. Allogeneic bone from tissue banks carries the risk of immune rejection and is subjected to uncontrolled resorption. Animal-derived products such as deproteinized bovine bone are very popular in oral surgery, but there are safety concerns with the possible transmission of diseases. Synthetic bone substitutes such as calcium phosphate bioceramics are increasingly used for filling small bone defects because of their biocompatibility and osteoconductive properties. MSCs associated with calcium phosphate bioceramics have shown to induce de novo bone in preclinical and clinical studies. These cells can be easily isolated and amplified in culture from a bone marrow aspiration. When mixed with biomaterials, these cells attach on their surface and the extemporaneous mixture can be applied to atrophied alveolar bone for its regeneration. GBR membranes are essential for favoring bone regeneration while preventing fibrous tissue invasion. However,

synthetic resorbable membranes should be preferred over animal-derived products made from porcine skin for safety and ethical reasons. Furthermore these collagen membranes exhibit a rapid resorption when exposed to the proteases of the oral cavity. This chapter also presents future directions in bone regeneration, such as the use of 3D-printed personalized scaffolds and allogeneic MSCs.

Chapter 9 explores issues related to cell-based therapies in bone regeneration. Cell-based therapies hold great promise for regenerative treatment of bone defects. MSCs are most commonly used to prepare cell-based constructs for bone repair. Although preclinical and clinical evidence of successful bone healing by MSC-based constructs exists, those are far from becoming implemented as standard treatment in clinics. Considerable variation in cell-based construct preparation and study design between studies emphasize the need for a standardized manufacturing protocol and controlled trials. Furthermore the mechanism by which transplanted cells contribute to bone regeneration remains to be unraveled to further aid in developing strategies to increase bone regenerative efficacy. Additionally, in view of the impractical generation procedure of cell-based constructs with time-consuming ex vivo manipulation, directions to improve feasibility and cost-effectiveness of such cell-based constructs are increasingly being explored.

Chapter 10 extensively reviews pharmacological interventions targeting bone diseases in adjunction with bone grafting. Skeletal diseases are often difficult to treat by means of systemic pharmacological intervention due to poor drug uptake and systemic toxicity, both of which limit therapeutic efficacy. Therefore bone-targeting agents have been developed to target drugs to the skeleton. The majority of these bone-targeting agents exploit their affinity to positively charged Ca^{2+} ions that are abundantly present in the mineral phase of bone. A better understanding of bone biology provides new opportunities to develop novel bone-targeted molecular therapeutics to treat bone diseases, such as osteoporosis, osteomyelitis, osteosarcoma, and bone metastasis. This chapter illustrates the most important features of the most commonly applied bone-targeting agents. Subsequently, various strategies aimed at conjugating these bone-targeting agents to either drugs or biomaterial-based systems for local delivery are reviewed. The chapter concludes with a summary of the most promising preclinical applications of bone-targeting drug delivery systems.

Chapter 11 addresses the modern assessment methods of bone-to-biomaterials regeneration. Mainly, it focuses on the application of high-resolution X-ray imaging modalities currently available for the assessment of biomaterials and (bone) tissue engineered constructs, with a specific focus on micro-computed tomography (CT) and CT-derived techniques. It also discusses the development, applications, and limitations of both in vivo and ex vivo micro-CT imaging methods. Moreover, it describes in detail state-of-the-art X-ray imaging techniques, like X-ray phase contrast, scatter contrast, fluorescence contrast, and hybrid X-ray imaging. Finally, it presents challenging nanoresolution multimodal in vivo imaging. Such techniques are providing a simultaneous view into associated molecular, functional, and anatomical changes.

Finally, Chapter 12 aims to explore the frontiers in dental implant therapy and bone grafting and how much preclinical research efforts are needed to achieve the desired clinical translation of the science of dental implants and bone grafts. Advances in various areas of biomaterial science have been significantly contributing to bone tissue-engineering research. This chapter outlines the progress in biomaterial design for developing a biofunctional material that can accelerate therapeutic potential. It discusses various approaches inspired from native bone ECM for modification of biomaterial substrates for bone tissue-engineering applications. Significant efforts have been made to produce biomaterials with biological, compositional, and structural properties. Nevertheless, major issues remain that need to be addressed. Most of the approaches have focused on bone formation. However, considering that bone tissue has a complex structure with unique mechanical features, and bone regeneration is a multifactorial process that includes osteogenesis, angiogenesis, inflammation, and bone resorption, the biomaterial should be designed to provide multiple signals to orchestrate all these healing events. Another concern is the immunogenicity of the transplanted biomaterials. Although most synthetic polymers are biocompatible, the long-term fate of their degradation product and their effect in the body are still not well understood. Presently, most biomaterials affecting in vivo bone regeneration have been tested in small animals with mesoscale defect models. Therefore there is still a need to investigate the potential of biomaterials in larger animal models with relatively larger defect sizes that have better relevance to clinical problems associated with humans.

Rationale of book

In clinical dentistry, dental implants and bone grafts are becoming increasingly crucial. The evolution of these materials and techniques has led to an increase in successful dental treatment as well as patient satisfaction. This is because research on alveolar bone biomaterials (dental implants and bone grafts) has vastly expanded with increased understanding at the molecular and cellular level. However, knowledge of these biomaterials and biological aspects is still surprisingly limited. Thus this book presents a critical review of the science of alveolar bone biomaterials that will help to propel the continuing evolution of modern dental implants and bone grafts.

Goals of book

On completion of reading this book, dental practitioners/scientists should be able to:

- Understand the structure, function, and pathology of the alveolar bone system
- Understand the rationale and clinical indications of dental implants and alveolar bone replacements/reconstruction

- Consider the issues involved in selecting alveolar bone biomaterials (dental implants and bone grafts)
- Understand the biological basis of interactions between alveolar bone and biomaterials
- Utilize information available about the cellular and molecular basis for bone-implant regeneration in vivo and in humans
- Explore ongoing frontier research of dental implants and bone grafts within all relevant fields

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Chapter 1

Alveolar bone science: Structural characteristics and pathological changes

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Chapter outline

1.1 Introduction

Alveolar bone is a critical component of the tooth-supporting apparatus in the maxillofacial skeleton. A healthy alveolar process, comprising the alveolar bone, periodontal ligament, and cementum is required to maintain a healthy dentition [1,2]. Unlike other connective tissues, bone is a specialized connective tissue that is rigid and resilient. It is primarily responsible for supporting the soft tissue integument and protecting internal organs. The rigidity and resilience of bone are contributed by the mineralization of collagen fibers and noncollagenous proteins within the bone matrix [3,4]. Although alveolar bone is similar in microstructure and cellularity to bone in other parts of the body, the physiological and functional needs of the dental apparatus make it unique among all osseous tissues [3].

