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30 Years of Guided Bone Regeneration

THIRD EDITION

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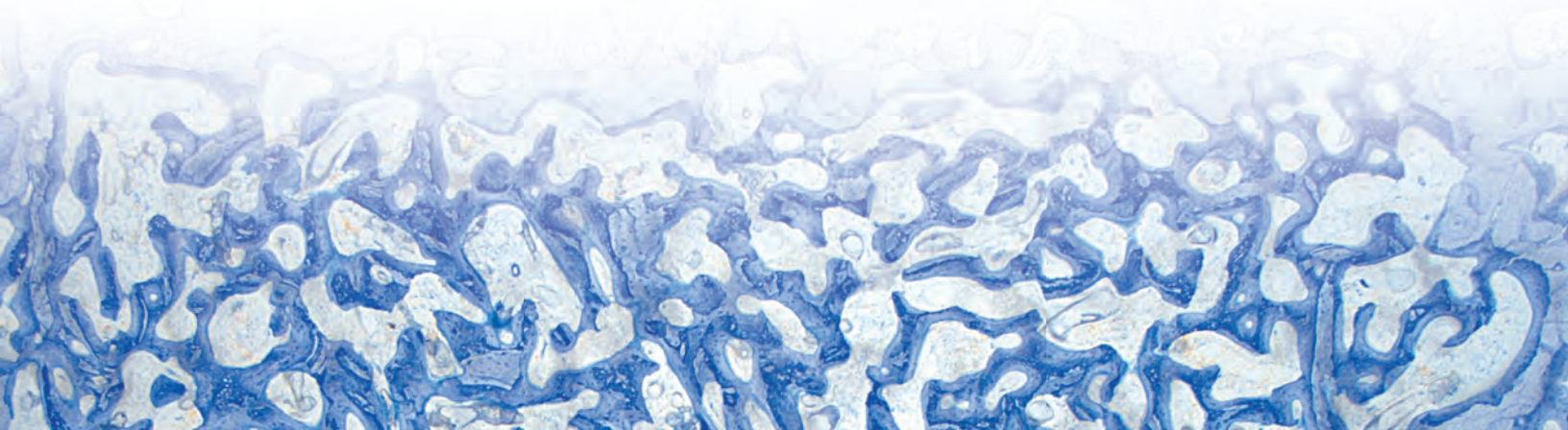

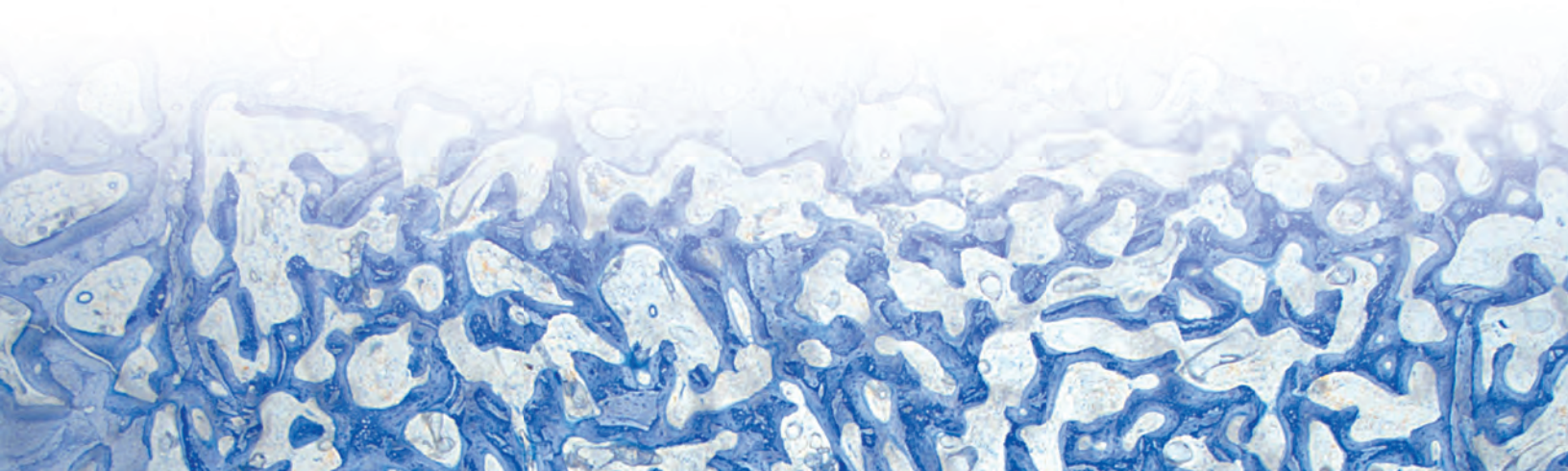

Foreword

There have already been three decades of scientific documentation and successful clinical experience in the field of GBR—a truly impressive accomplishment! In this third edition of an already well-established textbook, authored and edited under the judicious leadership of Professor Danny Buser, a carefully selected international panel of experts has updated and shed light from all relevant angles on one of the most significant recent achievements of contemporary dental medicine. The text not only surveys 30 years of progress made; it also comprehensively defines the current state of the art in GBR and its tremendous impact, namely on implant dentistry. Clinical protocols aimed at reducing overall treatment complexity and time, as well as diminishing patient morbidity, have been developed and refined during recent years. In addition, based on the remarkable levels of reliability and predictability of GBR, numerous new avenues for clinical application have been opened.

In fact, the knowledge of which techniques and associated biomaterials are recommended today, linked to the indispensable robust scientific documentation, provide the clinician with the basis for target-oriented clinical decision making in view of the subsequent treatment. This includes the consideration of the practitioner's individual state of education and competence. Namely, the SAC concept—which objectively differentiates straightforward, advanced, and complex cases in relation to the difficulty level of a given clinical situation—is of particular importance and has been strongly promoted by the main author for many years.

The current third edition of a textbook that has twice already previously reached the status of a true standard of reference has clearly outperformed its two predecessor issues. Beyond any doubt, oral surgeons, periodontists, prosthodontists, and general practitioners, as well as dental students, will find all the detailed information relevant to successful implementation of GBR in daily practice, ultimately to the benefit of countless patients.

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Dedication

This textbook is dedicated to Robert K. Schenk, Prof Dr med, who was Professor of Anatomy at the University of Bern, Switzerland. He was a world-renowned scientist in the field of bone physiology and bone healing. His instruction on the basics of bone healing was what allowed for the tremendous progress with GBR we made in the 1990s. Dr Schenk's chapter on the basics of bone healing in the first GBR book was a sensation at that time. He was able to illustrate his knowledge with fantastic histologic pictures produced by his lab. Besides his generosity to share his knowledge and wisdom, he was a true friend and mentor.

Robert K. Schenk, Prof Dr med (1923–2011)

Preface

The utilization of barrier membranes for the regeneration of bone defects has significantly changed implant dentistry in the past 30 years and clearly expanded the utilization of dental implants in patients. This principle is called guided bone regeneration (GBR or GBR technique), and was first described in 1959 by Hurley and colleagues for the treatment of experimental spinal fusion. In the 1960s, the research teams of Bassett and Boyne tested Millipore filters for the healing of cortical defects in long bones and osseous facial reconstruction, respectively. The authors utilized these filters to establish a suitable environment for osteogenesis by excluding fibrous connective tissue cells from bone defects. However, these studies did not lead to a clinical application of barrier membranes in patients at that time.

The clinical potential of barrier membranes was picked up in the early 1980s in the field of periodontology by the research team of Nyman and Karring, who systematically examined barrier membranes for periodontal regeneration. A few years later, barrier membranes were also tested for the regeneration of bone defects in experimental studies. The first three studies were done in Gothenburg by Dahlin and Nyman. Based on promising results in these studies, clinical testing of barrier membranes began in implant patients in the late 1980s. After 5 years of intensive experimental and clinical work, the first edition of the textbook *Guided Bone Regeneration in Implant Dentistry* was published in 1994, and it received a high interest by readers in the field of implant dentistry. In 2009, the second edition of the GBR book was published with an update of the scientific knowledge and the surgical techniques being utilized after 20 years of a wide clinical application of GBR.

