Decision Making in Dental Implantology

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Atlas of Surgical and Restorative Approaches

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Foreword

With today's rapidly changing and improving technologies available in implant dentistry, the clinician performing surgical and restorative treatments on implant patients must make an appropriate selection of treatment options to achieve successful outcomes for their patients. The demands and expectations of the implant patient today place more pressure on treating clinicians to provide both functional and highly esthetic results. Many teaching and educational courses today focus only on the mechanical aspects needed to provide the dental patient with an implant. Currently, there are too many training courses and textbooks on how to prepare an implant recipient site, how to perform hard and soft tissue augmentation procedures, and subjective management of complications. The biologic principles of osseointegration as introduced by P.-I. Brånemark in the early 1980s are lost or forgotten. The authors of this new textbook have clearly and sequentially moved through the stages of managing an implant patient. They have returned to the scientific and biologic basis of implant dentistry by providing evidence-based principles. Using the clinical practice guidelines established by the American Dental Association, the recommendations made in this textbook have included rankings for implant procedures based on the strength of the literature and level of scientific evidence.

The textbook takes the reader through every clinical scenario, from the fully edentulous to partially edentulous, including the patient missing a single tooth. The chapters clearly delineate the different thought processes the clinician must go through when treating the functional (posterior) zone versus the esthetic (anterior) zone. The chapters are very well illustrated with the authors' documented cases, highlighting the concepts and biologic principles that the surgical and restorative team must consider. There is equal focus on the restorative and surgical aspects of implant dentistry and procedures for both specialties are thoroughly covered with systematic reviews followed by a measurement of strength and level of certainty for the treatment recommendations.

The publication of this textbook is timely and surely will become the go-to reference for clinicians actively providing dental implant treatment for their patients and seeking evidence-based approaches to treating their implant patients.

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Decision Making in Dental Implantology

Decision making is a key to the successful management of patients, particularly when dental implants are considered beneficial to the achievement of the treatment goals. Many factors come together to bring predictability to treatment outcomes and each is given appropriate, chronologically correct consideration in this Atlas. The holistic approach to presentation of information by the authors is refreshing and timely in an era where patient centered philosophies are coming to the fore.

The authors appropriately consider and interpret the scientific foundation for clinical decision making, and through recognition of publication quality increase the credibility of information provided in subsequent chapters. Interpretation of the evidence by clinicians with superior training and experience is seen, through the excellent clinical presentations, to result in patient rehabilitations that are sound functionally and pleasing from the esthetic perspective. Importantly, the reader can rely on the protocols presented through patient care as a result of the diagnostic and treatment acumen presented.

The patient documentation is meticulous and of the highest quality and their treatment recommendations are both understandable and usable by the reader. This is important because the information provided will ultimately result in benefit to a broader spectrum of patients. By presenting patient related information as comprehensive treatments, the authors encourage treatment teams to consider this treatment approach.

The authors are to be commended for their efforts. This Atlas provides a benchmark for quality treatment outcomes both now and in the future. Congratulations on bringing a valuable addition to the information base related to patient care utilizing dental implants.

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Preface

We all know that the advances in the field of dentistry, the ever-changing area of the evidence base, and the sometimes dazzling array of proposals for new treatment procedures would make it seem that the basic concepts of treatment may no longer be a reality. Indeed, this is not true. This new book, *Decision Making in Dental Implantology: An Atlas of Surgical and Restorative Approaches*, came to join together important basic biologic and surgical procedures of periodontology and implantology with the most predictable and well-established treatment approaches available in the literature.

We have tackled the important task of writing an atlas, focusing attention on the management of predictable dental implant treatment approaches in order to achieve significantly positive clinical functional and esthetic results, based on well-established prosthodontic procedures. It is anticipated that the proposal of any treatment approach for the various clinical scenarios must be based on a concept of having the best source of evidence shared within a large audience. In this atlas, we tried to achieve that key idea (i.e. to establish the best practical way to treat patients with implant dentistry procedures).

More than a simple "beautiful presentation of cases," we tried to work with professionalism and passion to present the most solid treatment options clinicians may face during daily practice. This atlas is the outcome of more than 20 years of experience in the field of implant dentistry, in private practice as well in clinical education.

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CHAPTER 1

Current Status of Clinical Practice with Dental Implants: An Evidence-Based Decision Making Overview

Osseointegration and its application to the treatment of completely or partially edentulous patients in clinical practice

Since the first experimental study from the end of 1960s [1], the titanium implant has been used as a biocompatible feasible alternative in the treatment of completely or partially edentulous patients. Basically, the systematic use of dental implants in dentistry as a scientifically proven therapeutic approach occurred in the 1980s, while in the 1990s it strongly grew in terms of potential clinical applications (Figure 1.1 and 1.2).

Currently, titanium implant-based procedures are seen as the gold standard for the replacement of teeth lost as a consequence of periodontitis, caries, endodontic pathology, and trauma. As a result, it can be argued with a high degree of certainty that implant-based therapies alone or in association with hard- and soft-tissue reconstructive procedures (most of them developed during the same period) are essential for the achievement of excellent clinical treatment in dentistry. These principles are grounded in the accomplishment of so-called osseointegration between the implant surface and living alveolar bone, (i.e. a direct bone deposition on implant surfaces at the light microscopic level) [2]. Additionally, others factors have influenced implant therapy among professionals over the last 20 years: the high success rates and the clinical/functional predictability of prosthetic restorations examined by long-term periodontal and implant dentistry research (Figure 1.3 and 1.4) [3–8].

Anatomical implications to implant therapy and the current impact of guided bone regeneration

The success rate of this treatment modality has been influenced by many elements, such as the successful osseointegration of the dental implants, smoking, the relationship between the final restoration(s) and the adjacent teeth, occlusal loading, and the health of the surrounding soft and hard tissue [9–18]. However, and apart from them, the initial anatomical conditions of the site intended to receive an implant merit close attention as they will drive the initial treatment path.

The bone defects in the alveolar ridge have always been considered a major obstacle to clinical therapy with osseointegrated dental implants, especially in partially edentulous patients. Tooth loss leads to changes of the alveolar ridge anatomy (i.e. bone resorption in both height and thickness) and to the development of bone defects: (a) limited bone thickness, (b) reduced bone height, (c) vertical bone defects, (d) bone defects' combined height and thickness, (e) periodontal attachment loss of the teeth adjacent to the edentulous area, and (f) large bone loss resulting from infections/dentoalveolar trauma or previous surgical procedures (Figure 1.5 and 1.6) [19–24]. These features may not only significantly hinder the placement of implants but also affect the proposed restorative therapy in terms of function and aesthetics.

From the late 1980s and early 1990s, the introduction of the principles of guided bone regeneration (GBR) in implantology dramatically changed the treatment of the areas presenting anatomical limitations [19, 21–23]. This therapy involves the application of bone-filling materials (in particles or blocks) covered by barrier membranes isolating the overlying soft tissue in order to allow cells to populate the bone defect area. As a result, areas previously contraindicated for implant therapy could be treated with bone augmentation techniques, prior to or simultaneously with implant placement [24].

Biomaterials for bone filling, or bone substitutes, have shown significant progress over the past two decades. Currently, there are options of biomaterials with osteoconductive properties that can be effectively and safely used in clinical practice [25]. It is noteworthy that these materials are responsible for maintaining the space at the defect area (i.e. the three-dimensional configuration of the future regenerated bone), providing support for the membrane. It is well known that membranes are essential for the application of GBR techniques, as is that absorbable materials are currently the most widely used membranes, owing to their user-friendliness compared to traditional, non-absorbable materials (i.e. expanded polytetrafluoroethylene (e-PTFE)) (Figure 1.7 and 1.8).

Furthermore, several implant surfaces, designs, and materials have been settled to increase bone-implant contact (BIC) and primary implant stability. These advances promote substantial improvements in success rates for dental implants in posterior intraoral regions and low-density bone sites. Initial enhancements on surface roughness leading to more effective microtextures have been followed by chemical modifications to speed up the initial bone apposition process, as well as to optimize BIC and the osseointegration interface. These developments have significantly increased the predictability of implant therapy, and at the same time decreased periods of wound healing/bone repair (i.e. osseointegration period). Likewise, such innovations have allowed the

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consolidation of the clinical use of shorter implants (< 8 mm in length), a condition that considerably increases the treatment options of sites with bone height limitation [26, 27].

In addition, experimental research conducted on the dynamics of alveolar bone repair has proven what many periodontists had already perceived by clinical experience: fresh post-extraction alveolus/sockets heal differently from edentulous alveolar ridges following the installation of a dental implant [28, 29]. Consequently, different approaches advocating the use of bone substitutes used to fill the residual space between the implant surface and the fresh socket walls have been proposed as a way of counterbalancing future alveolar ridge dimensional changes/remodeling following tooth extraction. Comparably, the use of soft-tissue grafts has been expanded beyond the "conventional keratinized tissue gain" to promote the maintenance the alveolar ridge contours, particularly in areas with esthetic demands. Nowadays, there is a great deal of evidence to support clinical treatment protocols for immediate implant placement in esthetic sites (Figure 1.9).

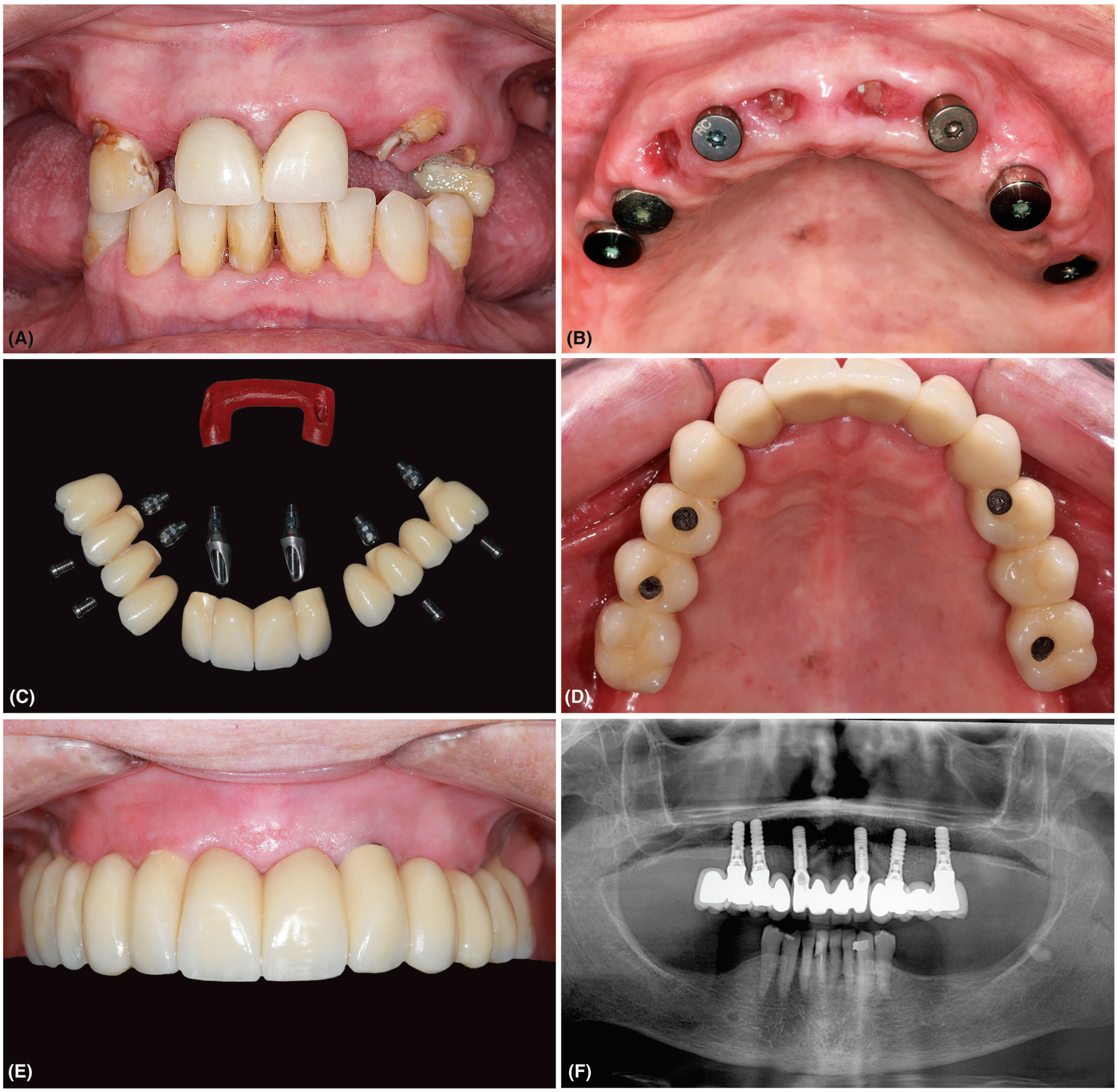

Figure 1.1 (A) Initial clinical status with several missing teeth before the full-mouth reconstruction. (B) After osseointegration around six implants in the maxilla the remaining teeth were extracted. (C) The abutments and the three four-unit porcelain-fused-to-metal restorations: two posterior screw-retained restorations and one anterior cemented restoration. (D, E) Clinical view of the final rehabilitation in position – occlusal and buccal views. (F) Panoramic radiograph.

Implant: Abutment connections

The connections between the implants and abutments can basically be divided into two groups: external connections and internal connections. External connections provide a less stable, small area of overlap between the parts (implant/abutment) that can lead to loosening of the fixing screw. Currently, these are indicated for prosthetic rehabilitations containing several connected implants.

It is important to note that the greater the overlap of the internal surfaces of the implant/abutment, the greater its resistance to horizontal loads. Implants with internal connections present more overlap at the implant/abutment connection, a condition that provides greater stability, and this makes them better indicated for cases involving single crown restorations. It should be noted that the implant systems that have conical internal connections (i.e. fitting joint) have demonstrated the best mechanical results – for this reason they are also called "high-stability systems." Another condition that should be highlighted in the implant/abutment connection is the concept of reduced platform (i.e. prosthetic abutment with a diameter smaller than the implant shoulder

Figure 1.2 (A) Patient smile before treatment. (B) Initial clinical status with several missing teeth before the full-mouth reconstruction. (C) Initial panoramic radiograph. (D) First mockup shows the unfavorable position of teeth #6, 7, and 11 regarding the planning for restorative treatment. (E) Occlusal view of the anterior teeth. (F) Panoramic radiograph after the placement of six implants in the maxilla.

Figure 1.2 (G, H) Clinical views after implant placement before and after teeth extraction. (I) The three four-unit porcelain-fused-to-metal restorations prior to installation. (J) Clinical try-in of the three four-unit screw-retained porcelain-fused-to-metal restorations. (K) Occlusal view of the abutments. (L) Right-side partial fixed restoration before the pink gingival application. (M) Pink gingival simulation with acrylic resin.