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Anatomically, alveolar bone is exclusive to the maxilla and mandible, wherein it develops occlusal to the basal bone, coinciding with the development of dentition. In principle, the alveolar bone remains as long as the teeth are in occlusion, and undergoes resorption following loss of teeth [3,5]. With the advent of dental implantology and osseointegration, contemporary dentistry has undergone a paradigm shift towards rehabilitating missing teeth with different types of dental implants [6]. Since alveolar bone is an essential element for dental implant osseointegration, knowledge regarding the techniques to preserve and reconstruct alveolar bone have gained greater predominance over the last decade [1,3,5]. Understanding the biology and characteristics of alveolar bone have therefore become an imperative part of successful implant dentistry [7].

1.2 Embryology of alveolar bone

Alveolar bone development closely follows the development of maxilla and mandible through membranous ossification. Although maxillary and mandibular development begins as early as the fourth to sixth weeks of intrauterine life, alveolar bone development does not begin until the formation of teeth [2,3]. During the fourth week of intrauterine life, embryologic development of the face, including the upper face, midface (nasomaxillary complex), and mandible, begins from five primordia. These include the frontonasal process in the midline, and the bilateral maxillary and mandibular processes surrounding the primitive mouth or stomodeum [3,8] (Fig. 1.1). Both the maxillary and mandibular processes arise from the first branchial arch. While the mandible in its entirety is formed from the mandibular process, maxillary development along with the palate is contributed in part by the maxillary and frontonasal processes [3,8,9] (Fig. 1.2).

Mandibular bone formation begins bilaterally around the inferior alveolar nerve and its terminal incisive branch, thereby forming a bony groove housing those nerves. In addition, this bony groove also houses the developing tooth germs. Medial and lateral to this groove, alveolar bone plates extend superiorly to form the body of the mandible [3]. Anteriorly, the mandibular process merges across the midline giving rise to the mandible and anatomic lower third of the face along with tongue [9]. Nevertheless the mandibular symphysis remains in fibrous union until after birth, when it is finally ossified through membranous ossification [3,9].

Contrary to mandibular alveolar process development, maxillary alveolar development is more complex owing to the simultaneous development of maxillary antrum and associated midfacial (nasal, orbital, and maxillary) structures [3,8]. However, formation of the medial and lateral maxillary alveolar bone plates, enclosing the primary tooth germs, occurs in a similar fashion to that of the mandible. With time, the tooth germs develop and are progressively separated from each other by bony partitions, giving rise to the alveolar sockets that house the teeth and their supporting structures [3,8].

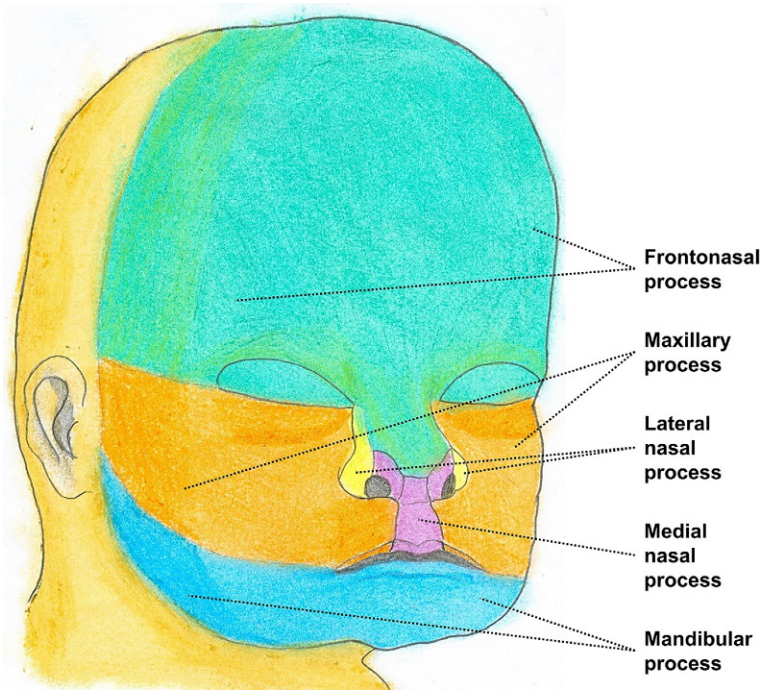

FIG. 1.1 Graphical representation of late fetal facial development in an anterior oblique view showing contributions from the different facial processes; frontonasal process *(green)*, maxillary processes *(orange)*, lateral nasal processes *(yellow)*, medial nasal processes *(purple)*, and mandibular processes *(blue)*.

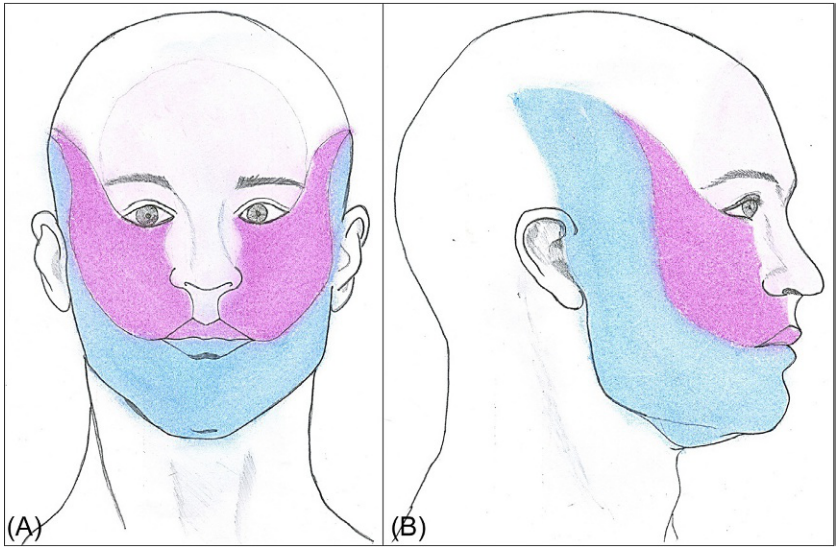

FIG. 1.2 Developmental origins of the maxillofacial skeleton in an adult (A) frontal view and (B) lateral view showing contributions from the maxillary processes *(purple)* and the mandibular processes *(blue)*.

Embryologic development of teeth is attributed to the neuroectoderm or neural crest ectomesenchyme, which underlies the stratified squamous epithelium of primitive mouth or stomodeum. Around the sixth week of intrauterine life oral ectoderm in the primitive maxilla and mandible proliferates into horseshoe-shaped bands, signifying the future dentoalveolar processes [8,10]. This primary epithelial band gives rise to a superficial vestibular lamina and a deeper dental lamina. Both of these laminae proliferate into the underlying ectomesenchyme [8,10]. While the vestibular lamina grows rapidly and degenerates to form the labial or buccal vestibule, the dental lamina undergoes localized expansions called placodes, which develop subsequently into tooth buds. Altogether, the dental lamina gives rise to 52 tooth buds, 20 for primary teeth and 32 for permanent teeth through the lingually proliferating successional lamina [11–13]. The sequence of tooth development from the dental lamina to tooth eruption is shown in Fig. 1.3.