In the past 12 years, the scientific knowledge and the clinical experience have evolved further. During these years, many fine-tuning efforts have been made for the various surgical techniques to improve the regenerative outcomes, or to reduce the surgical invasiveness for patients. Therefore, it was time to make a new effort to once again analyze the scientific basis of the GBR technique and its clinical applications. The result is in your hands, the third edition of the GBR book, called *30 Years of Guided Bone Regeneration in Implant Dentistry*. This book is again written for the surgical clinician with an interest and experience in implant dentistry.

As an introduction to the topic of the book, chapter 1 discusses the development and fine-tuning phase of the GBR technique over the past 30 years. Chapter 2 covers the biologic basis of bone regeneration and presents a scientific update on bone formation and bone remodeling. The excellent histology utilizing nondecalcified sections is based on more than 30 years of experimental research, and it presents the details of bone regeneration in general and the details of bone formation in membrane-protected defects with bone grafts or bone substitutes in particular. Chapter 3 is completely new and describes the molecular and cellular characteristics of autogenous bone chips, and how they release various growth factors when put in a mixture of blood and physiologic and sterile saline. Chapter 4 is also completely new and describes the hard and soft tissue alterations following tooth extraction. Clinicians need to understand these biologic mechanisms for proper selection of the most suitable treatment option in postextraction implant placement. Chapter 5 is also new and systematically describes the surgical and anatomical factors influencing the regenerative outcome of GBR procedures, including the interesting classifications of defect morphology.

In the clinical section of the book, chapters 6 to 14, clinical procedures associated with different indications of the GBR technique are presented in detail. Each chapter deals with specific indications and describes the criteria for patient selection, the step-by-step surgical procedure, and aspects of postoperative treatment. Emphasis is given to incision technique and flap design; the selection, handling, and placement of barrier membranes; the combination of membranes with autogenous bone grafts and low-substitution bone fillers; and aspects of wound closure. These chapters of the book reflect the immense progress and excellent documentation of GBR in the past 10 to 15 years, and its outstanding importance in daily practice of implant therapy.

Acknowledgments

As editor, I cordially thank all authors and coauthors for their great effort and time to realize this textbook. It has been very intensive work during a pandemic crisis, but a satisfying experience to collaborate with colleagues of such international reputation and high quality. Some of them are long-term personal friends, which makes the pleasure even greater. I also want to share that all authors, including myself, agreed to have the authors' royalties entirely paid into the Buser Implant Foundation, a foundation established in August 2019 right after my retirement as Professor and Chairman at the Department of Oral Surgery and Stomatology, University of Bern, after 20 years of service. The foundation's objectives are the promotion of education and research in the field of implant dentistry by providing personal stipends and junior investigator grants to young colleagues of our profession. The first Buser Foundation Scholarship in Implant Dentistry has been awarded in spring 2021.

I also thank Bernadette Rawyler, who created all the beautiful digital artwork in my chapters. These illustrations have made it much easier to communicate the correct messages and necessary information from the authors to the reader.

Last but not least, I also cordially thank Bryn Grisham and Marieke Zaffron of Quintessence Publishing for their excellent collaboration to realize this book. The quality work and the quality printing of Quintessence was again superb and is highly appreciated. It reflects almost 30 years of close collaboration with Quintessence Publishing, both in Berlin and in Chicago. I thank Horst Wolfgang Haase, Christian W. Haase, as well as Alexander Ammann for this excellent collaboration over so many years, which was based on trust, respect, and friendship.

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The Development of Guided Bone Regeneration Over the Past 30 Years

Daniel Buser, DDS, Prof em Dr med dent

Modern implant dentistry based on the concept of osseointegration recently celebrated its 50th birthday.[1] The tremendous progress made in the rehabilitation of fully and partially edentulous patients is based on fundamental experimental studies performed by two research teams. One team was located in Sweden and headed by Prof P-I Brånemark from the University of Gothenburg; the other was located in Switzerland and headed by Prof André Schroeder from the University of Bern. In the late 1960s and 1970s, the two research groups independently published landmark papers describing the phenomenon of osseointegrated titanium implants.[2–4] An *osseointegrated implant* was characterized by direct apposition of living bone to the implant surface.[5–7]

In the early phase of this development, several prerequisites were identified for osseointegration to be achieved.[2,3] Some of these have been revised over the past 50 years; others are still considered important. In order to achieve osseointegration, the implant must be placed using a low-trauma surgical technique to avoid overheating the bone during preparation of a precise implant bed, and the implant must be inserted with sufficient primary stability.[5,8] When these clinical guidelines are followed, successful osseointegration will predictably occur for nonsubmerged titanium implants (single-stage procedure) as well as for submerged titanium implants (two-stage procedure), as demonstrated in comparative experimental studies.[9,10]

When clinical testing of osseointegrated implants first began, the majority of treated patients were fully edentulous. Promising results were reported in retrospective studies.[11–13] Encouraged, clinicians increasingly began using osseointegrated implants in partially edentulous patients, and the first reports on this utilization were published in the late 1980s and early 1990s with promising short-term results by various groups.[14–18] As a consequence, single-tooth gaps and distal extension situations have become more and more common indications for implant therapy in daily practice. Today, these practices dominate in many clinical centers.[19–21]

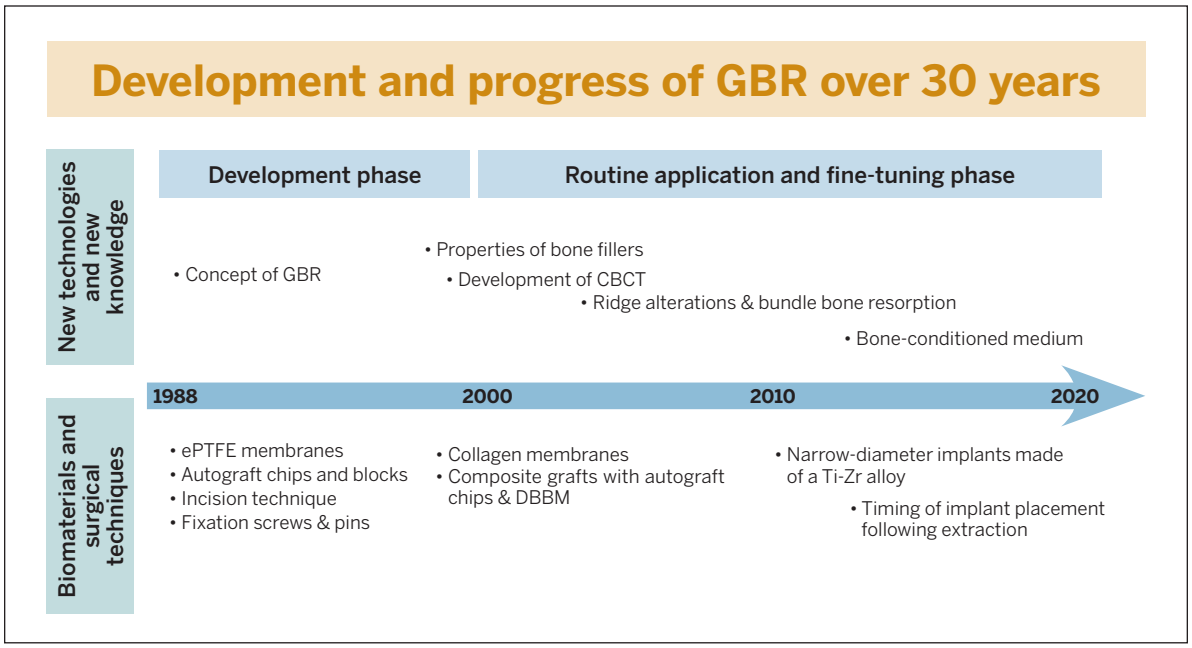


Fig 1-1 Development of GBR over 30 years since the late 1980s. ePTFE, expanded polytetrafluoroethylene; DBBM, deproteinized bovine bone mineral; Ti-Zr, titanium-zirconium.