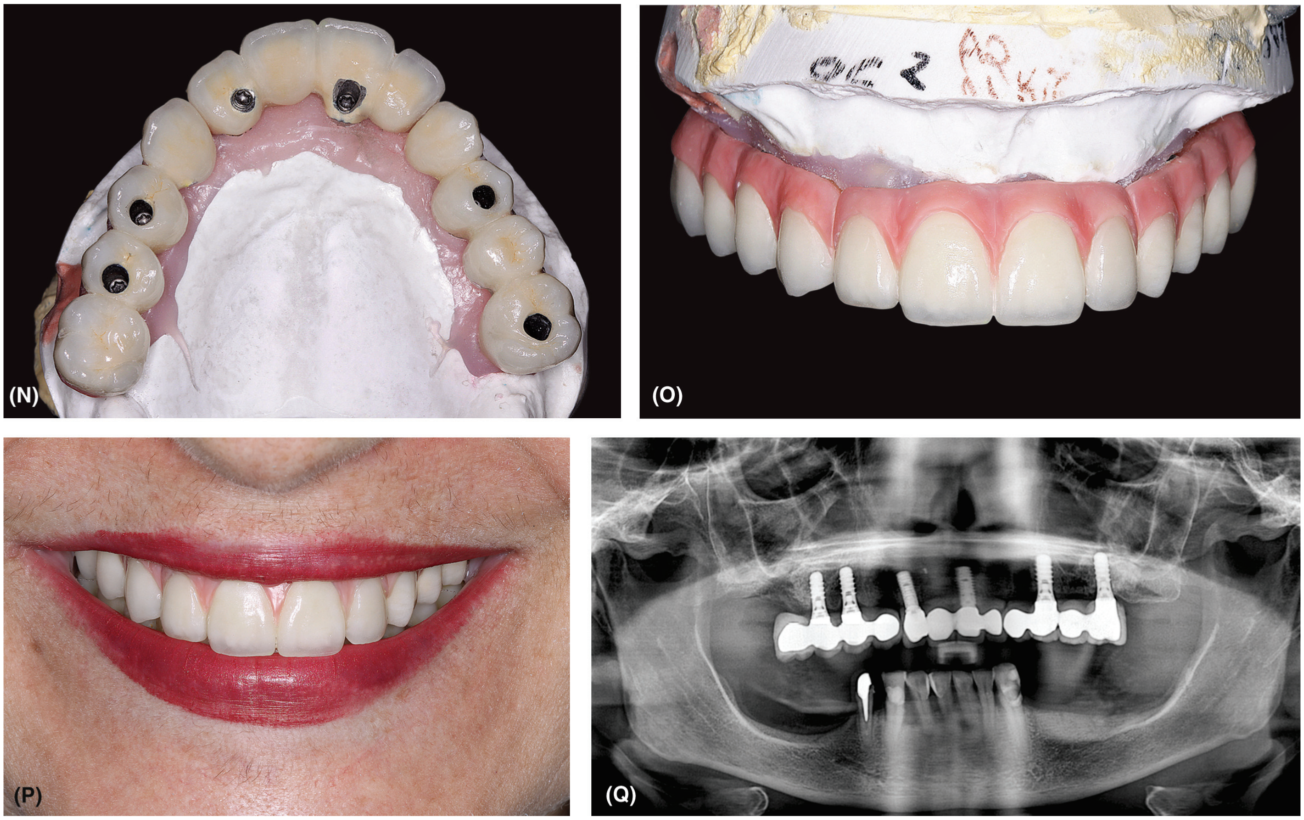

Figure 1.2 (N, O) Restorations completed – occlusal and buccal views. (P) Patient smile after treatment. (Q) Panoramic radiograph.

diameter - platform switching) - which is considered an excellent choice for areas with higher esthetic requirements, given that the success of treatment of these sites seems to be associated with the stability of the peri-implant bone crests and the greater thickness of soft tissue around the joint implant/abutment (Figure 1.10) [30–32].

Evolution of imaging diagnosis methods

CBCT has greatly improved the diagnosis and, consequently, the treatment plan in contemporary dentistry. Currently, high-resolution scanners acquire far superior images over the three spatial planes with lower exposure doses. This apparatus can provide high-definition images from teeth, edentulous areas, soft-tissue thickness of donor/recipient sites, and other important facial structures. It is import to consider that modern implantology/implant dentistry no longer support surgical procedures (i.e. implant placement and GBR) being performed without the assistance of proper high-quality diagnostic images (Figure 1.11) [33, 34].

Root-treated teeth: Decision making for implant placement

Controversy still surrounds the need for replacing teeth with questionable prognosis by implants. Meticulous clinical and radiographic evaluation (e.g. visual inspection assisted by optical microscope, periodontal probing, exploratory surgical procedures, use of CBCT imaging) is important before condemning any tooth. The clinical decision making process can be influenced by several factors, such as tooth root fragility (by considering its role in future restorations), occlusal pattern, masticatory forces, and the patient's age and ability to chew. A frequent scenario found in clinical practice regards vertical root fractures (VRF), a condition of difficult diagnosis, especially in cases where the root fragments are not separated. At this stage, conventional and/or digital periapical radiographs are unlikely to be able to show the presence of VRF, because of the limitation of two-dimensional imaging. To be radiographically visible, the X-ray beam should be positioned in the same focal plane as the fracture, because small changes in the horizontal angle may not allow the detection of the line of the fracture. The vertical fracture may show clinical signs (e.g. presence of fistula or swelling of the gingival tissues at the level of root fracture) and symptoms such as discomfort or pain during chewing or after a percussion test (Figure 1.12 and 1.13) [33].

Evidence-based decision making in implant dentistry: "What is the importance of founding a treatment plan on evidence-based clinical approaches?"

While it is true that there are many treatment modalities discussed and promoted in dentistry literature, the validity of dental implants for modern practice is supported by evidence-based clinical results.

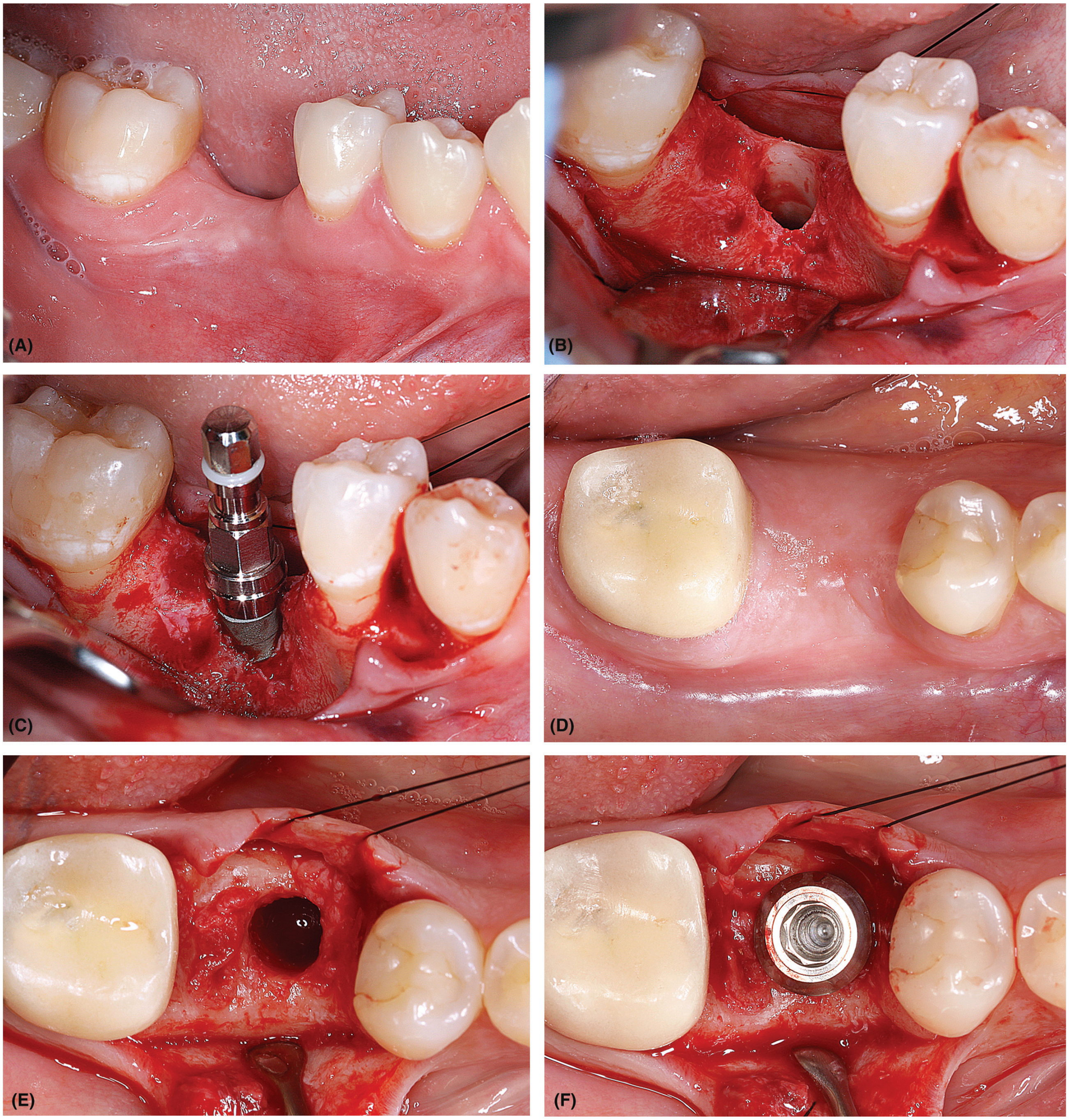

Figure 1.3 Two implant sites in tooth #30 with different characteristics. (A) Tooth #30 is missing and a bone defect is present at the alveolar ridge. (B) Implant site with thin bone walls. (C) Implant in position (4.1 mm diameter). A dehiscence-type defect is present at the buccal aspect. (D) Tooth #30 is missing and the alveolar ridge contour is well preserved. (E) Implant site with thick bone walls (more than 2 mm of width). (F) A wide-diameter implant (4.8 mm diameter) in position.

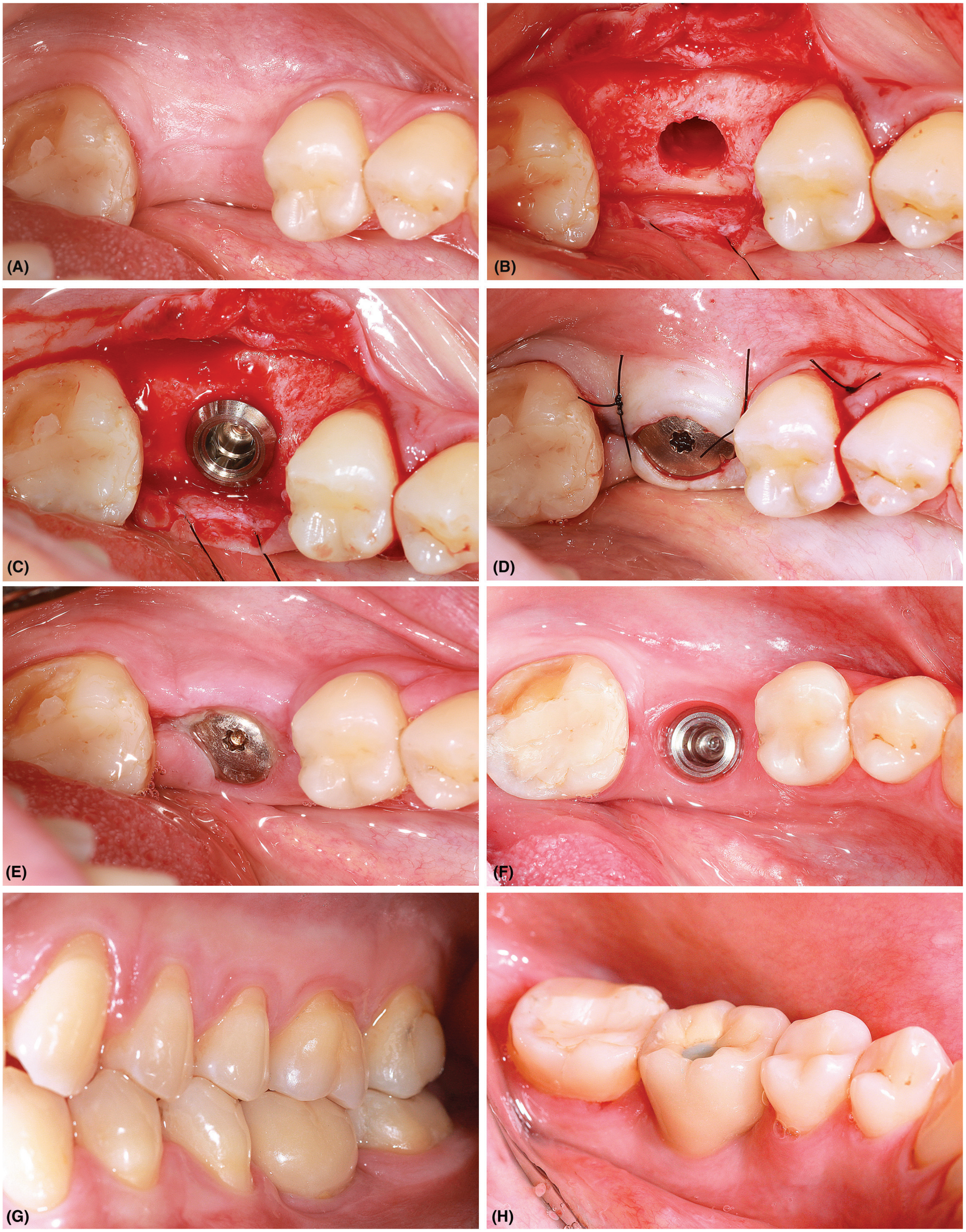

Figure 1.4 (A) Tooth #19 is missing. (B) Implant bed. (C) A wide-diameter implant (4.8 mm diameter) was placed. (D) Wound closure. Non-submerged healing. (E) Aspect one week after operation. (F) Aspect eight weeks after operation. (G, H) Porcelain-fused-to-metal screw-retained restoration in occlusion and lingual views.