The earliest sign of development of alveolar bone proper coincides with the developing primary dentition. Each tooth bud undergoes different stages of proliferation, differentiation, and organization to form the crown of a tooth. Once crown formation is complete, root development ensues through interaction between the dental follicular mesenchyme and the Hertwig epithelial root sheath (HERS). HERS is composed only of the outer and inner enamel epithelial layers [8,10]. Mesenchymal cells from the dental follicle undergo simultaneous differentiation into cementoblasts, fibroblasts, and osteoblasts. These cells lead to cementum deposition on the developing root surface, formation of periodontal ligament fibers, and formation of the bony socket walls, respectively [8,10].

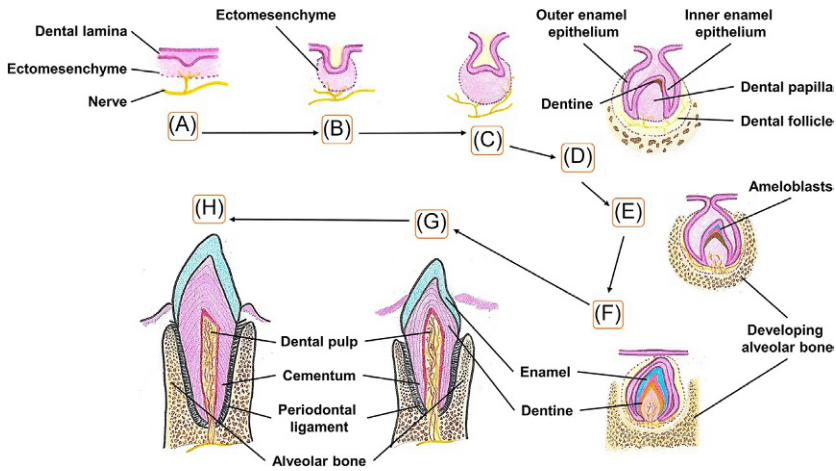

FIG. 1.3 Embryologic development of tooth and its supporting structures, showing the stages of development: (A) initiation, (B) bud stage, (C) cap stage, (D) bell stage with dentinogenesis, (E) amelogenesis, (F) development of crown and alveolar bone, (G) root formation and continued alveolar bone development, and (H) maturation of tooth and its supporting structures.

This concomitant development of the triad of periodontal tissues results in embedding of periodontal ligament fibers within both the cementum and alveolar bone proper. Periodontal ligament progressively increases in length in response to root formation and tooth eruption. Similarly, alveolar bone surrounding the tooth increases in height and continuously remodels during tooth eruption and follows the periodontal ligament [3,12]. Upon tooth eruption, a fully functional dentoalveolar process, comprising the tooth, completed root, alveolar bone, and periodontal ligament, is finally created [3,8,10]. Physiologically, alveolar bone is in a constant state of dynamism throughout life. It remodels in response to occlusal wear and tear and masticatory forces placed on the tooth, and transmitted through the periodontal ligament [3,8,10] (Figs. 1.3 and 1.4).

Similar to other anatomical sites, the two major cell types participating in the development of alveolar bone are osteoblasts and osteoclasts [4]. Osteoblasts are derived from the dental ectomesenchyme, and are responsible for the formation of bone matrix and its mineralization. After bone formation, the osteoblasts either undergo apoptosis or become osteocytes encased in a lacunae within the bone matrix or transform into bone-lining cells covering almost all quiescent bone surfaces [4]. Osteoblasts are highly active postmitotic cells containing a cytoplasm rich with secretory and synthetic organelles necessary for bone matrix deposition. Conversely, osteocytes are smaller and relatively less active cells with fewer cytoplasmic organelles. Nevertheless osteocytes have extensive cell processes that communicate with other osteocytes in the bone matrix, through canaliculi and gap junctions [4,5].

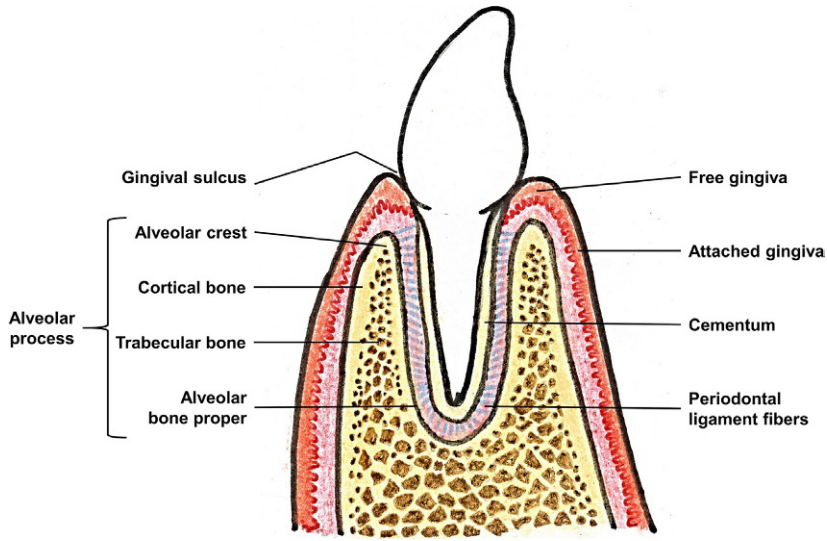

FIG. 1.4 Anatomy of the alveolar process supporting a fully erupted tooth and components of alveolar bone.

In contrast to the osteoblasts, osteoclasts are derived from hematopoietic progenitors of the monocyte macrophage system [14]. Although they originate as mononuclear cells, osteoclasts fuse during maturation to form multinuclear cells with polarized nuclei and a ruffled border. This ability of osteoclasts enables them to attach to the bone matrix and subsequently aids in bone matrix resorption. During their active phase osteoclasts exhibit numerous large and small cytoplasmic vesicles, containing cathepsin, close to the ruffled border. In addition small spherical vesicles containing plasma membrane and lysosomal enzymes, identified by a single indentation on their surfaces are also seen. These vesicles participate in osteoclastic degradation and recycling of the plasma membrane components [5,15] (Fig. 1.5).