One of the most important prerequisites for achieving and maintaining successful osseointegration is the presence of a sufficient volume of healthy bone at the recipient site. This includes not only sufficient bone height to allow the placement of an implant of adequate length, but also a ridge with sufficient crest width. Clinical studies in the 1980s and 1990s showed that osseointegrated implants lacking a buccal bone wall at the time of implant placement had an increased rate of soft tissue complications and/or a compromised long-term prognosis.[22,23] To avoid increased rates of implant complications and failures, these studies suggested that potential implant recipient sites with insufficient bone volume should either be considered local contraindications for implant placement or should be locally augmented with an appropriate surgical procedure to regenerate the local bone deficiency.

During these early decades, several attempts were made to develop new surgical techniques to augment local bone deficiencies in the alveolar ridge in order to overcome these local contraindications for implant therapy. The proposed techniques included vertical ridge augmentation using autogenous block grafts from the iliac crest in extremely atrophic arches,[24,25] sinus floor elevation procedures in the maxilla,[26–28] the application of autogenous onlay grafts for lateral ridge augmentation,[29–31] or split-crest techniques such as alveolar extension plasty.[32–34]

During the same period, in addition to these new surgical techniques, the concept of guided bone regeneration (GBR) with barrier membranes was introduced. Based on case reports and short-term clinical studies, various authors reported first results with this membrane technique for the regeneration of localized bone defects in implant patients.[35–40]

This textbook will provide an update on the biologic basis of the GBR technique and its various clinical applications for implant patients. Clinical experience with GBR in daily practice now spans 30 years. These 30 years can be divided into a development phase and a phase of routine application with extensive efforts to fine-tune the surgical procedure (Fig 1-1). The focus was on improving the surgical technique, expanding the range of applications, improving the predictability for successful outcomes, and reducing morbidity and pain for the patients.

Development Phase of GBR

The use of barrier membranes for implant patients was certainly triggered by the clinical application of barrier membranes for periodontal regeneration, called *guided tissue regeneration* (GTR). GTR was first developed in the early 1980s by the group led by Nyman et al.[41,42] The initial studies were performed with Millipore filters, which had already been used in experimental studies in the late 1950s and 1960s for the regeneration of bone defects.[43–45] However, these studies had no impact on the development of new surgical techniques to regenerate localized defects in the jaws, because the potential of this membrane application was probably not recognized at that time.

The two papers by Nyman et al[41,42] in the field of GTR, both of which demonstrated successful treatment outcomes of GTR procedures, were received with great interest and led to increased research activities in the mid to late 1980s.[46–49] These studies were already being performed with expanded polytetrafluoroethylene (ePTFE), which is a bioinert membrane and became the standard membrane for GTR and GBR procedures during the development phase of both techniques. The use of ePTFE membranes for bone regeneration was initiated in the mid 1980s by the group of Dahlin et al, who performed a series of preclinical studies.[50–52] These studies confirmed the concept that the application of an ePTFE membrane established a physical barrier that separated the tissues and cells that could potentially participate in the wound healing events inside the secluded space. The barrier membrane promoted the proliferation of angiogenic and osteogenic cells from the marrow space into the bone defect without interference by fibroblasts. These events were nicely demonstrated by Schenk et al[53] in a landmark experimental study in foxhounds. The current biologic understanding of wound healing events in membrane-protected bone defects is presented in detail in chapter 2 of this textbook.

The use of ePTFE membranes for GBR procedures started in the late 1980s. The main objective was to achieve regeneration in peri-implant bone defects in implant sites with local bone deficiencies. The GBR technique has been used with both simultaneous and staged approaches. Implant placement with simultaneous GBR was predominantly used for immediate implant placement in postextraction sites to regenerate peri-implant bone defects[35,36,38] or for implants in sites with crestal dehiscence defects.[40] The staged approach was used in clinical situations with healed ridges but an insufficient crest width. The membrane technique was used to enlarge the crest width with a first surgery, and implant placement took place after 6 to 9 months of healing in a second surgical procedure.[37]

Early on, several complications were observed with both approaches, and modifications of the surgical techniques were proposed to improve the predictability of successful treatment outcomes. One frequent complication was the collapse of the ePTFE membranes, which reduced the volume of the regenerated tissue underneath the membrane. In addition, some of the regenerated sites demonstrated insufficient bone formation and the formation of a periosteum-like tissue underneath the membrane.[37,40] Therefore, bone fillers such as autografts or allografts were recommended by various groups, primarily to support the membrane and reduce the risk of membrane collapse.[54–56] The combination of ePTFE membranes and autogenous bone grafts provided good clinical outcomes for both approaches. Some of these patients are still being followed and documented up to 25 years after surgery (Figs 1-2 to 1-4).