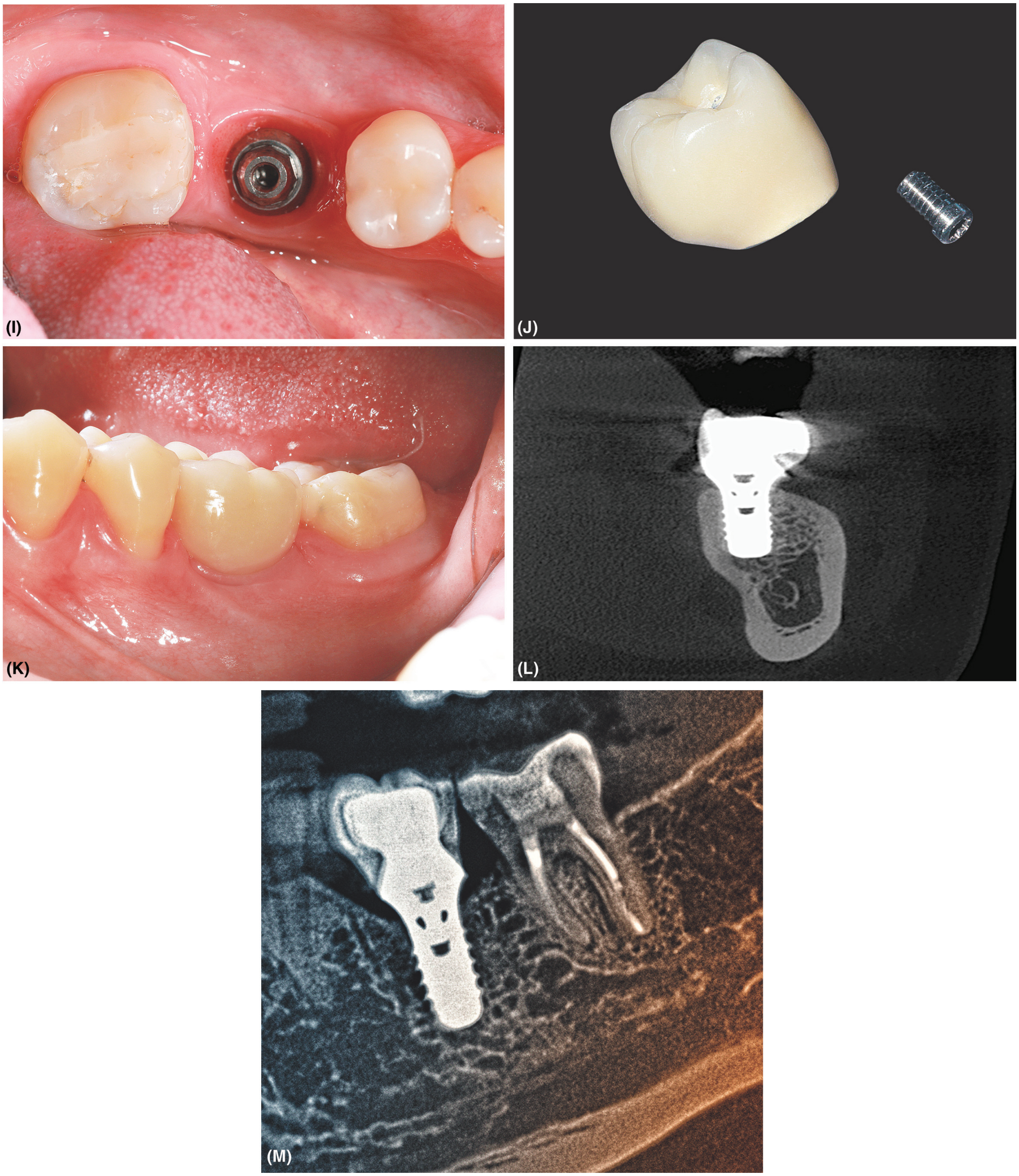

Figure 1.4 (I) Eight-year follow-up shows healthy peri-implant soft tissue. (J) Screw-retained restoration. (K) Restoration replaced in position. (L, M) Eight-year follow-up cone beam computerized tomography (CBCT) image shows excellent bone levels around the implant.

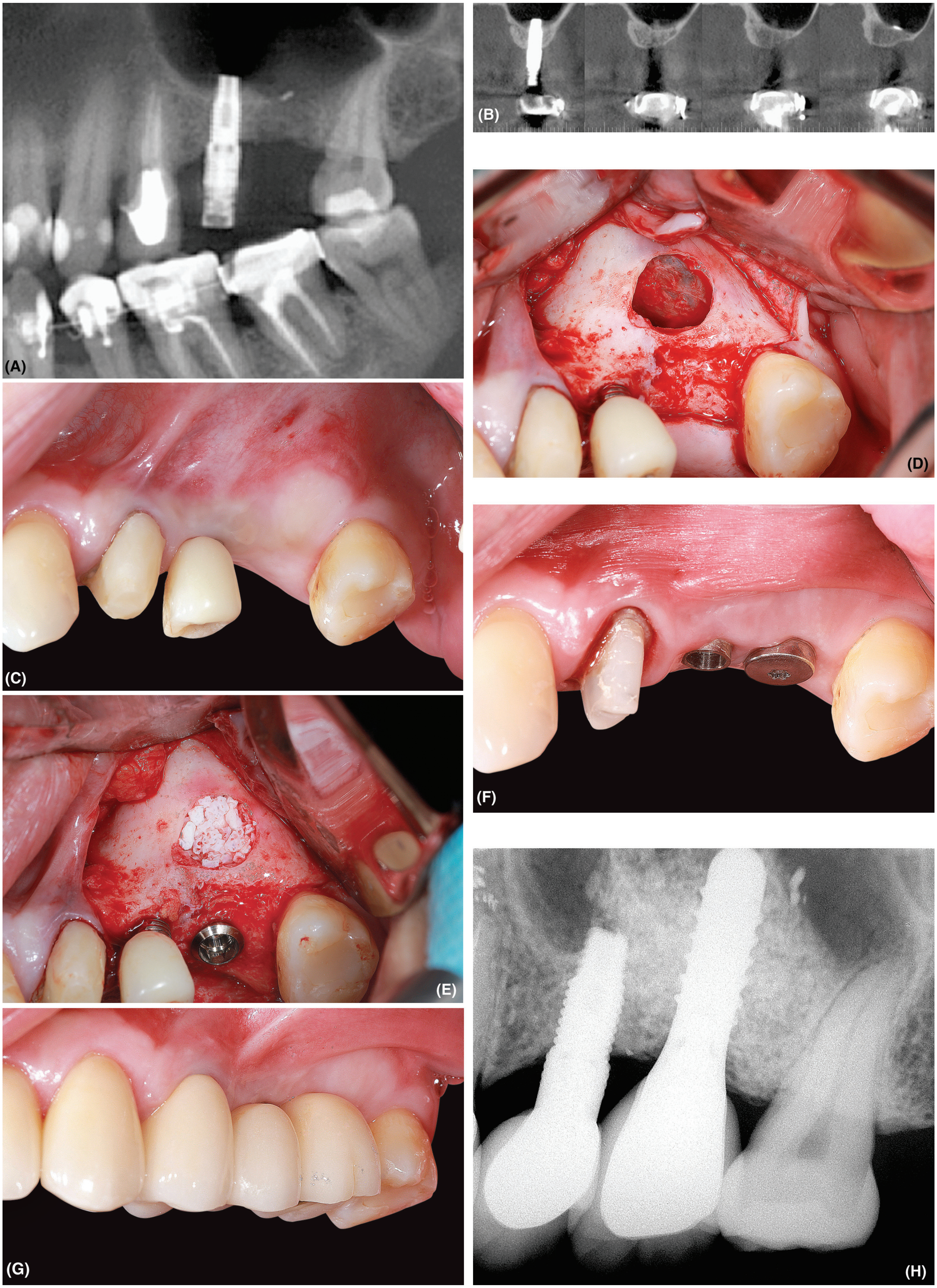

Figure 1.5 (A, B) Tooth #14 is missing. CBCT shows limited bone height because of the sinus floor presence. (C) Initial clinical aspect. (D) Sinus grafting using the lateral window technique (sinus lifting procedure). (E) Bone substitute filling the sinus followed by implant placement (simultaneous approach). (F) Healing aspect six months after procedure. (G) Buccal view of the final restorations. (H) One-year follow-up periapical radiograph.

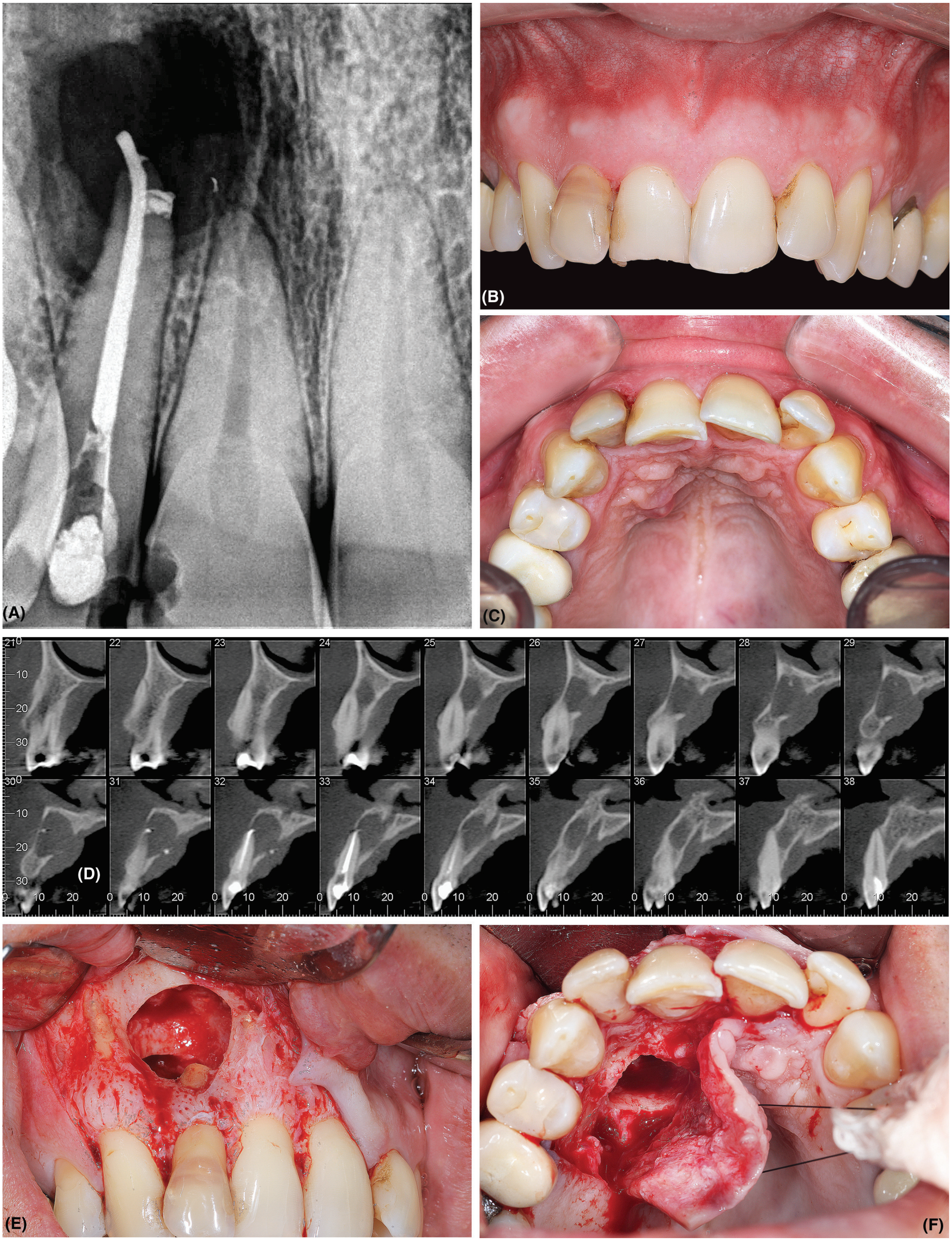

Figure 1.6 (A–D) Extended periapical lesion associated with teeth #7 and 8 compromising direct implant placement. (E, F) Surgical treatment – buccal and palatal views – after apicoectomy of tooth #7 and extensive bone defect cleaning.

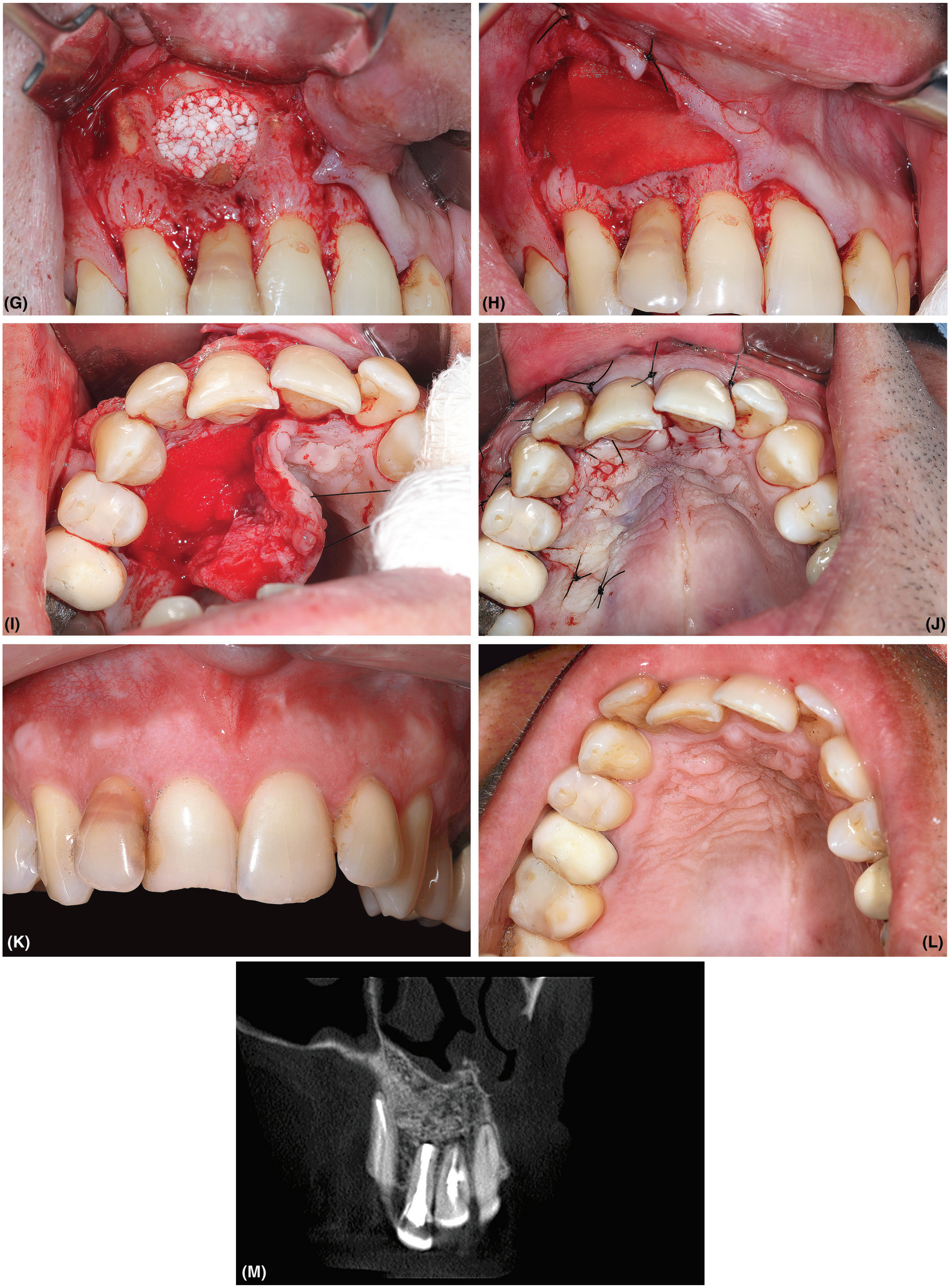

Figure 1.6 (G) Deproteinized bovine bone matrix (DBBM (Bio-Oss® collagen)) filling the transmaxillary defect. (H, I) Collagen membrane covering the defect – buccal and palatal aspects. (J) Wound closure with interrupted sutures. (K, L) Two-year clinical follow-up after surgery – buccal and palatal views. (M) CBCT control two years after surgery shows no residual bone defect.