1.3 Classification of alveolar bone

As mentioned earlier, alveolar bone is a specialized part of the mandible and maxilla that forms the primary support structure of teeth. It undergoes constant remodeling in order to accommodate to the changing morphology and physiological demands of the dental structures it contains. Alveolar bone is composed of bundle bone, formed in layers with a parallel orientation along the coronal-apical direction of a tooth [16]. Sharpey's fibers extend obliquely from the thin lamella of bone that lines the socket wall and are continuous with the fibers of periodontal ligament [16]. Within the alveolar process, alveolar bone proper lines the alveolus or tooth housing [17]. It is composed of a thin plate of cortical bone with numerous perforations (or cribriform plate) that allow the passage of blood vessels between the bone marrow spaces and periodontal ligament [17]. The coronal rim of alveolar bone forms the alveolar crest, which generally

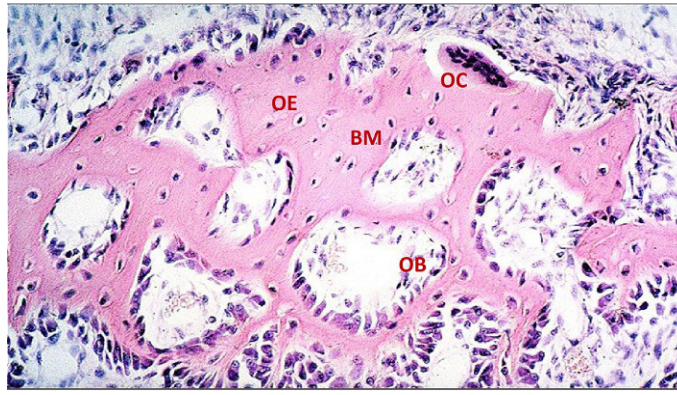

FIG. 1.5 Histological section (H and E, ×100) of bone obtained from a healing extraction socket showing, new bone formation with osteocytes (OE) entrapped in the bone matrix (BM). Islands of new bone formation by osteoblasts (OB) and remodeling through resorption by osteoclasts (OC) is also seen.

parallels the cemento-enamel junction (CEJ) and is at a distance of 1–2 mm apical to CEJ. The radio-dense, compact bone lining the alveolus proper, and into which Sharpey's fibers insert, is termed the lamina dura [18] (Figs. 1.4 and 1.6).

Proper development of alveolar process is dependent on tooth eruption, and its maintenance depends on tooth retention. When teeth fail to develop (e.g. anodontia), the alveolar process fails to form. Similarly when teeth are extracted (e.g. partial or total edentulism), most of the alveolar process undergoes involution, leaving behind only the basal bone as a major constituent of jawbone [18]. In order to achieve full-mouth functional rehabilitation of edentulous jaws, a detailed knowledge about the changing anatomical form of jaws is essential. However, one of the most critical issues during clinical diagnosis and treatment planning is the ability to adequately classify remaining alveolar structures. Unfortunately the majority of the reported classification systems for alveolar bone are either subjective or incomplete [17].

Following extraction or loss of teeth, the basilar processes of mandible and maxilla remain relatively stable. However, changes in the shape of the alveolar process are highly significant both in the vertical and horizontal axes. Nevertheless these changes follow a predictable pattern. Therefore an ideal classification system for the alveolar bone should aim to serve as a simplified descriptive model of the residual ridge and assist in communication between clinicians. It should offer an objective baseline to evaluate and compare different treatment options, and aid in the selection of appropriate surgical and prosthodontic techniques. Furthermore, an awareness of the pattern of resorption and remodeling that takes place in various parts of the edentulous jaws enables clinicians in deciding upon interceptive techniques to preserve the residual alveolar process [17,18]. The different classification systems for the alveolar bone reported in the literature are described in Table 1.1.

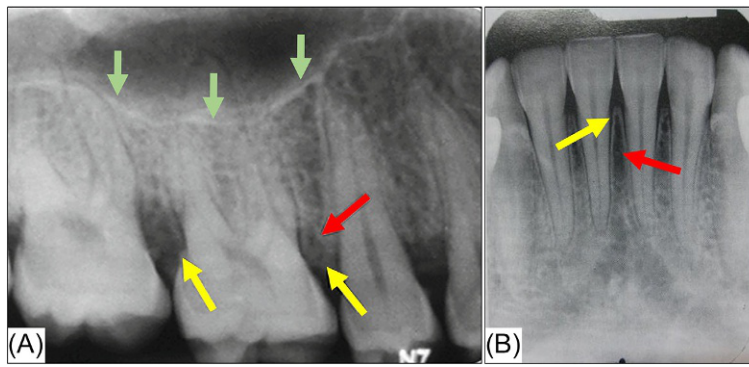

FIG. 1.6 Dental periapical radiographs: (A) Showing the alveolar crest *(yellow arrows)* mesial and distal to first maxillary molar, trabecular alveolar bone in the interdental septum *(red arrow)*, and floor of the pneumatized maxillary antrum *(green arrows)*; (B) Showing the alveolar crest *(yellow arrow)* between mandibular central incisors and trabecular alveolar bone in the interdental septum *(red arrow)*. The radio-dense lamina dura is seen surrounding teeth in both radiographs.

TABLE 1.1 Different classification systems for the alveolar bone

Classification scheme	Basis for classification	Description
Lekholm and Zarb (1985) [19]	Based on conventional radiographs and histological component	**Type 1**: Homogenous cortical bone **Type 2**: Thick cortical bone with marrow cavity **Type 3**: Thin cortical bone with dense trabecular bone with good strength **Type 4**: Very thin cortical bone with low density trabecular bone of poor strength
Misch (1990–2008) [7,20]	Based on descriptive morphology, radiographic density obtained through computed tomography, and clinician tactile analysis	**D1** represents a homogenous, dense cortical bone, mostly found in anterior mandibles with moderate bone resorption (>1250 HU) **D2** is a combination of dense-to-porous cortical bone on the crest and trabecular bone from 40% to 60% on the inside, most frequently in the anterior mandible, followed by the posterior mandible (850–1250 HU) **D3** is composed of thinner porous cortical bone on the crest and fine trabecular bone within the ridge (350–850 HU) **D4** has the least trabecular density with little or no cortical crestal bone (150–350 HU) **D5** (<150 HU)
University of California Los Angeles (UCLA) classification [21]	Based on bone volume and shape in three dimensions	**Type I**: Sufficient bone in horizontal and vertical dimensions **Type II**: Insufficient bone volume on the buccal side **Type III**: Knife-shaped alveolar bone or major deficiency bone volume on the buccal side, but with sufficient heights **Type IV** Insufficient alveolar heights and width
Cawood and Howell's ridge classification [22]	Based on alveolar process resorption levels in jaw cross-sections	**Class I:** Dentate **Class II:** Immediately post extraction **Class III:** Well-rounded ridge form, adequate in height and width **Class IV:** Knife-edge ridge form, adequate in height and inadequate in width **Class V:** Flat ridge form, inadequate in height and width **Class VI**: Depressed ridge form, with some basilar loss evident characteristic shapes resulting from the resorptive process