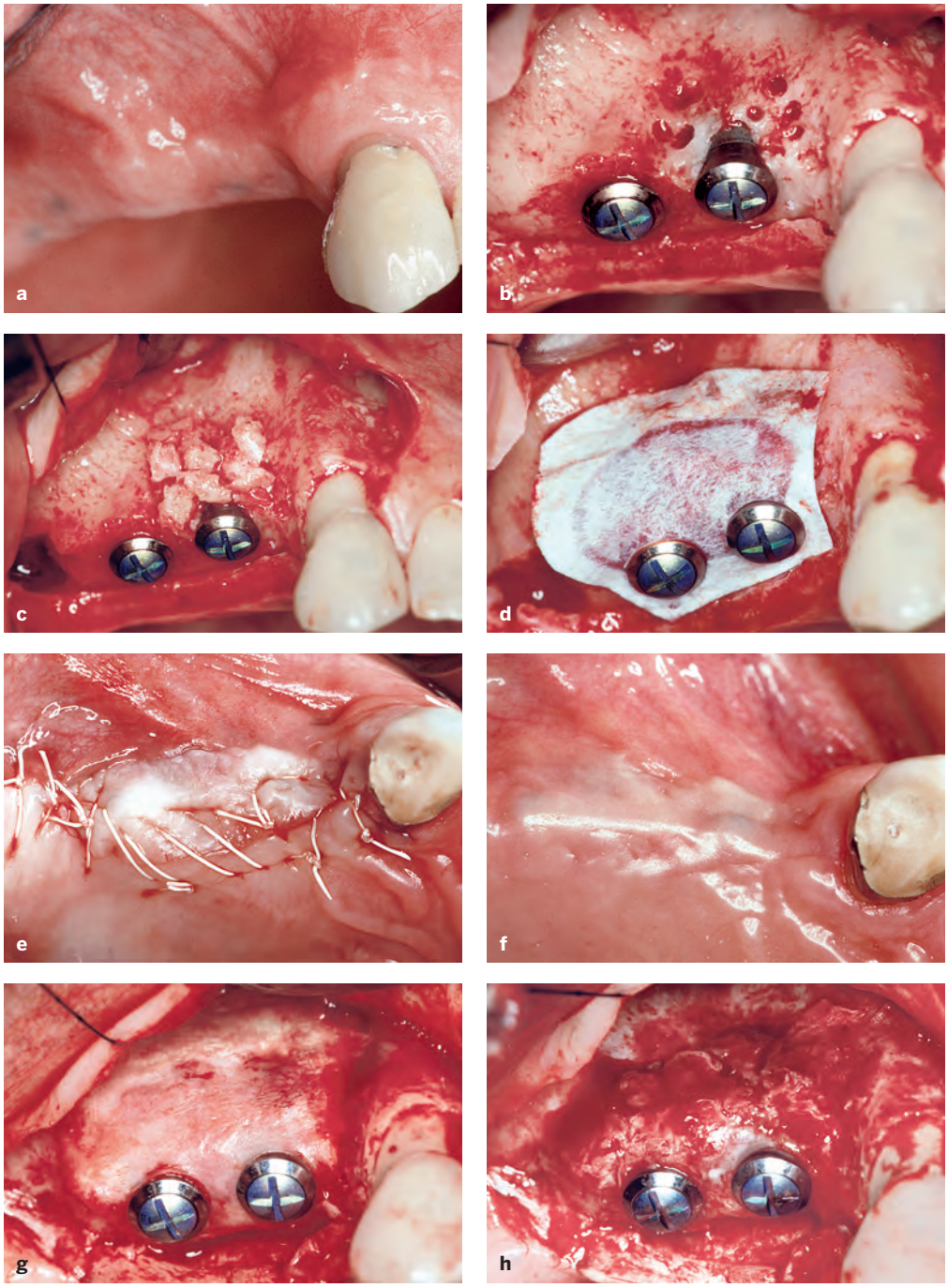


Fig 1-2 Case 1. *(a)* Preoperative status (1991). Distal extension situation in the right maxilla of a man with a healed ridge. Two titanium implants were planned to allow a fixed prosthesis. *(b)* Both implants were placed, resulting in a crestal dehiscence defect at the mesial implant. The cortical bone surface was perforated with a small round bur to open the marrow cavity and stimulate bleeding in the defect area. *(c)* Locally harvested bone chips were applied to support the ePTFE membrane and to stimulate new bone formation in the defect area. *(d)* A bioinert ePTFE membrane was applied to function as a physical barrier. The punched membrane was stabilized around the necks of both implants. *(e)* Following incision of the periosteum, the surgery was completed with a tension-free primary wound closure. *(f)* Clinical status 4 months after implant surgery. The wound healing was uneventful. *(g)* Reopening after 4 months of healing. A second surgery was necessary to remove the nonresorbable membrane. *(h)* The clinical status following membrane removal showed successful bone regeneration in the defect area at both implants. →

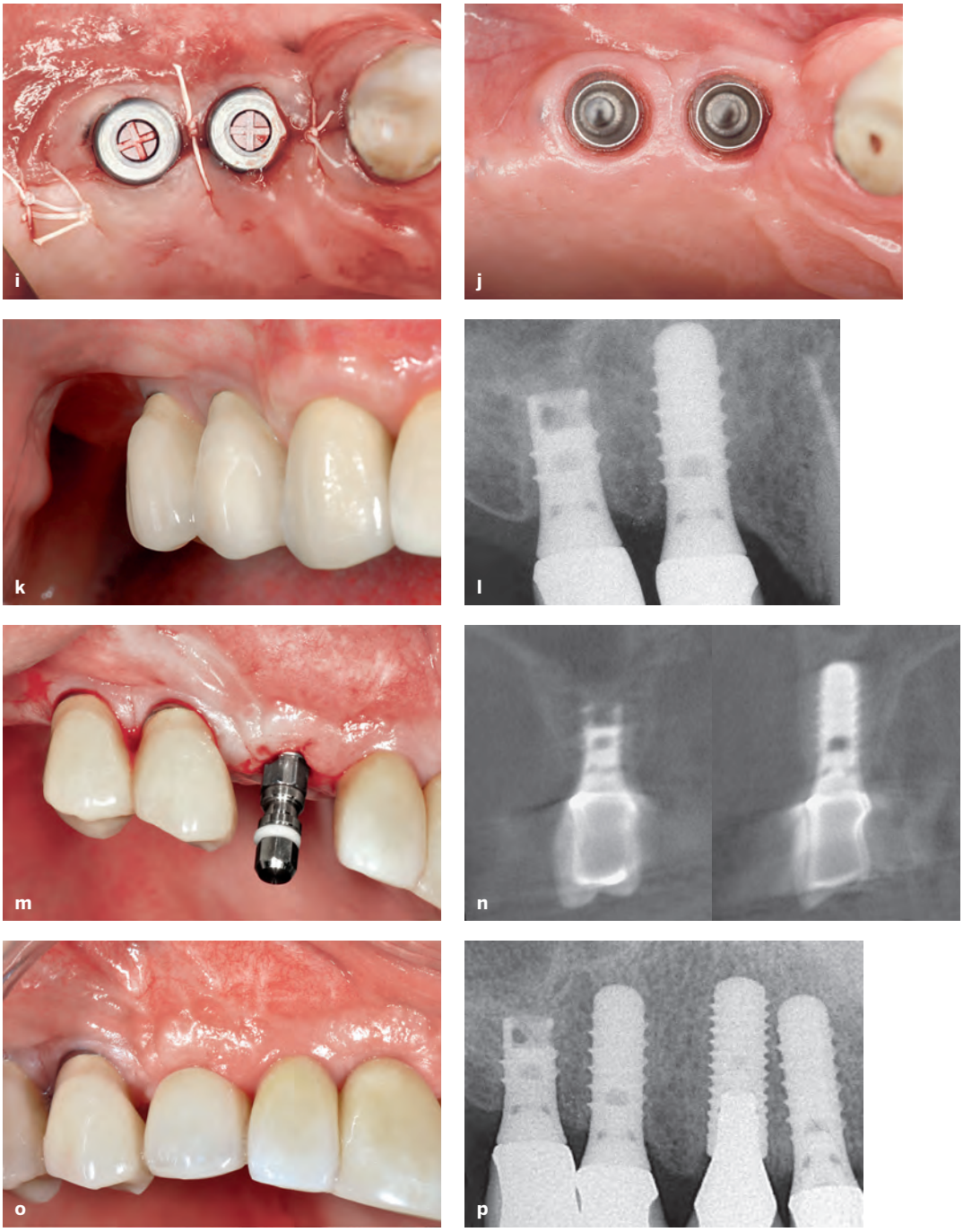


Fig 1-2 Case 1. *(cont) (i)* Longer healing caps were applied, and the soft tissue margins were adapted and secured in place with interrupted sutures. *(j)* Two weeks later, the soft tissues had healed, and both implants could be restored with a single crown. *(k)* The clinical status at the 15-year follow-up examination (2006) showed a satisfactory treatment outcome with stable peri-implant soft tissues. *(l)* Radiographic follow-up at 15 years: The bone crest levels were stable around both implants, which are splinted. *(m)* In 2010 (19 years after the initial surgery), an additional implant was placed in the canine site as late implant placement with a flapless approach. The clinical view during surgery showed stable peri-implant soft tissue at both implants in the premolar sites. *(n)* During perioperative examination of the canine implant site, a CBCT scan was taken. The orofacial cuts showed a thick facial bone wall for both premolar implants, which had been in function for 19 years at the time. *(o)* Clinical status after completion of the new single crown at the canine site. The treatment outcome was very satisfactory considering when the GBR procedure was done (1991). *(p)* Periapical radiograph after completion of therapy. The two tissue-level implants in the premolar sites had been in function for 19 years, and both showed stable peri-implant bone crest levels. This was the final follow-up examination, as the patient sadly developed dementia and passed away a few years later.