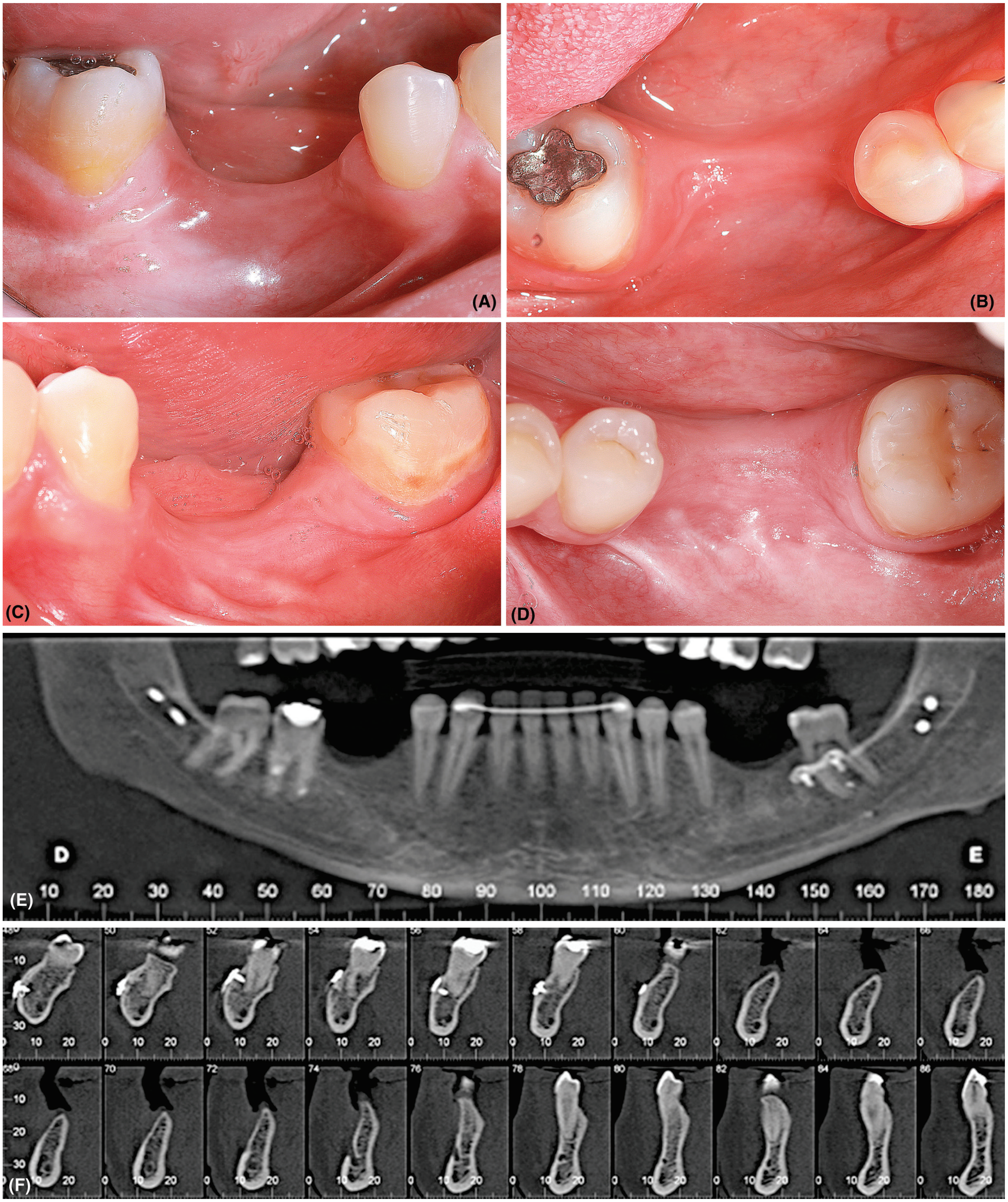

Figure 1.7 (A–D) Adult female with several missing lower posterior teeth. Localized alveolar ridge defects are present both sides. (E, F) CBCT images.

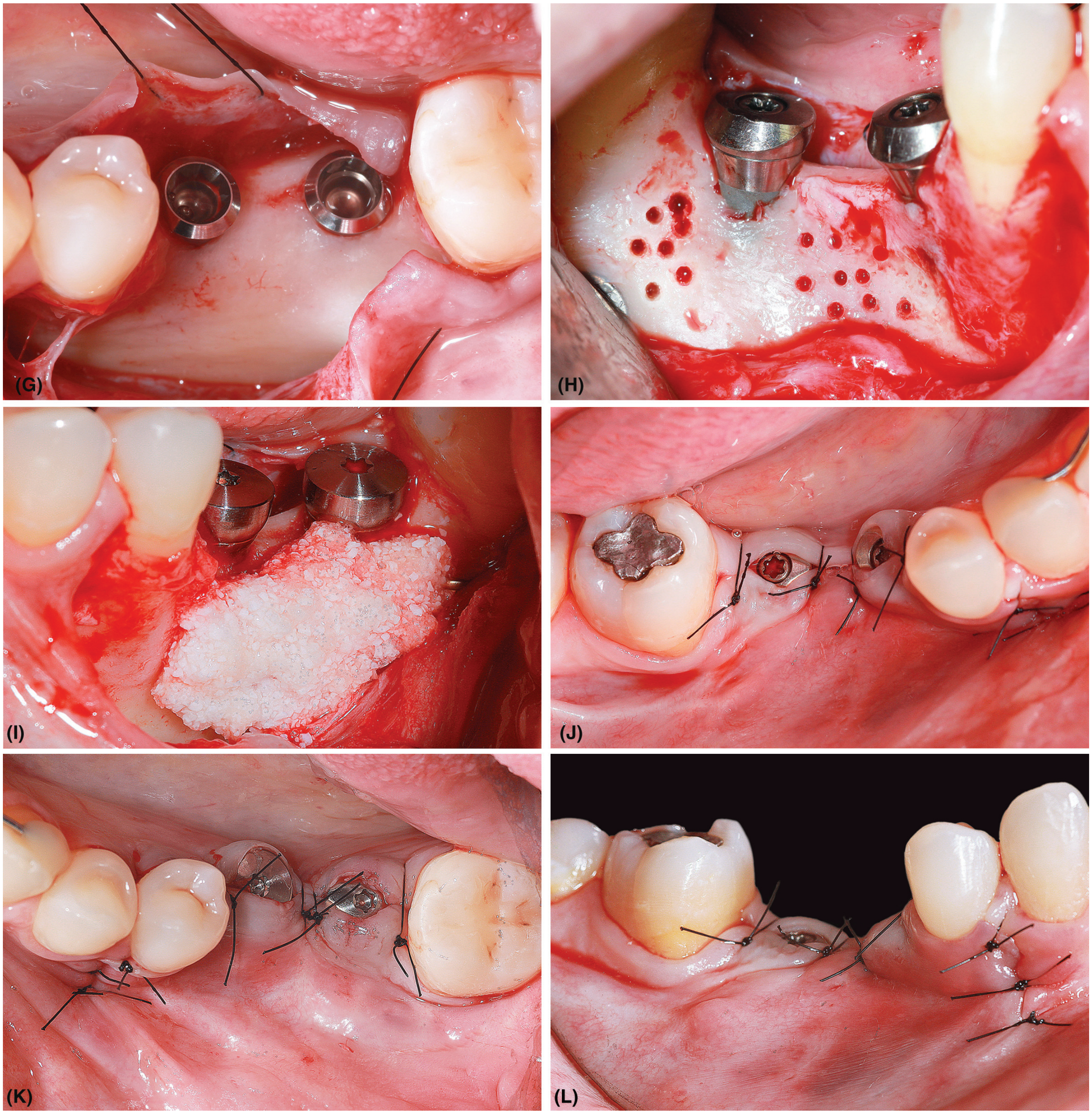

Figure 1.7 (G) Implant placement – left side. (H) Buccal cortical perforation for blood supply at the defect site – right side (I) Bone substitute DBBM (Bio-Oss collagen) filling the bone defect area – right side (J–L) Wound closure bilaterally (nylon 5-0).

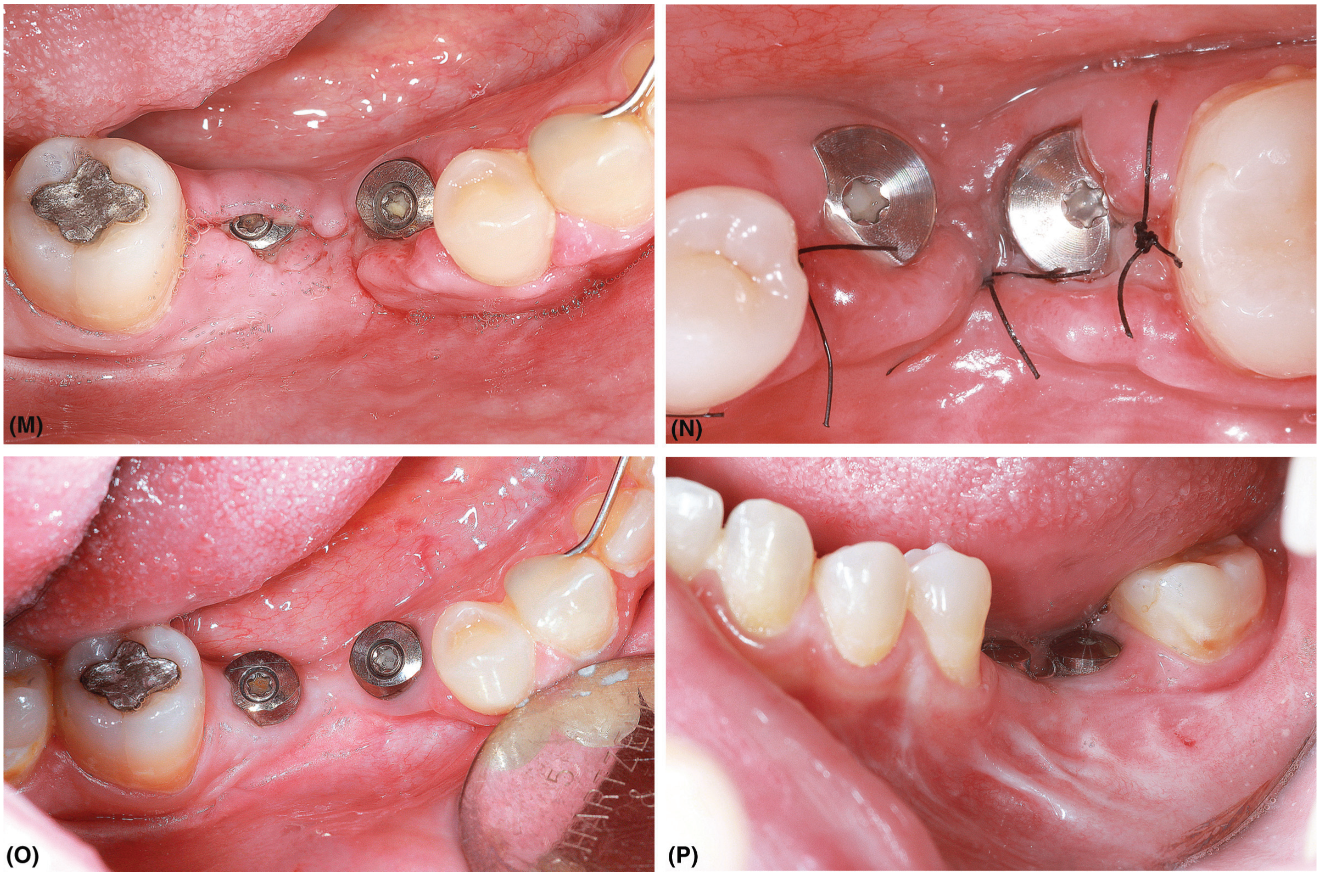

Figure 1.7 (M, N) Healing aspect one week after operation. (O, P) Healing aspect 16 weeks after operation.

This assumption implies that health promotion must be derived from the best source of information available in order "to translate the outcomes of efficacy research into clinical effectiveness" [18], in other words to adapt the findings of university research to clinical practice.

To achieve this objective, outcomes gathered from systematic reviews (SRs) are used throughout this book to recognize and provide evidence-based solutions to and options for the most common clinical scenarios found in clinical practice. As an instrument used by researchers and clinicians to establish the decision making process, an SR is considered the best type of study to appraise the cost and impact of treatment approaches. Conversely, many clinicians have not judiciously managed the information (i.e. its key findings) of an SR. Thus, it is important to provide them with a way of navigating understanding and those research findings that can (or cannot) be applied to clinical practice

Given the importance of applying research recommendations to practice, this book uses SR summaries and evidence-based ratings when discussing the strength and reliability of various implant procedures, and supports this with evidence from the literature. The aim of this is to assign various treatment modalities discussed in this book a level of validity (i.e. high, moderate, or low), based on the criteria defined by the US Preventive Services Task Force (USPSTF) and adapted by the American Dental Association (Table 1.1 and 1.2) [35]. Consequently, "Clinical Recommendation Summaries" summarizing "the strengths and weaknesses of the evidence in terms of benefits and harms" have been generated [35]. These aim to give accurate and explicit rationale for clinical practice, as well as the reasons for the recommendations. As a result, once the balance between benefits and downsides is decided, the following *Strength and direction of recommendation regarding the need for therapy and procedures* are applied [35]:

- Strongly in favor: Evidence strongly supports the intervention/procedure.
- In favor: Evidence supports the intervention/procedure.
- Weakly in favor: Evidence suggests implementing the intervention/procedure after alternatives have been considered.
- Expert opinion for: Evidence is lacking; the level of certainty is low. Expert opinion guides this recommendation.
- Expert opinion against: Evidence is lacking; the level of certainty is low. Expert opinion suggests not implementing the intervention/procedure.
- Against: Evidence suggests not implementing the intervention/procedure or discontinuing ineffective procedures.