Classifications of edentulous jaw morphology by Kent et al. [23]	Based principally on the panoramic or cephalometric radiograph	**Class I:** Alveolar ridge is adequate in height but inadequate in width, usually with lateral deficiency or undercut regions **Class II:** Alveolar ridge is deficient in both height and width, and presents a knife-edge appearance **Class III:** Alveolar ridge is resorbed upto the level of the basilar bone, producing concave form on posterior regions of the mandible and a sharp, bony ridge form with bulbous, mobile soft tissue in the maxilla **Class IV:** Resorption of the basilar bone produces pencil-thin, flat mandible or flat maxilla
Branemark et a1 [19].	Based on jaw-resorption morphology	**Class I:** Minimally resorbed **Class II:** Mildly resorbed **Class III:** Moderately resorbed **Class IV:** Severely resorbed **Class V:** Extremely resorbed
The classification of osseintegrated implant sites [24]		**Class A site** 1. The site has 10 mm or greater vertical bone present, and 6 mm or greater of horizontal bone available 2. The implant does not penetrate into the sinus or nasal fossa, impinge on the inferior alveolar nerve, or perforate the inferior border of the mandible 3. Bone quality: both cortical and marrow vascular bone is present; overall bone density is good; and bone has viability and strength **Class B site** 1. The site has 7 to 10 mm of vertical bone and at least 4 mm of horizontal bone available 2. The implant may penetrate slightly (1 to 2 mm) into the sinus or nasal fossa or extend beyond the inferior border (1 to 2 mm) as long as the respiratory epithelium or periosteum is not perforated 3. Bone quality is satisfactory

Continued

TABLE 1.1 Different classification systems for the alveolar bone—Cont'd

Classification scheme	Basis for classification	Description
		Class C site 1. The site has <7 mm of vertical bone or <4 mm of horizontal bone, especially where grafting procedures might be used (The implant should at minimum be 50% in native bone) 2. There is a total lack of cortical stop with a >2 mm penetration into the sinus or nasal fossa, a >2 mm penetration through the inferior border of the mandible has occurred, or minor nerve transposition surgery is required 3. Bone quality or density is poor **Class D site** 1. There is absent alveolar process or severe basal bone loss requiring bone graft reconstruction, for example, discontinuity defects or sites with only a few millimeters of bone available in horizontal or vertical dimensions. Class D sites have <50% of the implant in nongraft bone. 2. Near total aerification of the maxillae requires sinus lift and grafting procedures. In posterior mandibular sites, extensive nerve repositioning would be required. 3. Bone density and quality is poor: bone is lacking in marrow vascular component, or there is osteoporosis, reactive bone, or proximal perio-endodontic scars or lesions.
A classification of alveolar bone tissue for orthodontists and periodontists [25]	Based on cone-beam computed tomographic (CBCT) imaging to classify alveolar bone tissue	The alveolar bone supporting the tooth is classified into nine conditions: B1L1, B1L2, B1L3, B2L1, B2L2, B2L3, B3L1, B3L2, and B3L3. Wherein, B1, B2, and B3 represent buccal bone levels at cervical, middle and apical third of the roots respectively. Similarly, L1, L2, and L3 represent lingual bone levels at cervical, middle, and apical third of the roots respectively.

Cologne Classification of Alveolar Ridge Defects (CCARD) [26]	An anatomically and therapeutically based classification of ridge defects	**Part 1: Orientation of the defect** H: horizontal / V: vertical / C: combined / S (or + S): sinus area **Part 2: Reconstruction needs associated with the defect** 1: low: < 4 mm 2: medium: 4–8 mm 3: high: > 8 mm **Part 3: Relation of augmentation and defect region** ***i***: internal, inside the contour / **e**: external, outside the ridge contour This system describes each defect by a single defect code consisting of letters and numbers. Defect code H.1.i: Small defect up to 4 mm, inside the ridge contour; Defect code S.1: Small defect in the sinus area lower than 4 mm (internal/ external not required); Defect code C.2.e.S.1: Combined alveolar ridge defect of 4–8 mm, outside the envelope, with sinus defect <4 mm

1.4 Alveolar bone proper, alveolar process, and alveolar crest

Alveolar bone is continuously formed and remodeled around the roots of a tooth, as it erupts into the oral cavity aided by root development. This process continues until the tooth erupts into function and the root is entirely surrounded by alveolar bone [7] (Figs. 1.3 and 1.4). Physiological forces on the tooth after eruption and during function are transmitted to alveolar bone proper through embedded Sharpey's fibers of periodontal ligament. Sharpey's fibers, which provide a strong functional attachment between the cementum and alveolar bone proper, are calcified collagen fibers organized in bundles [3]. Interestingly, the portion of alveolar bone proper giving attachment to Sharpey's fibers is termed as bundle bone owing to the presence of these collagen fiber bundles. Radiographically, bundle bone appears as a radiopaque band called lamina dura and can be differentiated from the underlying trabecular bone [21,23] (Fig. 1.6). Adjoining the bundle bone, within alveolar bone proper, is cribriform lamellar bone, which contains numerous foramina for passage of blood vessels and nerves, supplying dental pulp and periodontium [3,27] (Fig. 1.4).

The alveolar process is comprised of alveolar bone proper, trabecular bone, and buccal, labial, and lingual cortical alveolar bone. At different regions of the maxillary and mandibular arches the alveolar process is contoured according to the morphology of the tooth it houses (Fig. 1.7). The cortical bone is lamellar in nature and contains Haversian systems for vitality of the bone. Anatomically the cortical bone of alveolar process is thinner in maxilla than in mandible. Similarly it is thinner in the anterior regions in comparison to the posterior

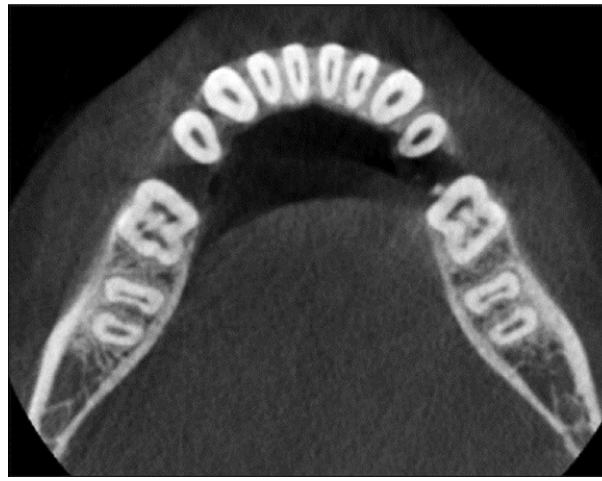

FIG. 1.7 Axial section of a computed tomography (CT) scan through the mandibular dentition at the level of roots, showing differential thickness of alveolar bone at different aspects surrounding the teeth.

regions. In addition to housing neurovascular bundles supplying the dentoalveolar apparatus, the trabecular bone is rich in bone marrow, which is a source of both osteogenic and hematopoietic precursors [7,28]. Surrounding the CEJ of a tooth, alveolar process is termed alveolar crest, wherein the alveolar bone proper and cortical bone merge together, without any trabecular bone. The alveolar crest is significantly more mineralized than apical alveolar bone [7,28]. Under normal circumstances, alveolar crest lies apical to the CEJ and its three-dimensional shape follows the shape of the root. This results in alveolar crest functioning as an inter-radicular septum between roots of multi-rooted teeth and as an inter-dental septum in between two teeth (Fig. 1.6).