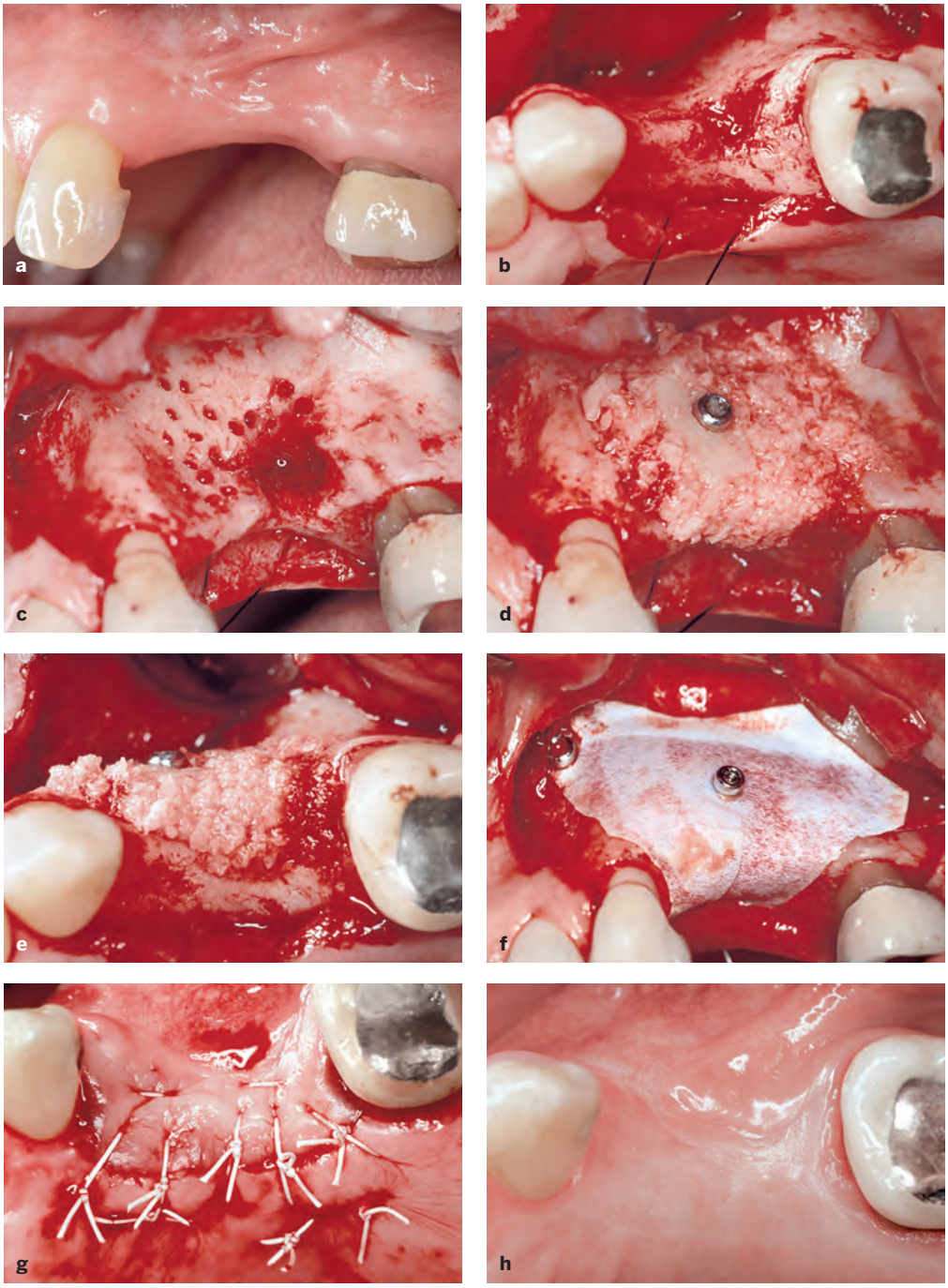


Fig 1-3 Case 2. *(a)* Preoperative view (1994). The buccal view of this woman's left maxilla shows two missing premolars. The buccal aspect is flattened. *(b)* The occlusal view during surgery shows a significant buccal flattening and a buccal bone defect in the area of the second premolar. *(c)* Prior to block application, the entire buccal bone surface was perforated to open the marrow cavity. The bone defect was debrided from scar tissues. *(d)* An autogenous block graft harvested from the chin was applied and fixed with a fixation screw. Bone chips were used to augment the entire surrounding area. *(e)* The occlusal view shows the volume of the augmented ridge. *(f)* Buccal view of the applied ePTFE membrane to cover the augmented ridge as a bioinert barrier membrane. *(g)* Primary wound closure was achieved with several mattress and interrupted single sutures using 4-0 and 5-0 ePTFE sutures. *(h)* Six months after ridge augmentation, the clinical status shows healthy soft tissues following a healing period free from complications. →

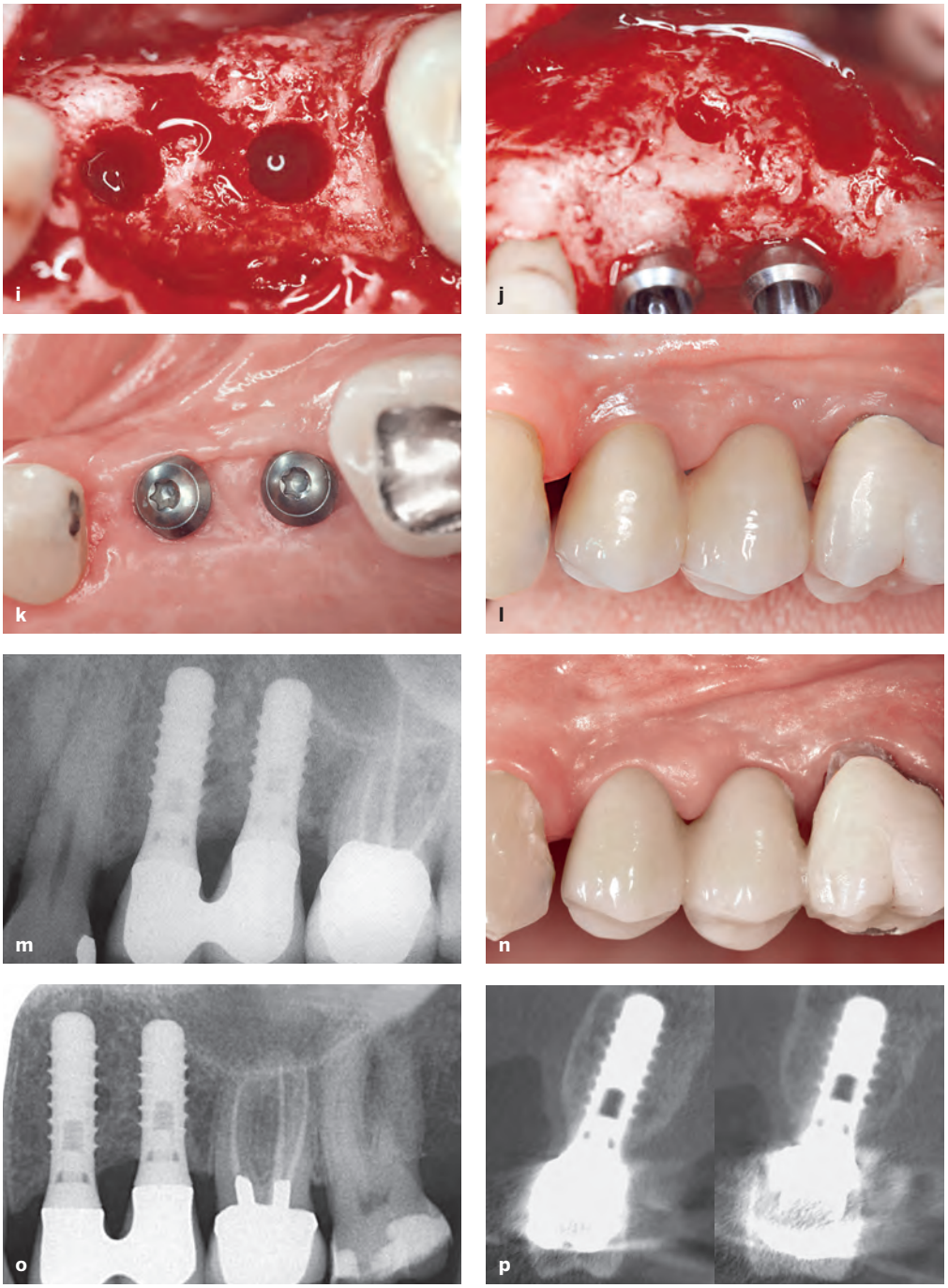


Fig 1-3 Case 2. *(cont) (i)* Following flap elevation and membrane removal, the occlusal view demonstrates an excellent ridge volume and thick buccal bone wall following implant bed preparation. *(j)* The buccal view confirms successful ridge augmentation. The block graft can still be recognized, and it is covered in some areas with newly formed bone. *(k)* Clinical status following 3 months of nonsubmerged healing for both implants. The peri-implant mucosa was healthy and included a nice band of keratinized mucosa. *(l)* Clinical status at the 10-year examination (2005) shows the two splinted implant crowns. The peri-implant mucosa was stable with no signs of a peri-implant pathology. *(m)* The periapical radiograph at the 10-year examination confirms stable bone crest levels around the two tissue-level implants with a hybrid design. *(n)* The 25-year follow-up examination (2019) shows the clinical status with quite healthy peri-implant mucosa, although the plaque control is no longer perfect in this elderly patient (age 86). *(o)* The periapical radiograph confirms stable bone crest levels at both tissue-level implants. *(p)* The CBCT scan shows fully intact, thick buccal bone walls for the implants in the first premolar (left) and second premolar (right) sites.