These recommendations aim to identify the level of evidence for –and, at the same time, offer the "scientific truth" behind – the various procedures and interventions discussed in the current dental literature on dental implants. It is important to point out here that these should not be understood as merely a "clinical guide" but as the preferred modes of treatment that could be implemented in clinical practice.

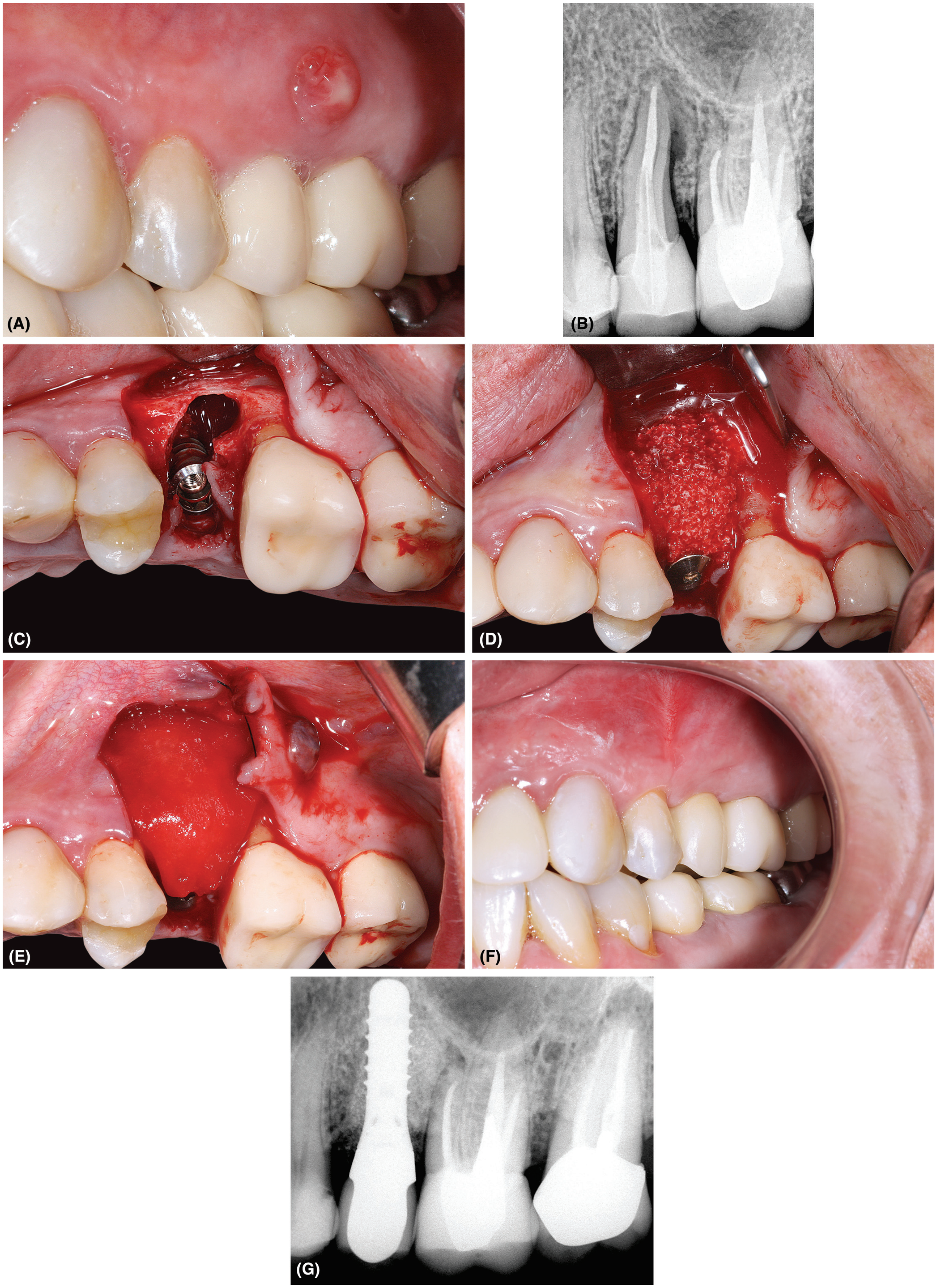

Figure 1.8 (A) Presence of infection with fistula associated with tooth #13. (B) Intraoral radiographic exam shows periapical lesion around tooth #13. (C) After remission of the acute phase, tooth #13 was extracted followed by an immediate implant placement. (D) The bone defect was filled with biphasic calcium phosphate (Straumann® BoneCeramic™). (E) Absorbable collagen membrane covering the grafted site. (F) Restorative treatment consisted of a screw-retained porcelain-fused-to-metal restoration. Healthy soft tissue with no signs of infection. (G) Three-year follow-up intraoral radiograph.

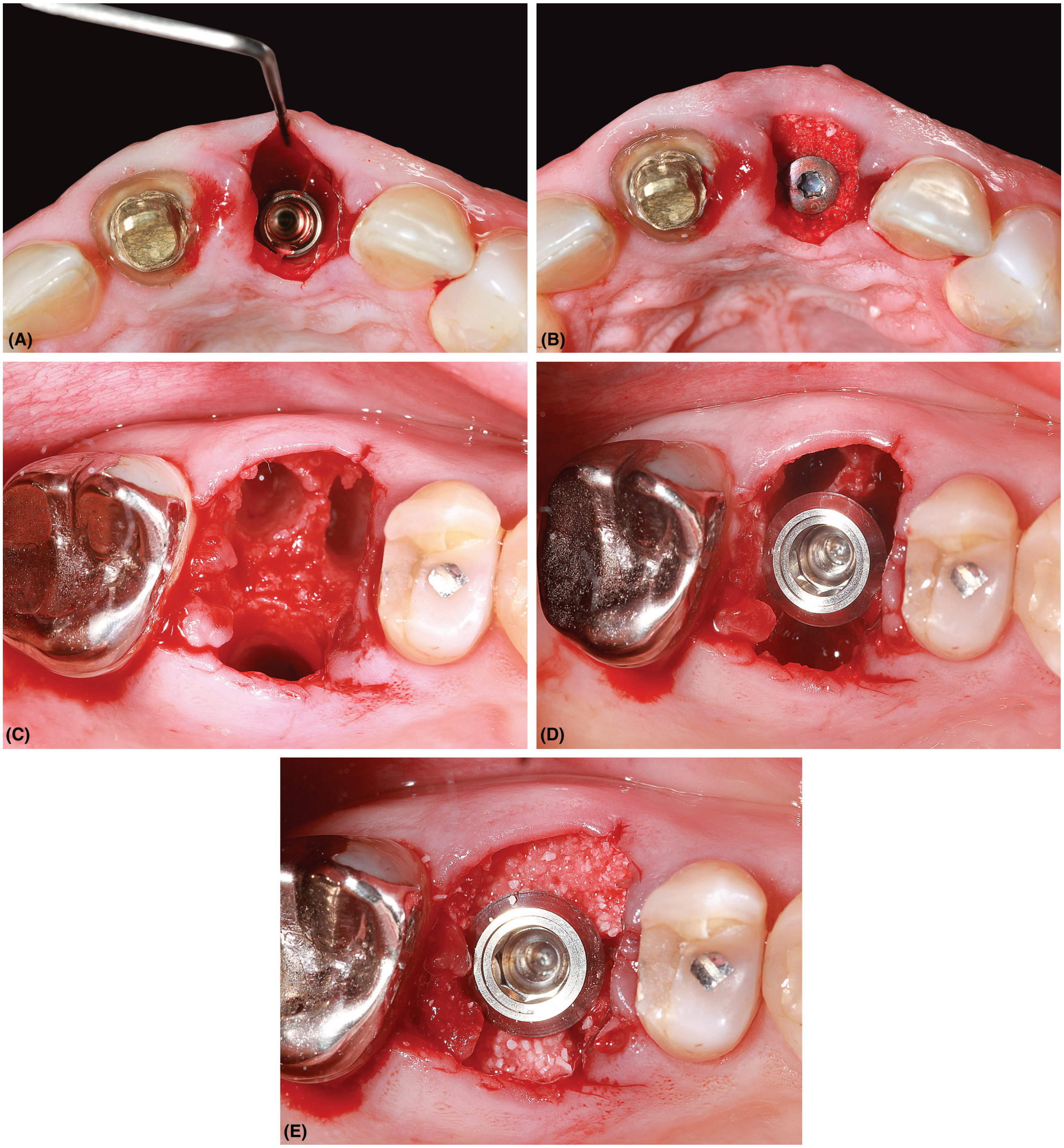

Figure 1.9 (A) Immediate implant placement at site #9. There is a bone defect at the buccal wall. (B) Defect filling with DBBM (Bio-Oss collagen). (C) Post-extraction alveolar ridge at site # 3. (D) Immediate implant in position (Straumann SLActive Wide Neck Tissue Level™). (E) Gap filling with DBBM (Bio-Oss collagen).

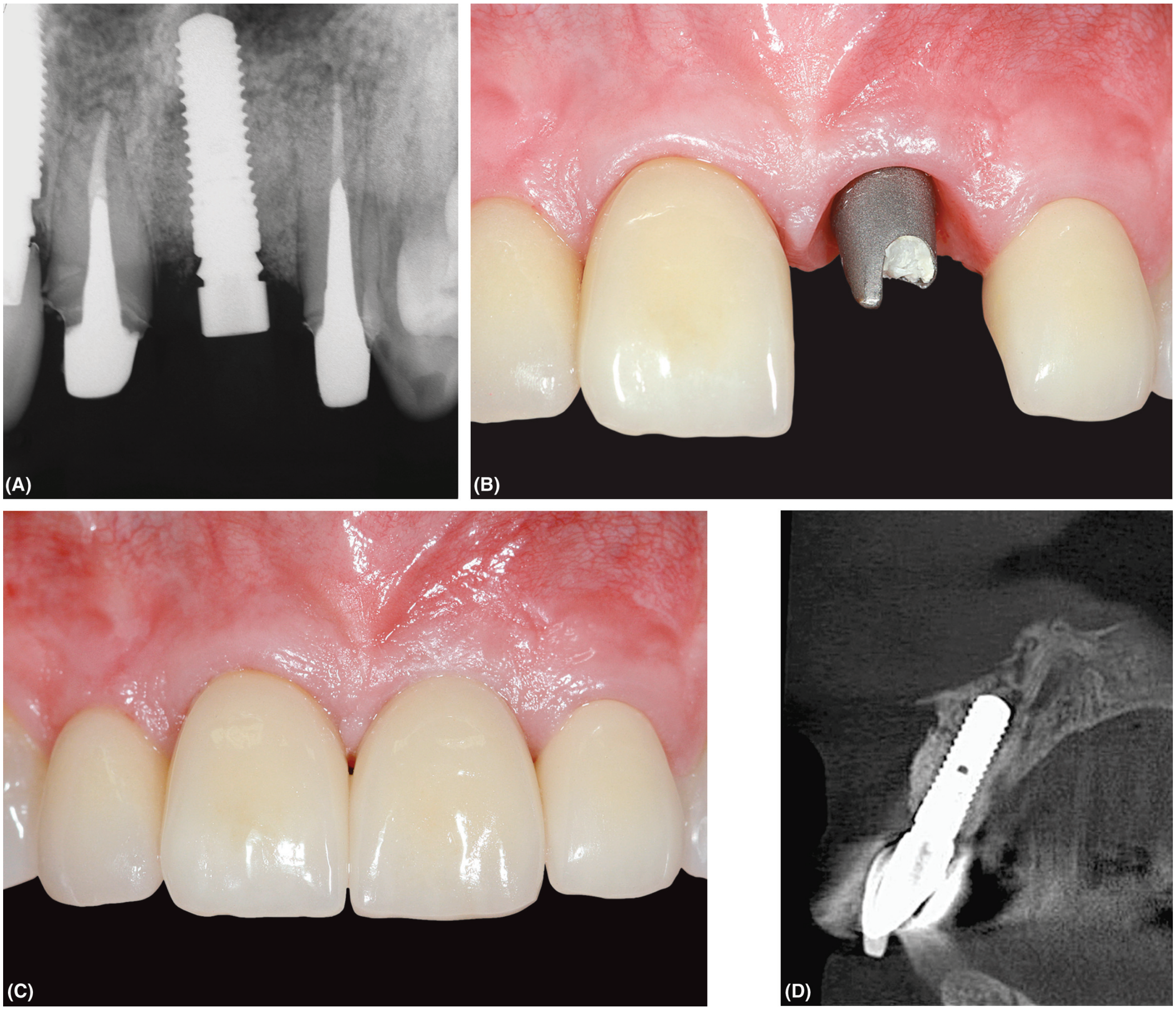

Figure 1.10 (A) Implant placed in site tooth #9 – periapical radiograph. (B) Customized cementable abutment in position. Healthy soft tissue two years post implantation. (C) e.max® cemented restoration. (D) CBCT shows thick bone walls after two years of loading. Bone substitute (DBBM (Bio-Oss collagen)) is clearly detectable at the buccal wall (arrow).

Figure 1.11 CBCT. (A) Parasagittal section. (B) Transaxial section.