An important clinical consideration during implant placement is the thickness of alveolar process at each point surrounding the tooth to be replaced. While it is thinnest at the level of alveolar crest, it increases in thickness towards the apex with increasing amounts of trabecular bone between bundle bone and cortical bone [2,3,7] (Fig.1.6). Moreover, thickness varies according to the amount of trabecular bone at each anatomical site in the dental arch and is usually thinner in anterior regions when compared to posterior regions [29] (Fig. 1.7). The thickness of alveolar process is also dynamic and increases in response to physiological forces. However, the stimulus for functional increase in alveolar bone thickness is through tensile forces applied on the bundle bone by its embedded periodontal Sharpey's fibers [2,3]. This substantiates the reasons behind a progressive decline in alveolar bone quality and quantity following dental extraction, resulting from loss of stimulation through periodontal ligament [30]. Therefore periodontal ligament, cementum, and alveolar bone are required to work synergistically in order to maintain a healthy dentition. In addition, they are also the key elements for dental adaptation to physiological forces such as mastication and therapeutic forces like orthodontic tooth movement [2,30]. On the contrary, dental implants do not have a functional periodontal ligament. Nevertheless, placement of dental implants and their subsequent loading within physiological limits helps to maintain the residual alveolar bone through stimulated bone apposition and mineralization (Mechanostat theory) [2].

1.5 Composition and micro-structure of alveolar bone

Alveolar bone is a mineralized connective tissue consisting approximately around 23% inorganic components, 37% organic matrix, and 40% water [5,31]. Similar to other bones in the body, the main inorganic components in alveolar bone are hydroxyapatite, calcium, phosphorus, hydroxyl, citrate, carbonate and traces of sodium, magnesium, and fluorine. The organic constituents include cellular elements and an organic matrix made up of collagen type I and noncollagenous proteins [5]. The three major cell types in alveolar bone are osteoblasts, osteocytes, and osteoclasts, in addition to bone marrow adipocytes and vascular endothelium. Physiologically the three major bone cells are responsible for the dynamic nature of bone tissue. They are constantly involved in a

cycle of remodeling, in response to physiological, functional, and metabolic needs [2,7] (Figs. 1.5 and 1.8). Osteoblasts are mononuclear cells responsible for bone deposition and they also regulate osteoclastic bone resorption through feedback mechanisms. They have a cytoplasm that is rich in alkaline phosphatase and possess surface receptors for parathyroid hormone and estrogen [5,11].

Osteocytes are stellate cells, which form an extensive network of interconnecting cytoplasmic processes through canaliculi and are placed surrounding the Haversian canals [4,5,11]. The individual cytoplasmic processes are connected through an intercellular gap junction made up of connexin. Due to their highly dynamic nature and the ability to remodel in response to physiologic functional forces, osteocytes in alveolar bone are regarded as mechano-receptors. This property of osteocytes guides the osteoclasts and osteoblasts for bone resorption and formation, respectively [14,31].

Osteoclasts are large, multinucleated giant cells. Morphologically, they present a foam-like appearance along with a homogeneous cytoplasm, owing to the presence of large quantities of secretory vesicles and vacuoles [14,15,32]. These osteoclastic vacuoles are rich in acid phosphatase and the cell is responsible for transport of ions, proteins, and secretory vesicles, which enable its phagocytic function at any localized area of the bone. The presence of an actin-vinculin-talin-containing clear zone is a unique feature of osteoclasts, which are actively involved in bone resorption. While osteoblasts turn into quiescent osteocytes after bone formation, osteoclasts are removed by apoptosis upon completion of their resorption functions [5,14,33].

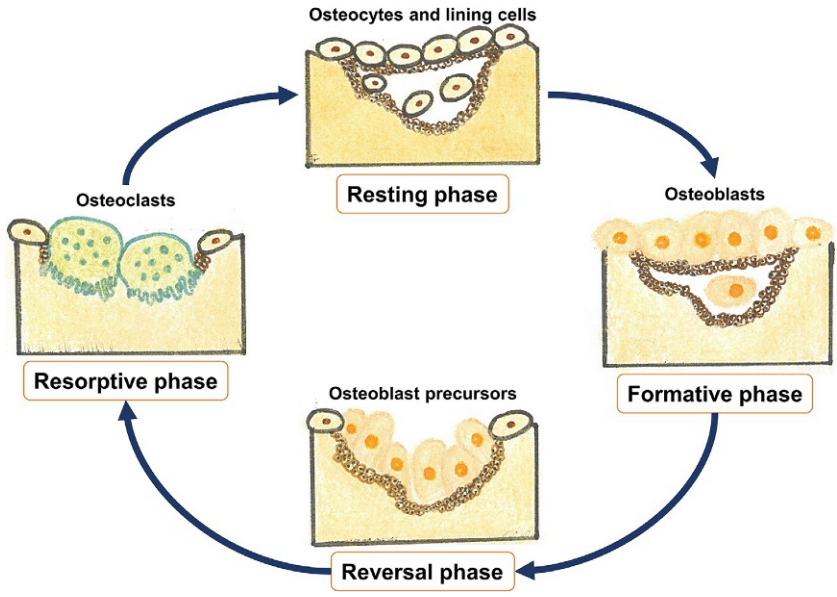

FIG. 1.8 Physiological remodeling cycle of the alveolar bone.

The organic matrix of alveolar bone predominantly consists of collagenous proteins (80%–90%), comprising collagen type I (95%) and collagen type V (5%) [5]. In addition, collagen type III and type XII are also found in trace quantities. While the osteoblasts in alveolar bone are responsible for the synthesis of collagen types I, V, and XII, collagen type III is secreted by the fibroblasts [5]. Moreover, alveolar bone contains numerous noncollagenous proteins such as osteocalcin, osteonectin, osteopontin, sialoproteins, proteoglycans, phosphoprotein, and bone morphogenic proteins (BMP), among others. Primarily classified as proteoglycans and glycoproteins, these noncollagenous proteins of alveolar bone represent approximately 8% of the organic matrix [4,5,14,31]. The noncollagenous proteins are responsible for regulating collagen synthesis and formation of ground substance. One important group of noncollagenous proteins, namely the BMP, are responsible for differentiation of osteoblasts from their pluripotential osteoprogenitor cells [5,11,14,31].

1.6 Anatomic considerations of alveolar bone

Anatomically and clinically, the parts of maxilla and mandible supporting the teeth comprise the alveolar process. Morphologically, alveolar bone is similar to skeletal bones. It has a sandwich construction composed of an outer layer of dense cortical bone on the buccal, labial, lingual, and palatal aspects, and an inner layer of bundle bone abutting the roots of teeth. The middle layer of trabecular bone is filled with marrow spaces [2]. This unique design of alveolar bone provides resilience and rigidity along with a low mass for given volume [2]. Clinically and radiographically, the cortical portion of alveolar bone is continuous with the cortical bone of maxilla and mandible on the bucco-labial and linguo-palatal regions. On the other hand, trabecular alveolar bone continues beyond the tooth roots slightly differently in the maxilla and mandible. While it is continuous with trabecular bone of the mandibular body, in the maxilla it is continuous with the maxillary bone only until the boundaries of maxillary antrum [2,7]. This is an important consideration while planning maxillary dental implant rehabilitation, as there is greater propensity for excessive pneumatization of maxillary antrum following dental extraction [2]. Both in the mandible and maxilla, trabecular bone is either absent or is very limited in the areas of alveolar crest, inter-dental septum, and inter-radicular septum [11,34]. Posteriorly, the alveolar process of maxilla fuses with the palatine process and mandibular alveolar process fuses with the external oblique ridge. These lines of fusion of alveolar bone with the maxilla and mandible represent the direction of transmission of occlusal forces to the viscerocranium [3].