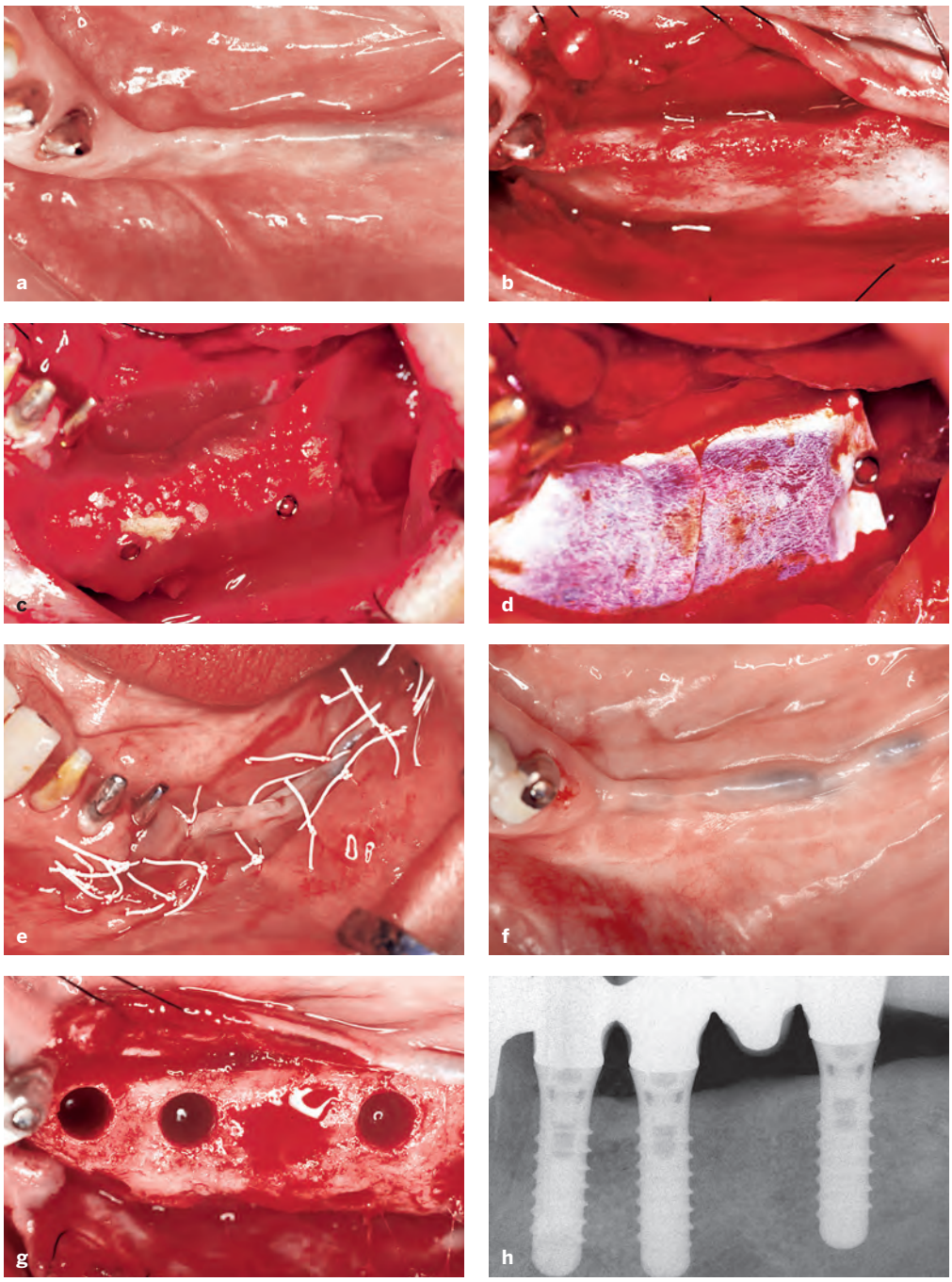


Fig 1-4 Case 3. *(a)* Preoperative view (1993). The occlusal view shows a distal extension situation in the left mandible. This woman's healed ridge was atrophic with a severe buccal flattening. *(b)* The intraoperative view shows a crest width of less than 3 mm. *(c)* Status following horizontal ridge augmentation with two block grafts harvested in the third molar area within the same flap. *(d)* The block grafts were covered with an ePTFE membrane. The membrane was stabilized with multiple miniscrews. *(e)* The surgery was completed with a tension-free wound closure with mattress and single sutures to achieve primary wound healing. *(f)* Clinical status after 6 months of healing free from complications. *(g)* Following flap elevation and membrane removal, an excellent augmentation outcome is visible in the areas of the first premolar and first molar, allowing for implants to be placed. *(h)* Following successful restoration, the periapical radiograph at the 1-year examination (1994) shows stable bone crest levels at all three tissue-level implants. →