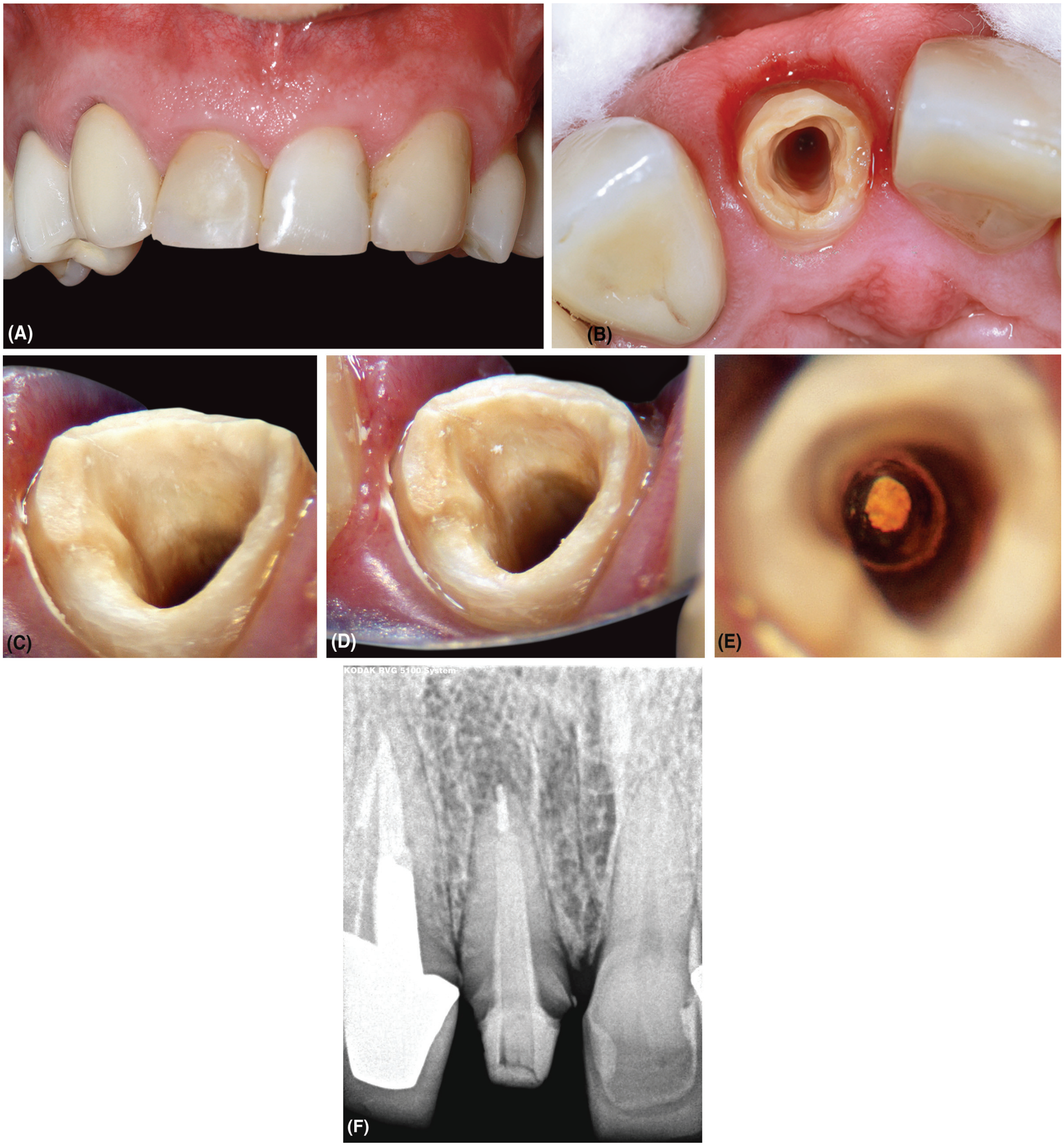

Figure 1.12 (A) Clinical restorative evaluation of tooth #8. (B) Root evaluation. (C–E) Magnification of root canal examination. (F) After careful evaluation tooth #8 it was decided not to remove the tooth and a fiberglass post was cemented inside the root canal – periapical radiograph.

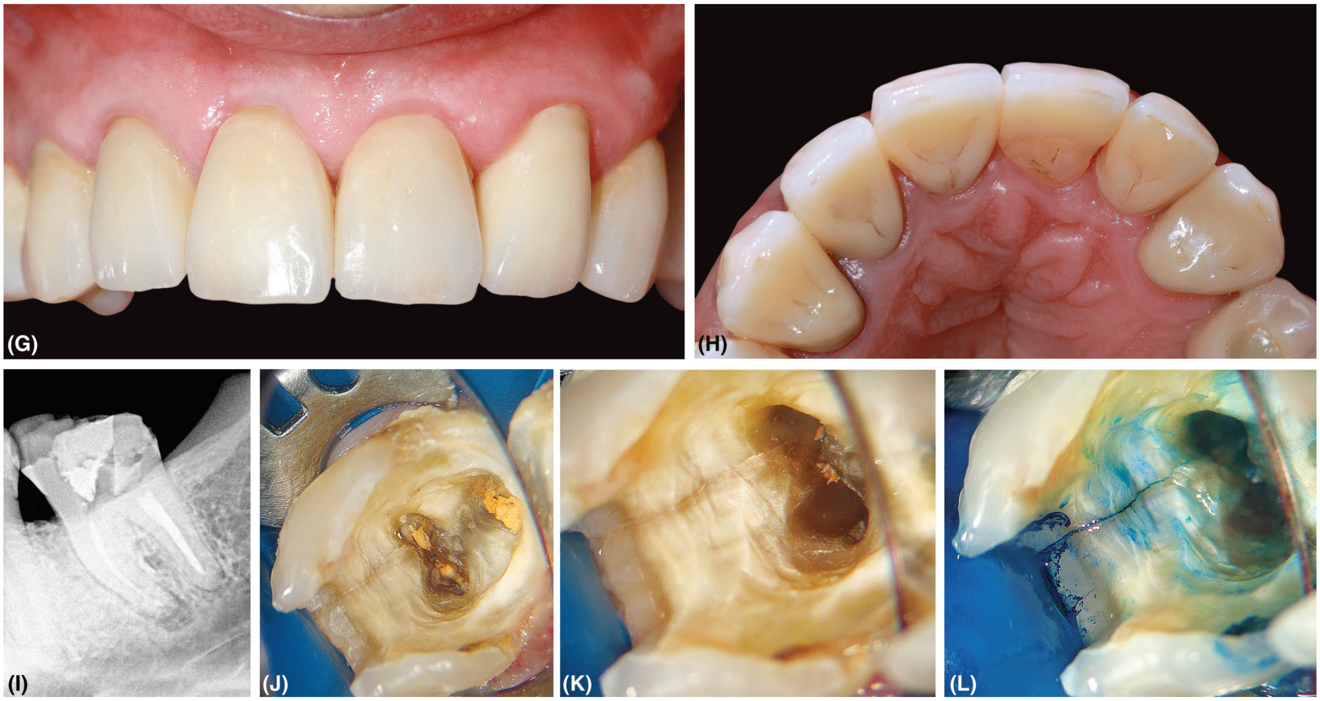

Figure 1.12 (G, H) Restorative treatment with e.max crowns and veneers – buccal and palatal views. (I) Initial X-ray shows endodontic lesion on tooth #18. (J, K) Clinical examination under microscope detected a fracture line at the mesiolingual canal. (L) Toluidine-blue staining the fracture line. *Source*: Courtesy of Dr. Marina Tosta – Endodontist.

Table 1.1 Level of certainty in the body of evidence included in the review

Level of certainty	Description
High	The body of evidence usually includes consistent results from well-designed, well-conducted studies in representative populations. This conclusion is unlikely to be strongly affected by the results of future studies. *This statement is strongly established by the best available evidence.*
Moderate	As more information becomes available, the magnitude or direction of the observed effect could change, and this change could be large enough to alter the conclusion. *This statement is based on preliminary determination from the current best available evidence, but confidence in the estimate is constrained by one or more factors, such as:* • the limited number or size of studies • plausible bias that raises some doubt about the results • inconsistency of findings across individual studies • imprecision in the summary estimate • limited applicability owing to the populations of interest • evidence of publication bias • lack of coherence in the chain of evidence.
Low	More information could allow a reliable estimation of effects on health outcomes. *The available evidence is insufficient to support the statement or the statement is based on extrapolation from the best available evidence. Evidence is insufficient or the reliability of estimated effects is limited by factors such as:* • the limited number or size of studies • plausible bias that seriously weakens confidence in the results • inconsistency of findings across individual studies • imprecision in the summary estimate • gaps in the chain of evidence • findings not applicable to the populations of interest • evidence of publication bias • a lack of information on important health outcomes.

Source: Adapted from [35].

Table 1.2 Balancing potential benefit and harm

Level of certainty	Net benefit rating: *Benefits outweigh potential harm*	*Benefits balanced with potential harm*	*No benefit or potential harm outweigh potential harm*
High	Strong	In favor	Against
Moderate	In favor	Weak	Against
Low	*Expert opinion for or against*		

Adapted from [35].

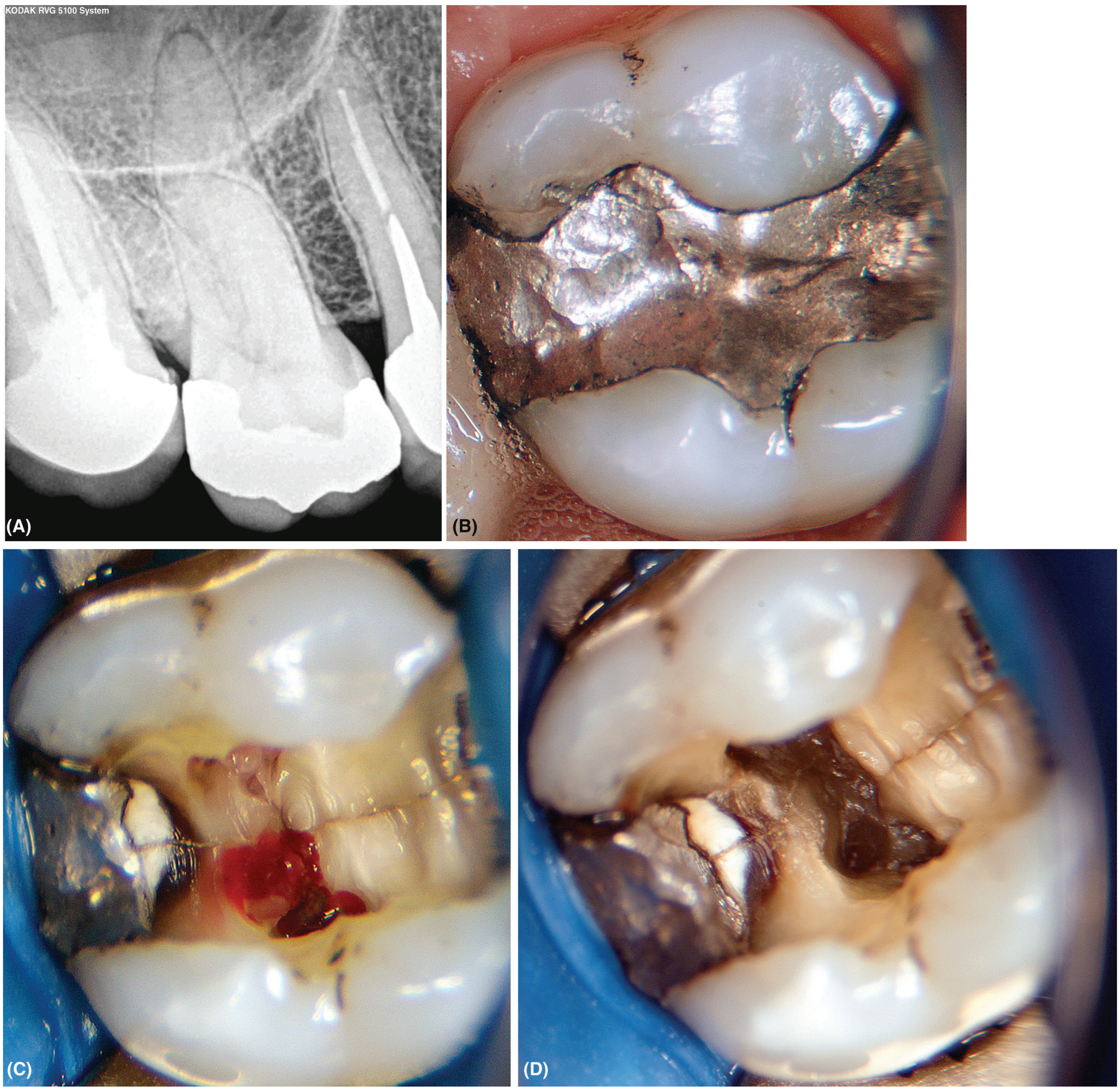

Figure 1.13 (A) Initial periapical radiograph of tooth #3. (B) Clinical evaluation of tooth #3. Patient reported pain, and temperature variation clinical tests showed compromised vitality. (C) After removal of an old amalgam filling, microscope check showed a fracture line. (D) After root canal cleaning, the diagnosis was further confirmed and tooth #3 was referred for extraction. *Source:* Courtesy of Dr. Marina Tosta – Endodontist.

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CHAPTER 2

Treatment Planning for Bone Defects in the Alveolar Ridge

The dilemma of treating alveolar ridge bone defects

The presence of bone defects in the alveolar ridge is a constant challenge to treatment approaches involving implant-supported restorations. These are normally originated from the physiological remodeling process (mainly because of buccal bone plate resorption) occurring after a tooth extraction [1]. However, the experience accumulated over more than 20 years in the study and treatment of bone defects located in the alveolar ridge affords clinicians a greater degree of predictability when indicating bone reconstructive procedures, prior to or simultaneously with the installation of osseointegrated implants [2–4]. The clinical impact on the treatment of bone defects in edentulous sites is of such an importance that, according to Schroder, "apart from the discovery of osseointegration phenomenon for over 20 years, the concept of guided bone regeneration (GBR) is the most important progress in Implantology . . . in the near past, patients with localized bone defects often had to be contraindicated for implant therapy" [5].

Various surgical techniques using a variety of bone-filling materials have been described over the past two decades, but the determining factor in the outcome of reconstructive surgery remains the morphology of the existing bone defect. Knowledge about the regenerative potential of bone tissue of the recipient bed is a key issue. It can define, for example, the type of bone-filling materials to be used (i.e. autogenous bone graft or xenogeneic or alloplastic biomaterials). Many clinical failures in reconstructive bone surgery are certainly related to the non-observance of the basic principles of wound healing (for details see [6]). Knowledge on bone repair mechanisms in defects located in cortical and cancellous bone, the phases of bone neoformation around different kinds of bone-filling materials, and their different time intervals is an essential prerequisite for the clinical success of implant therapy. This chapter discusses the most critical elements involved in the treatment of bone defects located in the alveolar ridge, and presents clinical alternatives to implant treatment according to different clinical scenarios.

Goals of reconstructive procedures

The primary objectives of the procedures used to reconstruct the alveolar ridge encompass the regeneration of the lost bone tissue, the achievement of function and esthetics in the long term, and to reduce the risk of complications. It is expected that treatment plans including GBR could be restricted as much as possible to fewer surgical procedures, and patients could experience low (or even no) postsurgical morbidity and reduced periods of bone healing.

Implant placement simultaneously with or prior to GBR

Currently, the simultaneous approaches involving implant placement and GBR have been used in most cases, leaving the use of GBR alone (i.e. a staged approach) for the treatment of more complex defects (sites involving a large amount of resorption that could not allow adequate implant fixation) [3–5]. It should be noted that staged approaches may be planned even for "non-resorbed" ridges, owing to the existence of conditions that make it impossible to implant shortly after tooth extraction (i.e. growing patients).

Condition of the alveolar ridge

The alveolar ridge condition can be set in three distinct phases: (1) post-extraction fresh socket, (2) early or recent sockets, and (3) healed ridges. Fresh and recent sockets are more likely to benefit from GBR because of the well-known advantage of the ongoing healing/remodeling process that occurs in the alveolar ridge following tooth extraction. However, healed ridges can benefit from GBR as well.