Alveolar process in a normal periapical dental radiograph shows the interdental septum between two teeth delineated by a radiopaque lamina dura and intervening trabecular bone, which appears less radiopaque. Lamina dura surrounds the roots of teeth and it appears separated from the root surface by means of a radiolucent periodontal ligament space. Lamina dura is the most significant

radiographic finding in alveolar bone, and is clinically equivalent to the alveolar bone proper. Radiographs of posterior teeth reveal a similar presentation in addition to the inter-radicular septum separating multiple roots of a tooth. Correlating clinically, in any disease process involving the alveolar bone, radiographic findings of an altered or obliterated lamina dura is considered diagnostic [35] (Figs. 1.6 and 1.7).

Maxillary alveolar bone on the buccal and labial side is supplied by the anterior, middle, and posterior superior alveolar neurovascular bundles. On the palatal aspect, it is supplied by branches of the nasopalatine and greater palatine neurovascular bundles. Similarly, mandibular alveolar bone is supplied by branches of the inferior alveolar neurovascular bundle and its mental and incisive branches. In addition, alveolar bone on the buccal aspect of mandibular molar teeth is supplied by the long buccal neurovascular bundle and lingual alveolar bone by the lingual neurovascular bundle [34,36]. Similar to skeletal bones, alveolar bone also receives blood supply through endosteal and periosteal capillaries. Since alveolar bone is a part of the periodontium, composed of cementum, periodontal ligament, and alveolar bone itself, it derives an additional source of blood supply through periodontal ligament, especially to the alveolar bone proper (bundle bone and lamellar bone) [2]. The highly vascular periodontal ligament is interposed between the cementum and bundle bone. This aspect of the periodontium is of clinical significance while deciding implant placement in order to judge the degree of vitality of surrounding bone [2,7]. Lymphatic drainage from alveolar bone passes through the lamellar cribriform portion of alveolar bone proper and joins lymphatics draining the periodontal ligament, and finally drains through the dental periapical region. Lymphatics from maxillary and mandibular alveolar processes drain into the sub-mandibular group of lymph nodes, along with lymphatics from the dentoalveolar region [34,36]. At a microscopic level, the functional units of alveolar bone, namely the osteon and Haversian system, are vascularized through Haversian and Volkmann canals [5,11]. Additionally, blood vessels and lymphatics to the periodontium also traverse through Volkmann canals in the alveolar bone proper. Nerve supply to the alveolar bone in maxilla and mandible is similar to that of the dentition. This could be explained by the common embryologic neuroectodermal origin of teeth and their supporting dentoalveolar apparatus including alveolar bone and periodontium [11,34] (Fig. 1.9).

1.7 Alveolar bone in disease and response to injury

The alveolar process exists and remodels continuously as long as a tooth is in function. It is capable of migrating along with the tooth either due to physiologic reasons or for orthodontic purposes. Alveolar bone loss through disruption of remodeling occurs in a wide range of clinical conditions, including following dental extraction, inflammatory diseases such as periodontitis, and in response to trauma and pathological conditions [32]. Once a tooth is extracted, alveolar bone undergoes excessive resorption and may even become displaced

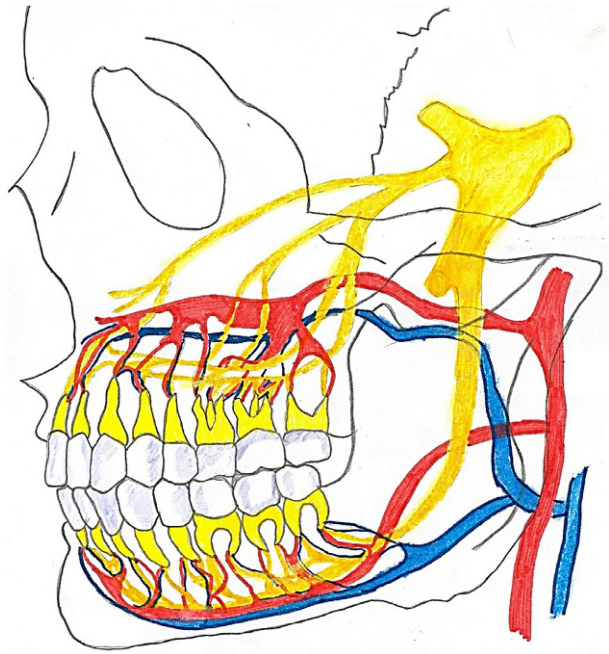

FIG. 1.9 Blood supply (arterial supply—*red*; venous drainage—*blue*), and nerve supply *(yellow)* of dentoalveolar process and alveolar bone.

in relation to the neighboring alveolar processes [2,37]. Following extraction, the tooth socket is filled with a blood clot, which progressively organizes into fibrous granulation tissue and is replaced initially by immature woven bone [2] (Fig. 1.10). Changes occurring in the extracted socket could be described as an overlapping sequence of inflammation, proliferation, and remodeling [37].

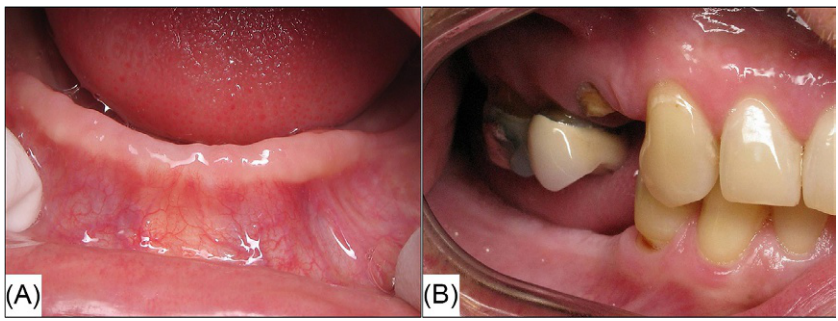

FIG. 1.10 Clinical intraoral photographs: (A) Showing a completely edentulous mandibular arch with extreme resorption of residual alveolar ridge both in thickness (labio-lingually) and in height; (B) Showing a partially edentulous posterior mandibular arch with reduction in thickness and height of residual alveolar ridge.

The immature bone formed in a healing extraction socket is similar to embryonic new bone and is a coarse fibrillar bone containing numerous, irregularly arranged, large osteocytes. The excessive cellularity of this immature bone accompanied by its inadequate mineralization makes the healing extraction socket radiolucent in comparison to adjacent normal bone. Over time this immature bone is replaced by an organized lamellar bone [3,8].