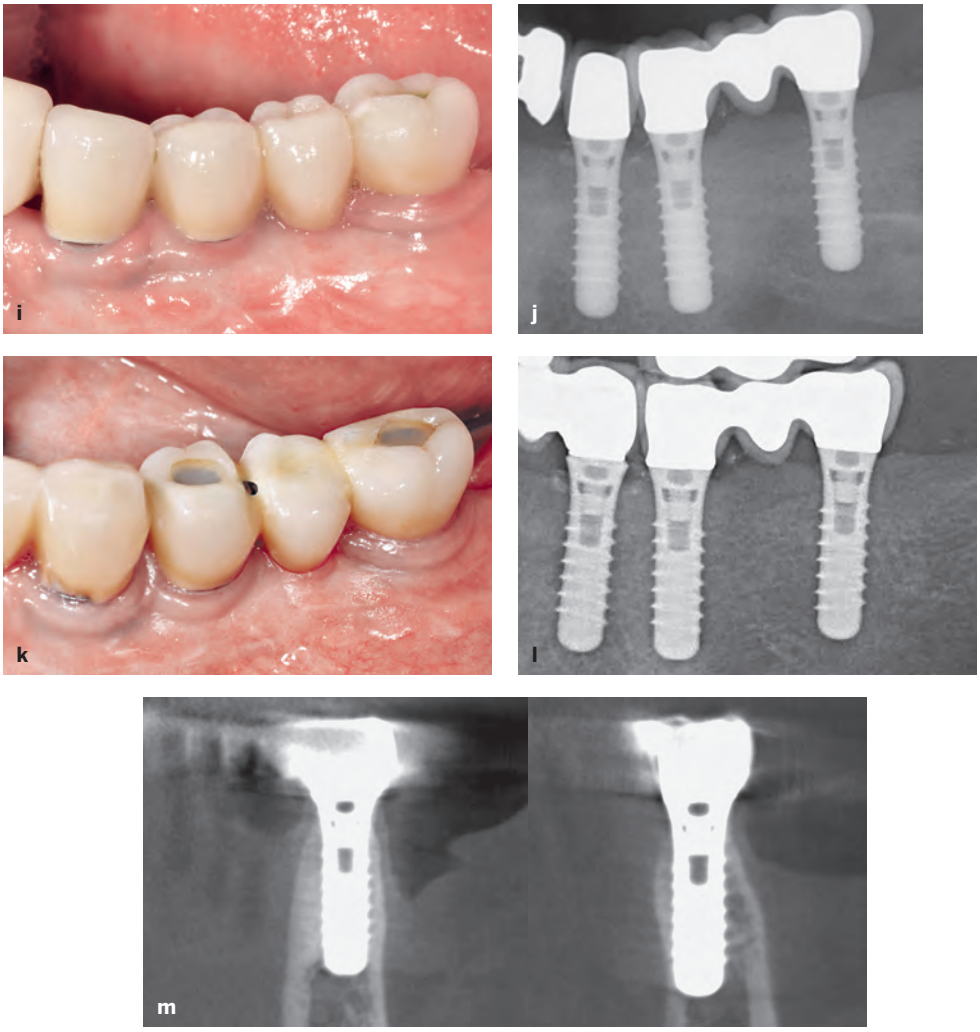


Fig 1-4 Case 3. *(cont) (i)* Clinical status at the 15-year examination. The peri-implant mucosa is stable but shows some signs of mucositis. *(j)* The radiograph confirms stable bone crest levels at all three tissue-level implants. *(k)* Clinical view at the 25-year follow-up examination (2019). The patient is now 85 years old, and the plaque control is no longer optimal. The mucosa around the tissue-level implants with a machined implant surface in the neck area shows very stable peri-implant tissues. *(l)* The periapical radiograph confirms stable bone crest levels at all three tissue-level implants after 25 years of function. *(m)* A CBCT scan is taken to examine the peri-implant bone volume. The orofacial cuts demonstrate fully intact buccal bone walls at the two implants in the first premolar and first molar sites, where a block graft augmentation with GBR was done in 1993.

Fig 1-5 Photo of the expert meeting in 1994 in Arizona with (from the left) Danny Buser, Bill Becker, Sascha Jovanovic, and Massimo Simion.

Box 1-1 Objectives for improvements of the GBR technique in the mid 1990s

- Improve the predictability of successful outcomes following GBR
- Reduce the rate of complications due to membrane exposure and membrane infections
- Make the GBR technique more user friendly, with easier application of the membrane during surgery
- Make GBR more patient friendly by eliminating a second surgical procedure for membrane removal whenever possible, and by reducing healing periods as much as possible

In 1994, an expert meeting took place in the United States to discuss the potential and the limitations of the GBR technique used in daily practice after 5 years of clinical experience (Fig 1-5). This meeting clearly showed that improvements of the GBR technique were needed to allow more widespread use in implant patients. The experts agreed that the GBR technique—based on the use of ePTFE membranes in combination with bone grafts or bone substitutes—had the following weaknesses and shortcomings:

- A significant rate of membrane exposures due to soft tissue dehiscences, often leading to local infection beneath the membrane and subsequently to a compromised regenerative outcome of the GBR procedure.[57–60]
- Difficult handling of the membrane during surgery due to its hydrophobic properties, requiring stabilization of the membrane with miniscrews or pins.[55,56,61]
- The need for a second surgical procedure to remove the bioinert, nonresorbable membrane, thereby increasing the morbidity and overall treatment time for the patient.

During this meeting, objectives were defined to improve the predictability and attractiveness of GBR procedures both for implant patients and for clinicians (Box 1-1).

It was clear to the participants at this expert meeting that these objectives could only be achieved with the use of a bioresorbable membrane. This trend was again initiated in the field of GTR, with the

introduction of the first bioresorbable membranes in the early 1990s.[62,63] Subsequently, numerous animal studies were performed to examine different bioresorbable membranes for GBR procedures.[64–74] In general, two different groups of bioresorbable membranes were evaluated[75]:

- Polymeric membranes made of polylactic or polyglycolic acid
- Collagen membranes produced from various animal sources

Paralleling these preclinical studies, clinicians started to use bioresorbable membranes in patients. The first published clinical reports predominantly tested collagen membranes,[76–80] and today, collagen membranes are routinely used in daily practice for GBR procedures.

In addition to selecting an appropriate barrier membrane, the selection of appropriate bone fillers for GBR procedures is just as important for the regenerative outcome of GBR procedures. In the early 1990s, autogenous bone chips were primarily used from a mechanical point of view. The role of these filler particles was to support the membrane to avoid a membrane collapse during healing. In the mid 1990s, a first preclinical study in minipigs by Buser et al[81] helped us to understand that bone fillers have different biologic characteristics in terms of their osteogenic potential and rate of filler substitution during bone remodeling.

The various biomaterials used for GBR procedures, such as bone grafts, bone substitutes, and barrier membranes, are also discussed in chapter 2.

Routine Application and Fine-Tuning Phase of GBR

Around the year 2000, GBR entered a phase of routine application in daily practice. Since then, the GBR technique has been the standard of care for the regeneration of localized bony defects in implant patients. This was confirmed in 2007 in a systematic review by Aghaloo and Moy,[82] who demonstrated that implants placed with the GBR procedure have favorable survival and success rates, and the GBR procedure was the only well-documented surgical technique among various surgical techniques used for localized ridge augmentation. The only other scientifically well-documented surgical technique for bone augmentation at that time was sinus grafting and sinus floor elevation in the posterior maxilla.

Over the past 20 years, however, significant progress has been made with GBR procedures, thanks to new developments in technology and a much better understanding of the tissue and graft biology involved.

The most important improvements are as follows:

- The development of a much better 3D radiographic technique based on CBCT
- Much greater knowledge of tissue biology in postextraction sites
- A much better understanding of the biologic characteristics of bone grafts and bone substitutes
- The development of new narrow-diameter implants

CBCT as the new 3D radiographic methodology

The development of the CBCT technique started in the late 1990s with a first publication by Mozzo et al,[83] and it represents probably one of the most important improvements in implant dentistry in the past 20 years. This new 3D radiographic technique allowed cross-sectional imaging with much better image quality and a clear reduction in radiation exposure when compared with the computed tomography (CT) technology used for dentistry in the 1990s. The CBCT technique allows cross-sectional imaging not only for the preoperative examination of patients, but also for the follow-up documentation of bone augmentation procedures.[84,85] During preoperative examination, CBCT helps to assess the extent of bone deficiencies in potential implant sites, and hence to categorize defect morphologies. These aspects are discussed in detail in chapter 5. In addition, CBCT is also one of the basic techniques necessary for the use of digital technology, including computer-assisted implant surgery (CAIS) in patients.

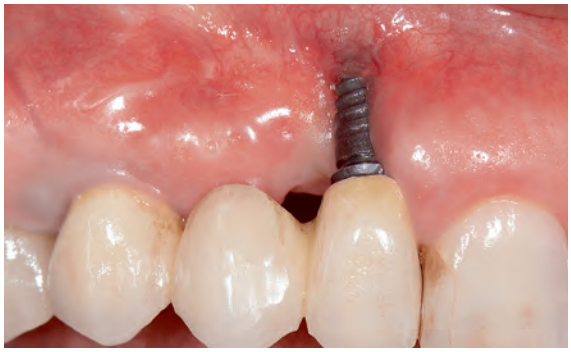


Fig 5-4 A facial malposition of the implant is often the main cause of severe mucosal recession.

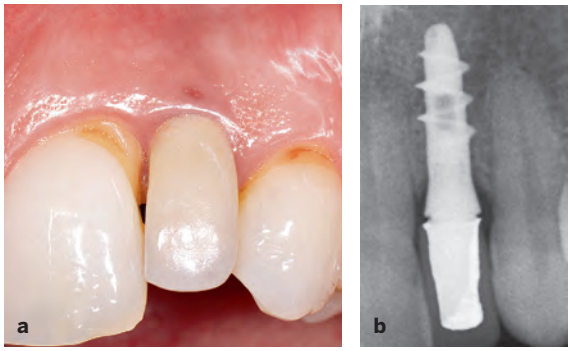


Fig 5-5 *(a and b)* When an implant with its platform is positioned too close to an adjacent root surface, the resulting complication is a recession of the papilla between the implant and the tooth.