Morphology and dimensions of the bone defect

Some classification systems [7–9] have been used to determine the types of alveolar ridge defects, predominantly according to the orientation of the defect: horizontal (Class I [7] Type B [8]), vertical (Class II/Type A) or mixed/combined (Class III/Type C) [7, 8]. As important as the type of defect is, the number of bony walls available in a bone defect is also critical, given the fact that angiogenesis within the defect area is directly related to close contact with preexisting native bone walls [6]. In contrast, the larger the defect size, the greater the distance between the native bone walls, the better should be the stabilization [10, 11] and the osteoinductive/osteoconductive potential of bone-substitute/filling material within the defect.

Decision Making in Dental Implantology: Atlas of Surgical and Restorative Approaches, First Edition. Mauro Tosta, Gastão Soares de Moura Filho, and Leandro Chambrone.

Biological mechanisms of bone grafts

A bone graft or substitute can be classified according to its biological mechanisms [12]:

- Osteoconduction: The capacity of a graft to allow bone growth on its surface or down into its pores (i.e. to act as scaffolding for the ingrowth of neovasculatue and bone formation originated from the defect bone's walls [13, 14]). Most bone-filling materials (e.g. autografts, allografts, xenografts an alloplastic substitutes) have this characteristic.
- Osteoinduction: This mechanism is associated with the ability of a graft to induce bone formation through the stimulation of primitive, undifferentiated, and pluripotent cells from the connective tissue (i.e. stem cells) to differentiate into mature bone cells (or the ability of generating a bone-forming cell lineage) [15, 16]. It occurs in the presence of growth factors released by autologous bone or when recombinant proteins (i.e. bone morphogenic proteins) are used in association with a bone substitute or a carrier to fill a bone defect. Osteoinduction is an inherent property of autologous bone grafts.
- Osteogenesis: The capability of a graft to induce direct growth or repair of bone via stem cells or osteoprogenitor cells contained in the graft. These cells, found exclusively in fresh autologous grafts, develop into living osteoblasts.
- Osteopromotion: The physical sealing of a bone defect by a mechanical barrier, creating a protected space into which only neighboring bone cells may migrate (i.e. "a soft-tissue exclusion principle using a membrane for bone healing and bone neogenesis" [17]). This concept aims to prevent the formation of soft tissues caused by the rapid proliferation of non-osteogenic cells in the affected area.

Along with these properties, bone repair is influenced by the osteogenic cells derived from the bone adjacent to the defect, the presence of adequate vascularization of the defect area, the achievement of a mechanically stable wound, and adequate space maintenance for bone repair in order to avoid a collapse of the defect site.

Types of bone-filling materials

The biomaterials used as bone substitutes in bone augmentation procedures are classified by the American Academy of Periodontology into four categories: autologous, allogeneic, xenogeneic, and alloplastic. Autologous bone grafts, or autografts, are tissues "transferred from one position to another within the same individual," whereas allogeneic grafts (allografts) are those "between genetically dissimilar members of the same species" (e.g. fresh frozen bone, freeze-dried bone allograft (FDBA) and demineralized freeze-dried bone allograft (DFDBA)) [18]. The xenogeneic grafts (xenografts) are those "taken from a donor of another species" [18], and these are subdivided into: animal bone matrix derivative (bovine or porcine), calcified coral, and calcified algae derivatives. The last group, the alloplastic materials (or synthetic), is formed by synthetic derivatives (i.e. "a synthetic graft or inert foreign body implanted into tissue" [18]), such as calcium phosphates (including the biphasic calcium phosphate (BCP)), polymers, and bioactive glasses.

Their main characteristics are:

- *Autogenous Bone Graft*: The autogenous bone constitutes the best bone graft material because of its superior unmatched mechanical and biological properties over the whole of the available bone substitute. Its osteoinductive potential, excellent properties of osteoconduction and rapid remodeling, and potential of osteogenesis yield a newly formed bone of better quality. Moreover, the availability of "bone stimulating molecules" stored in the autografts can be increased by fractioning the graft into particles – an approach that increases its surface area. However, its resistance to reabsorption is also reduced as the size of the autogenous particles decrease. The major disadvantages of using autogenous bone are the fast and unpredictable resorption, donor site morbidity, and limited intraoral availability. The need for a donor area increases the complexity and morbidity of the surgical procedure, and the postoperative discomfort. In addition, various postoperative adverse effects/complications have been described after autologous bone removal from intraoral donor sites, especially at the mentonian area (one of the most used sites), as well as at the ramus region (i.e. wound dehiscence, prolonged postoperative pain, hematoma, infection, mentonian ptosis, cutaneous sensory changes, and altered pulp sensitivity). Owing to the superior surgical trauma upon removal of autogenous bone graft from intraoral and extraoral donor sites, patients are inclined to prefer procedures involving only one surgical site when such potential postoperative complications/adverse effects are considered (a fact that also motivated the search for other bone substitutes) (Figure 2.1 and 2.2) [18].
- *Allografts*: There is evidence that the allogeneic bone-filling materials also contain osteoinductive molecules. However, it is questionable whether the concentration and activity of these molecules have clinical significance. Moreover, allografts present the same disadvantages of autografts, except for the availability of the material (Figure 2.3 and 2.4) [18].
- *Xenografts*: Xenografts have been more frequently used in the format of deproteinized bovine bone mineral (DBBM). The production process of DBBM preserves the original geometry of cancellous bone and its surface's natural characteristics, while the organic material is removed to avoid disease transmission risks. Their osteoconductive properties are well documented in the literature [19], and these grafts are usually enclosed by the new osseous matrix formed in the defect (Figure 2.5, 2.6, 2.7, and 2.8) [18].
- *Alloplastic or Synthetic*: The alloplastic materials are mostly formed of different formulations of calcium phosphate in the format of hydroxyapatite (HA), biphasic calcium phosphate (BCP), or beta-tricalcium phosphate (β-TCP). There have been major advances in the biological performance of these materials, owing to a better understanding of the optimal surface characteristics of particles for osteogenic cells and the improvements of manufacturing techniques. However, to date, these materials have not been able to mimic the surface characteristics of natural bone matrix, but the available alloplastic materials are already valuable alternatives for those patients and clinicians reluctant to use bone substitutes of natural origin (Figure 2.9 and 2.10).

In general terms, an ideal bone substitute should be biocompatible and present good osteoconductive properties in order to be gradually covered by newly formed bone. The main disadvantages of alternative materials (allogeneic, xenogeneic, or synthetic substitutes), when compared to autografts, are the small amount of newly formed bone tissue, the large amount of fibrous tissue existing between their residual particles, and the need for a longer period for bone healing. On the other hand, their main advantages are ease of use (better for less experienced clinicians), reduced chair time, reduced surgical trauma (as it involves only one

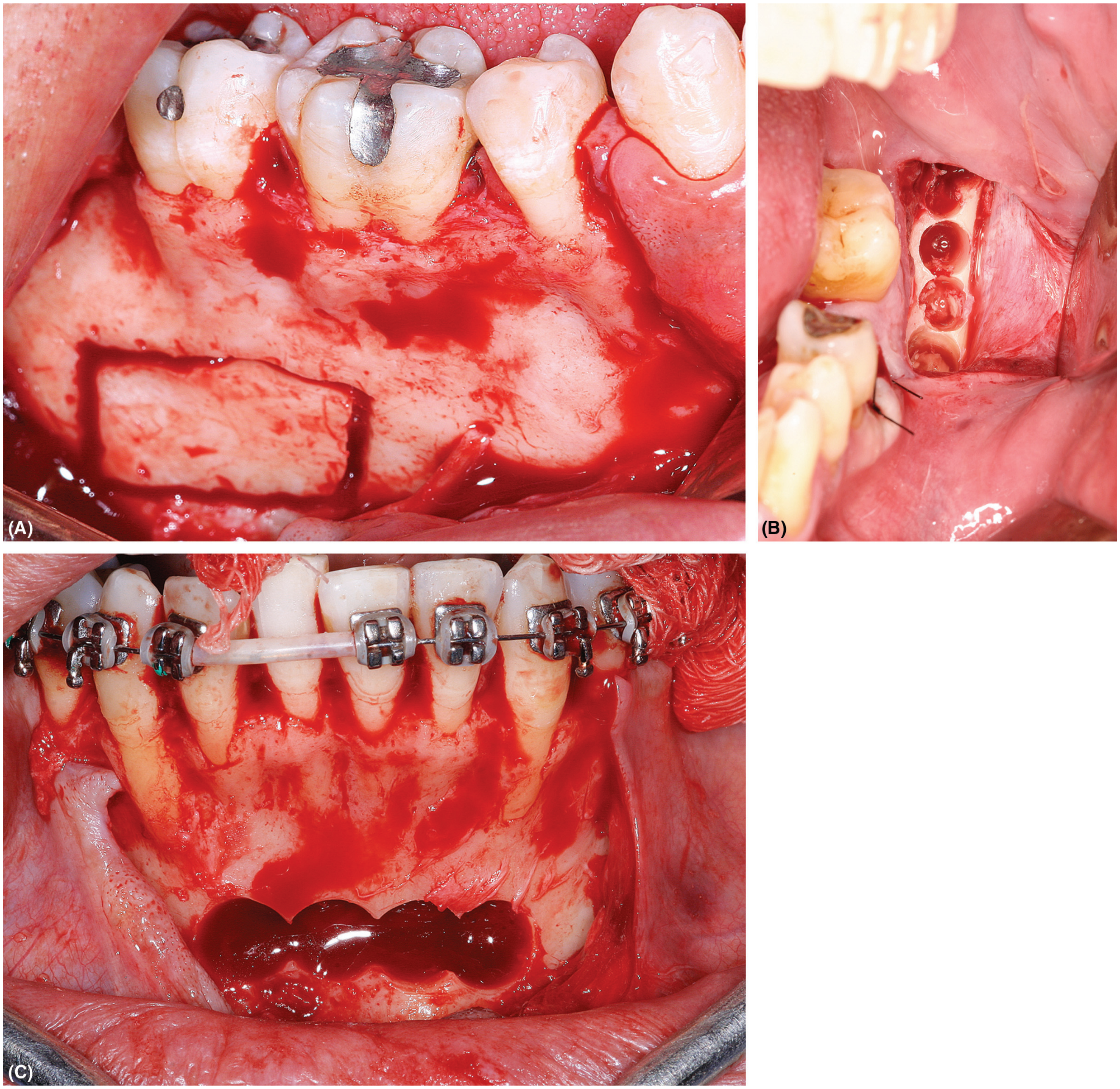

Figure 2.1 (A) Donor site – mandibular body. (B) Donor site – mandibular branch. (C) Donor site – mentonian area.

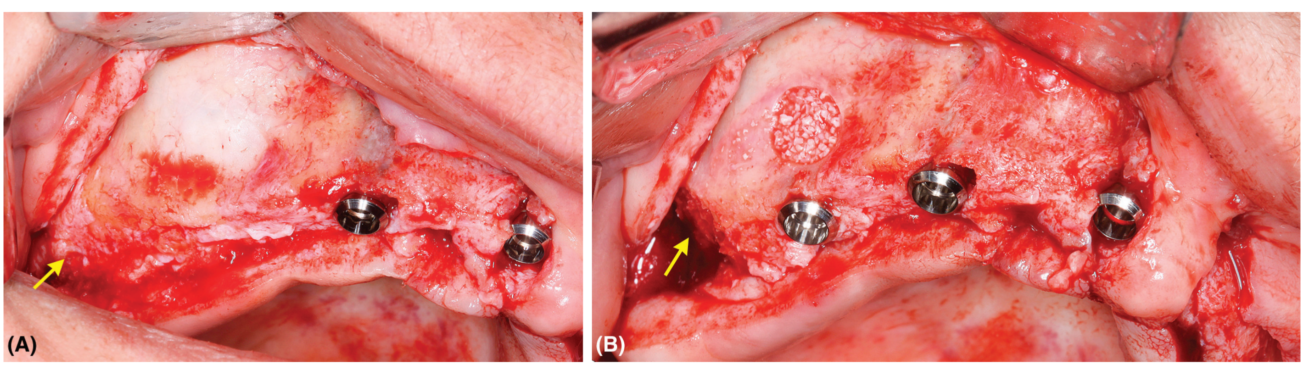

Figure 2.2 Donor site – tuberosity prior to (A) and after (B) its use as grafting material for sinus floor elevation associated with simultaneous implant placement.