Physiologically, healing of an extraction socket is similar to fracture healing in other bones, through callus formation. However, it is different due to the presence of specialized alveolar bone surrounding the tooth [7]. In the absence of physiologic stimulation through Sharpey's fibers, the alveolar bone proper and alveolar process start resorbing in sequence. Clinically it has been proven that placement of endosseous implants into the healing extraction socket limits the amount of alveolar bone resorption, thereby indicating a need for mechanical stimulation through occlusal forces for maintenance of alveolar bone [2,7]. It has further been reported that nearly 35% of spontaneously healed extraction sockets were not vital enough to support dental implants. This was due to the presence of empty lacunae along with reduced osteoblastic activity and increased numbers of osteoclasts and inflammatory cells [7]. Moreover, the loss of teeth has been reported to result in up to 50% decrease in alveolar bone volume, especially in the buccal, labial, and marginal aspects [7,37]. All of this proves to be a case in point for favoring early rehabilitation of dental extraction sockets either with implants or through bone grafting and socket preservation techniques [7,37] (Fig. 1.10).

In addition to resorption following dental extraction, alveolar bone loss also occurs in conjunction with periodontitis. Periodontal disease is characterized by significant degenerative changes in the alveolar bone proper, mostly as a result of inflammatory immune response to periodontal pathogens [32]. Although it begins as an inflammation of gingival tissue surrounding the teeth, it is capable of spreading to the periodontal ligament, leading to loss of attachment and subsequent resorption of the alveolar bone proper [8,11,36]. Moreover, inflammatory response to local factors and systemic inflammatory mediators are yet another major contributor to the etiopathogenesis of periodontal disease [8,36]. Periodontal ligament is the key element in supporting occlusal function of teeth. Damage to periodontal ligament results in loss of dental function and the ability to repair and remodel periodontal tissues, including alveolar bone [30]. In advanced cases, periodontal disease results in differential loss of the supporting alveolar bone leading to varying grades of clinical tooth mobility and a radiologic appearance of teeth supported by very little bone or no bone at all (floating teeth). While chronic periodontitis could either be localized to a particular tooth or be generalized, advanced and aggressive forms of periodontal disease are usually generalized, affecting the entire dentition (Fig. 1.11).

Interestingly, periodontal disease is not commonly associated with loss of pulp vitality, which in turn occurs as a result of irreversible pulpitis. Similar to periodontitis, pulpitis can also lead to alveolar bone resorption frequently in the

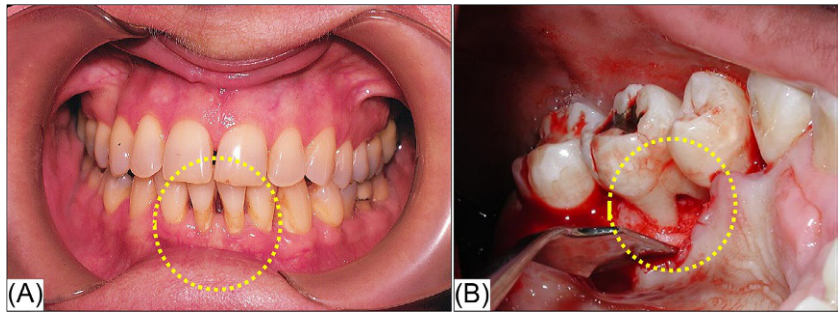

FIG. 1.11 Clinical intraoral photographs: (A) Showing gingival recession in mandibular incisor region; (B) Showing periodontal bone loss and root exposure in the mesio-palatal aspect of the first maxillary molar.

periapical region. Pulpitis or inflammation of pulpal tissues often occurs in response to dental caries or dental trauma. When inflammatory products from the pulpal tissues are released into the periapical region, they set forth a cascade of events leading to periapical periodontitis and alveolar bone loss. Clinically this is elicited by pain upon applying pressure over the tooth and radiographically as a loss of continuity in the lamina dura [8]. This periapical inflammatory process is also capable of stimulating embryologic odontogenic epithelial remnants leading to the formation of periapical granulomas and cysts. These inflammatory odontogenic lesions are associated with extensive alveolar bone destruction in the periapical and periodontal regions [12]. Similarly, developmental odontogenic cysts such as lateral periodontal cyst, botryoid odontogenic cyst, gingival cyst of the newborn and adult, and dentigerous cyst, and odontogenic tumors such as odontoma, which arise in close proximity to the tooth, are also associated with alveolar bone destruction [12].

In addition to local factors, systemic conditions are also implicated in hastening qualitative and quantitative loss of alveolar bone. Osteoporosis is a systemic disease affecting all the bones in the body and is characterized by a decrease in alveolar bone mass, at a rate faster than it could be replaced [38]. In general, the molecular and cellular mechanisms of osteoporosis are prevalent throughout the skeleton. However, its effects are pronounced in alveolar bone due to its dynamic nature and sensitivity to local stimuli such as masticatory loading and periodontal inflammation [2,38]. Clinically, patients with untreated osteoporosis possess a risk of spontaneous alveolar bone fractures, delayed postextraction healing, and failure of dental implant osseointegration. The clinical complications in alveolar bone are predominantly associated with primary osteoporosis. Nevertheless, secondary osteoporosis seen in systemic disease conditions such as estrogen deficiency, hyperparathyroidism, hyperthyroidism, and chronic renal failure are also capable of affecting alveolar bone [38]. In particular, estrogen deficiency has been shown to negatively influence bone mineral density during postimplantation healing of alveolar bone [39].

Diabetes mellitus is yet another systemic condition that has been reported to affect periodontal tissues. Literature reveals that uncontrolled diabetes not only prevents new alveolar bone formation but also hinders bone remodeling and postimplantation wound healing, resulting in impaired bone to implant contact [40]. It has been postulated that diabetes results in a systemic inflammatory state, which increases the level of pro-inflammatory cytokines within the gingival crevicular fluid. This leads to a direct effect on periodontal tissues, culminating in an increased incidence of periodontitis and tissue destruction [41]. A decrease in alveolar bone thickness due to hyperglycemia is also attributed to the inhibition of osteoblastic cell proliferation and collagen production [6]. Nevertheless, achieving optimum glycemic control and maintenance of long-term glycemic status is reportedly associated with favorable outcomes in terms of alveolar bone healing and implant osseointegration [41].

1.8 Conclusion

The primary support structure of the dentition is alveolar bone, as it develops along with it and resorbs once the teeth are extracted. Although similar to other bony tissues, it is specialized to the maxilla and mandible, wherein it continuously remodels to accommodate the functional and physiological needs of the dentition. The ability of alveolar bone to remodel in response to physiologic stimuli provides for a functional occlusion. However, this also becomes detrimental, as it hastens resorption in response to inflammatory stimuli. Understanding the characteristic features of alveolar bone is important because it provides insight with respect to the sciences related to the materials and the biological issues of dental implants and bone grafts.

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