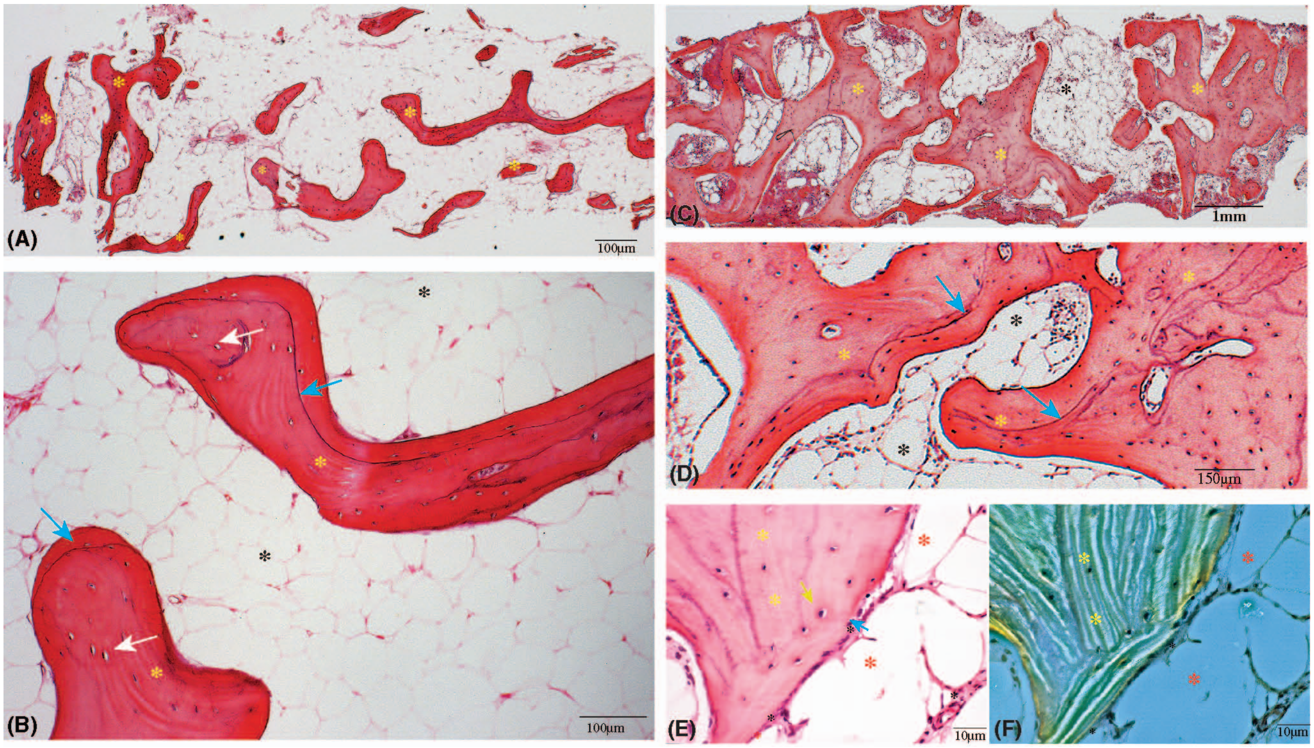

Figure 2.3 (A) Histological section of a grafted maxillary sinus with particulate autogenous bone. Decalcified tissue – HE (hematoxylin-eosin) staining. Panoramic view of the sample. Yellow asterisks represent mineralized bone matrix. Black asterisks represent medullary spaces. (B) Histological section of native bone area. Trabecular bone with viable cells, medullary spaces with aspect of normality and absence of inflammatory infiltrate. Decalcified tissue – HE staining. Yellow asterisks represent mineralized bone matrix. Black asterisks represent medullary spaces. White arrows point to osteocytes. Blue arrows indicate incremental growth lines. (C, D) Histological sections of maxillary sinus grafted with particulate autogenous bone. Noticeable bone neoformation, higher trabecular density, bone remodeling evidence, and reduced structural organization than native cancellous bone – HE staining. Yellow asterisks represent mineralized bone matrix. Black Asterisks represent medullary spaces. Blue arrows indicate incremental growth lines. (E) Histological section of a maxillary sinus grafted with BCP. Note the presence of newly formed bone and residual particles of substitute bone, newly formed bone (yellow asterisks), residual particles (red asterisks), soft-tissue components (black asterisks), osteocytes (Yellow arrows) and osteoblasts (blue arrows). Decalcified tissue – HE staining. (F) Image under polarized light, newly formed bone (yellow asterisk), residual particles (red asterisks), soft-tissue components (black asterisk). *Source:* These images were kindly provided by Professor Dr. Decio Junior dos Santos Pinto.

surgical site), and potentially less postoperative discomfort/adverse effects.

Membranes and guided bone regeneration (GBR)

The use of membranes as physical barriers in the treatment of bone defects (or GBR) is based on an already explained biological mechanism known as "osteopromotion" [19]. This principle is based on the exclusion of non-osteogenic cells of the bone defect during wound healing, in order to favor defects' selective filling by bone cells. The main properties of the membranes used in GBR procedures should be: biocompatibility, cellular occlusion, tissue integration, space maintenance, an easier clinical management, and low susceptibility to complications. The non-absorbable membranes of expanded polytetrafluoroethylene (ePTFE), widely investigated and used since the 1990s, have been gradually replaced by collagen or synthetic absorbable membranes. Specifically for the absorbable membranes, their lower susceptibility to postoperative complications and better/easier clinical management encouraged and increased their use amongst clinicians.

Assessment of grafted sites

Grafted sites should be clinically, and whenever possible histologically, evaluated. Clinical monitoring of tissue repair at early healing stages is important to account for potential intraoral postoperative complications (e.g. infection, dehiscence with graft exposure). Postoperative extraoral complication (e.g. exacerbated edema, large bruises, neurosensory changes) should also be monitored at this stage.

Imaging tests are a key resource, not only in the preoperative planning of reconstructive procedures but also in the postoperative evaluation and controls of the outcomes of therapy in the medium and long term. However, the quality of the newly formed tissue, especially when bone substitutes are used, cannot be assessed by imaging. Bone substitutes present higher radiopacity than cancellous bone tissue and so are more easily detected within imaging exams; however, it does not necessarily mean that these bone substitutes are able to promote the formation of an "appropriate bone" for implant placement.

Within histological analysis, grafted areas are usually evaluated qualitatively and quantitatively. Qualitative analysis is performed by light microscopy at different magnifications. This allows the general

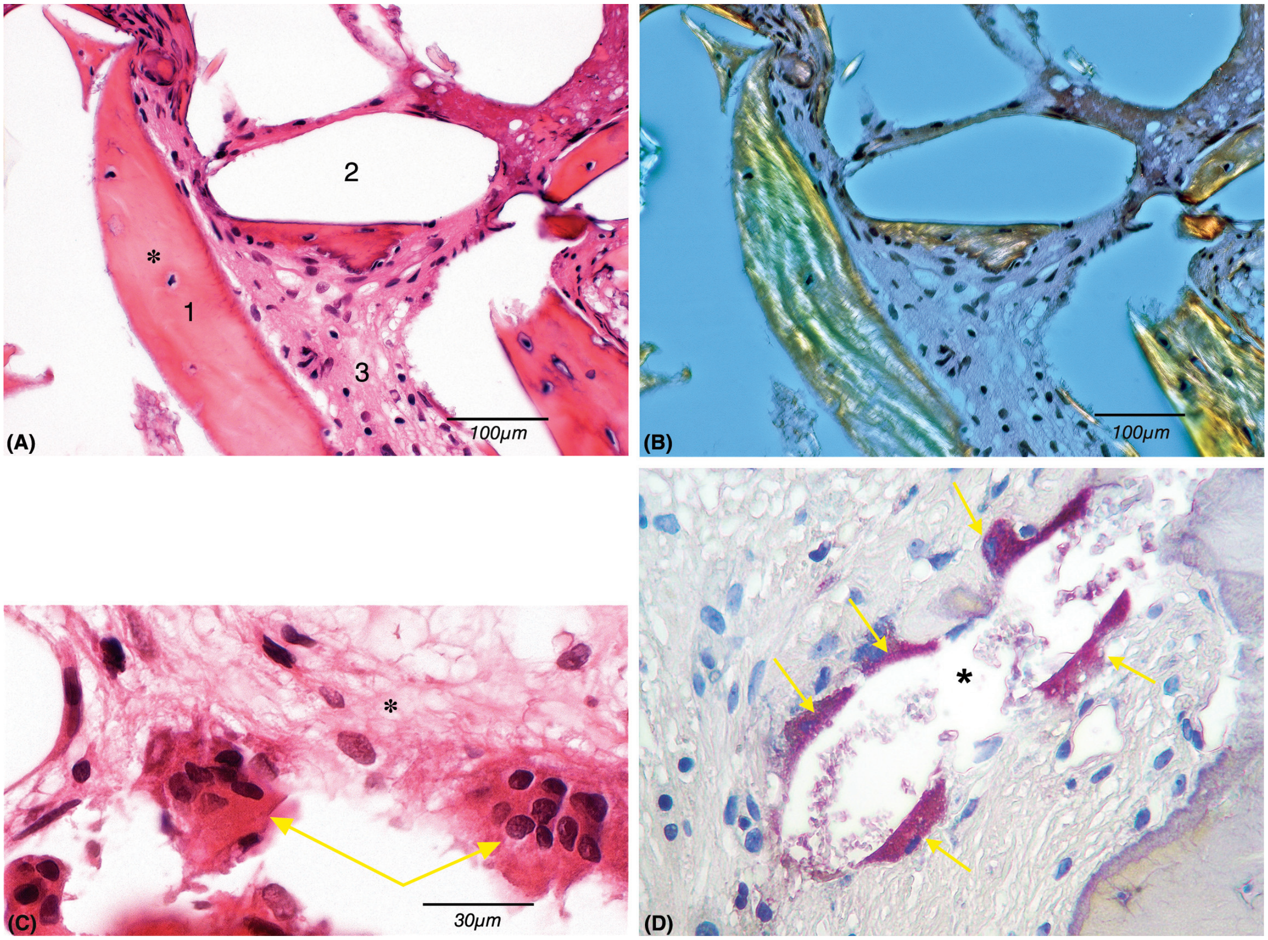

Figure 2.4 (A) Histological section of a maxillary sinus grafted with BCP, newly formed bone (1), residual particles of bone substitute (2), and soft-tissue components (3). Decalcified tissue – HE staining. (B) Image under polarized light, newly formed bone (1), residual particle (2), and soft-tissue components (3). (C) Multinucleated giant cells (yellow arrows) in contact with the surface of the residual particle of bone substitute (red asterisk), soft-tissue components (black asterisk). Decalcified tissue – HE staining. *Source:* Images A–C obtained by Professor Dr. Decio dos Santos Pinto Junior. (D) TRAP plus osteoclasts (yellow arrows) (tartrate-resistant acid phosphatase) around the BCP particle (black star). Original magnification 250×. *Source:* Image obtained by Prof. Luciana Corrêa.

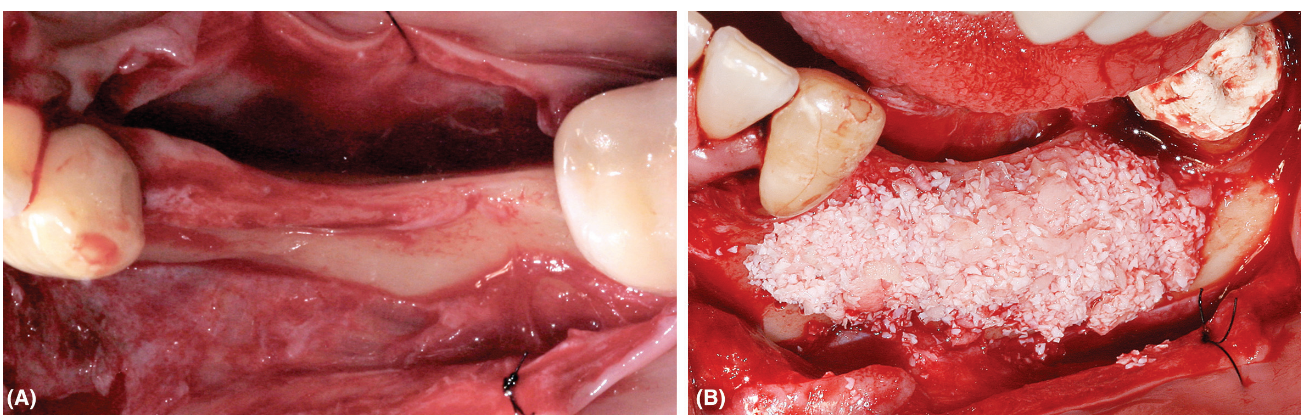

Figure 2.5 (A) Trans-surgical occlusal view. Observe the horizontal bone defect of the alveolar ridge. (B) Bone defect filled with particulate autogenous bone graft associated with deproteinized bovine bone.

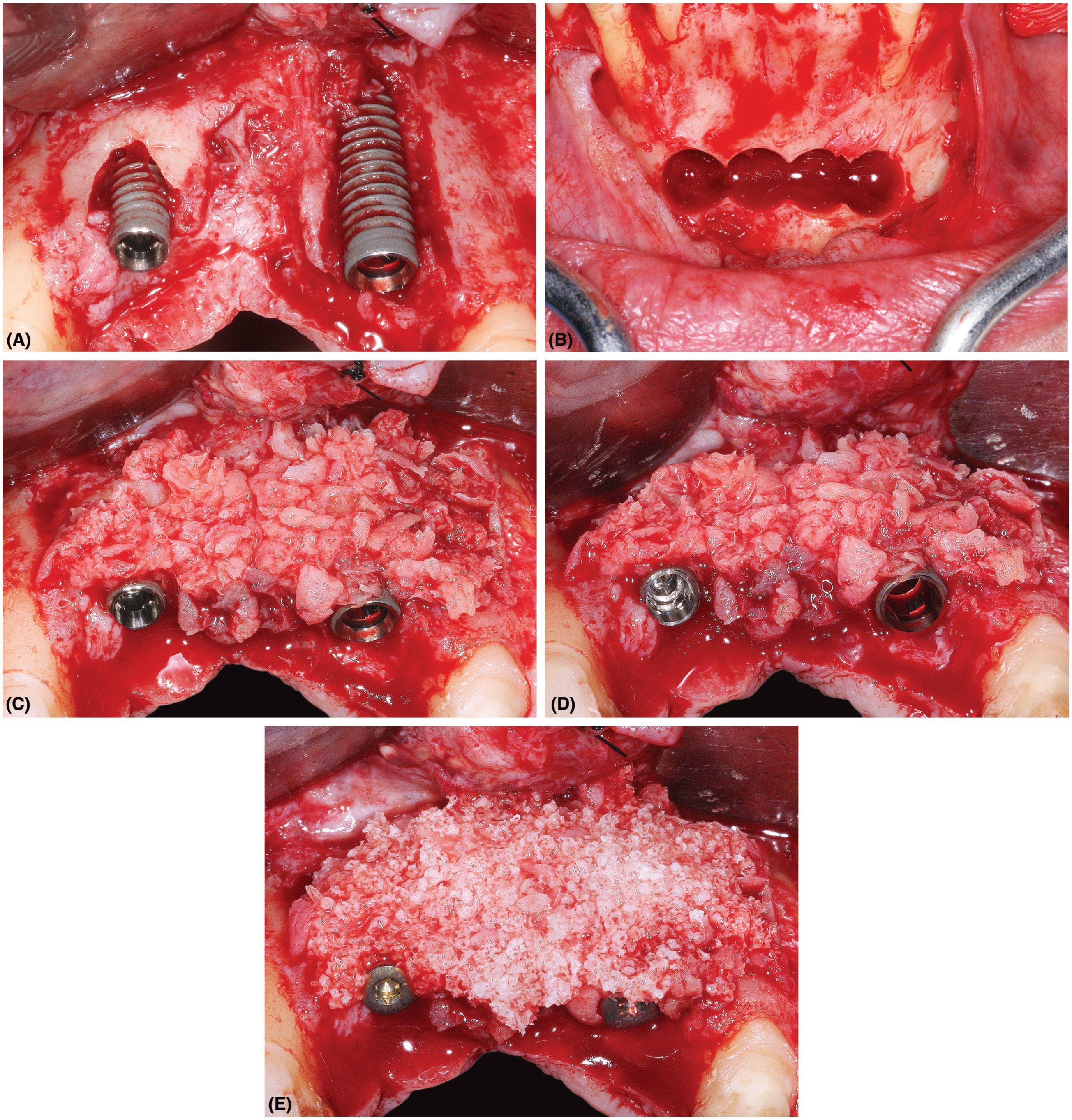

Figure 2.6 (A) Bone dehiscence around implants positioned in the anterior maxillary segment. (B) Donor site. Removal of four bone grafts from the mentonian area. (C, D) Autogenous particulate bone graft covering the whole area of the bone defect. (E) Bone substitute (Straumann® BoneCeramic™) covering the particulate autogenous bone graft.