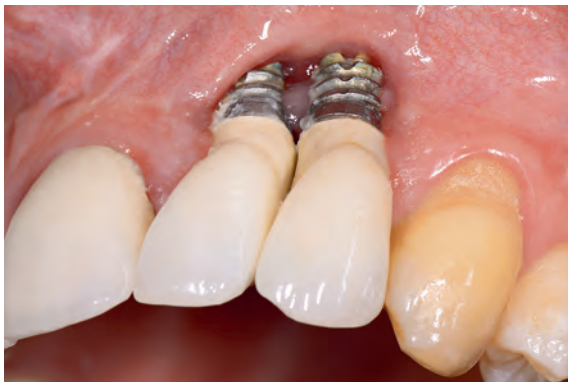


Fig 5-6 Two adjacent implants can also cause a severe esthetic complication when they are placed too close to each other (ie, < 3 mm). In this case, the facial malposition was a second contributing factor for the esthetic disaster.

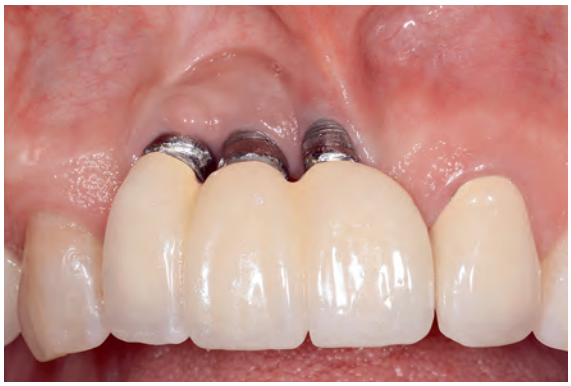
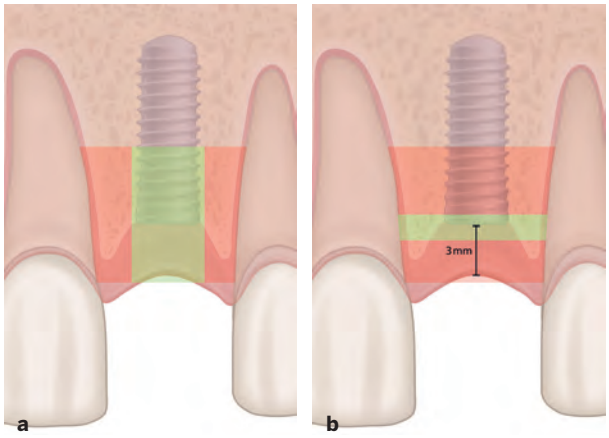


Fig 5-7 Esthetic failure caused by three adjacent implants placed too close to each other. A much better approach would have been the placement of only two implants to avoid adjacent implants.



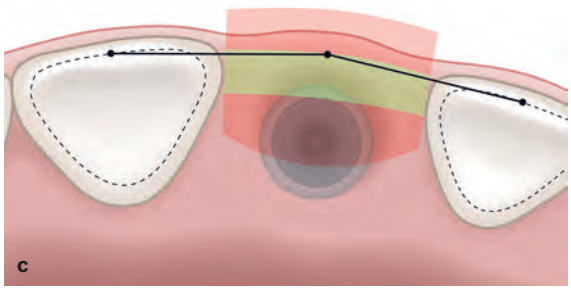


Fig 5-8 The concept of the comfort *(green areas)* and danger zones *(red areas)* established by the ITI Consensus Conference in 2003. It is important to have a correct position of the implant platform in all three comfort zones: *(a)* mesiodistal, *(b)* coronoapical, and *(c)* orofacial.[20]

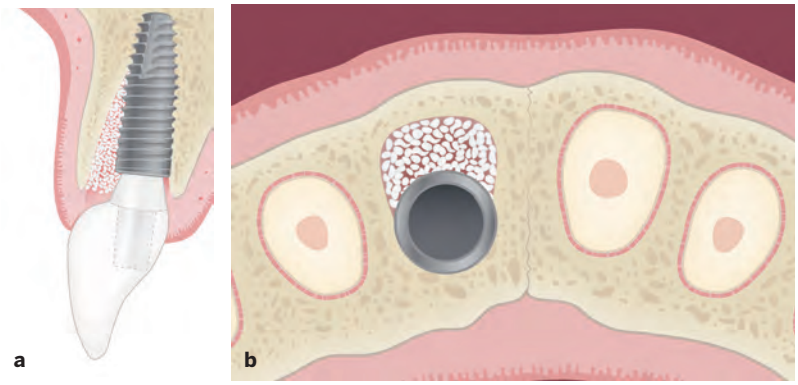


Fig 5-17 *(a)* Digital drawing of immediate implant placement with a thick wall phenotype. The flapless placement in a slightly palatal position is combined with internal grafting. There will be minimal bone resorption at the thin peak of the buccal wall. *(b)* The axial cut shows the thick wall phenotype (≥ 1 mm), which will offer a stable ridge volume. Note the internal grafting. This three-wall defect will have a quick bone regeneration.

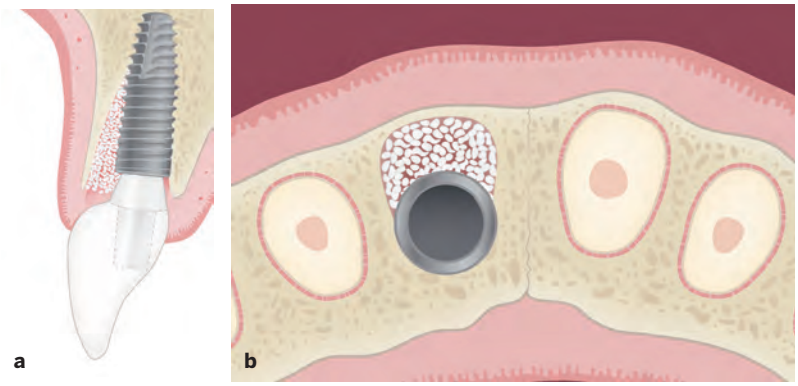


Fig 5-18 *(a)* Digital drawing of immediate implant placement with a thin wall phenotype and internal grafting. The thin buccal wall will resorb within 2 to 4 weeks due to bundle bone resorption leading to a buccal flattening of the ridge anatomy. *(b)* The axial cut shows the thin wall phenotype (< 1 mm). Due to bundle bone resorption, the thin buccal wall will be lost within 2 to 4 weeks and cause a buccal flattening of the ridge, and often a compromised esthetic outcome.

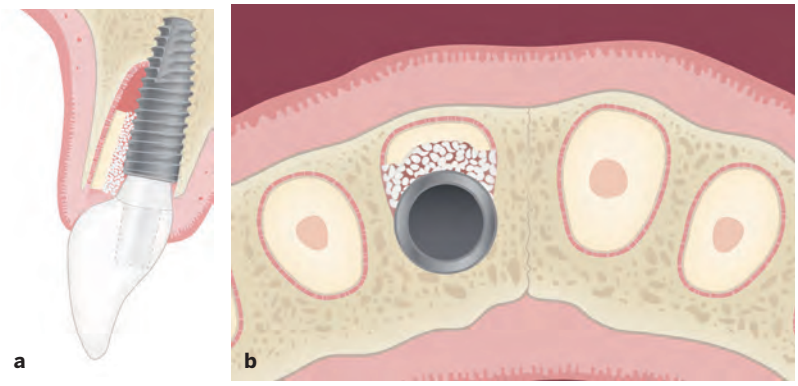


Fig 5-19 *(a)* This digital drawing shows the biologically interesting concept of SST. A thin remnant of the root is left on the buccal aspect to avoid bundle bone resorption. Following implant placement, most groups use an internal grafting as well. With SST, the ridge contour can be maintained, even in thin wall phenotypes. *(b)* The axial cut shows the potential weakness of the SST. With the root remnant in place, it is unclear if the space between the implant and root surface in the crestal area is predictably regenerated with bone, or if it may become an entrance point for peri-implant infections during long-term function.

complications. Of those, three patients developed a severe mucosal recession all in central incisor sites. It is most likely that the sites with esthetic complications had a thin wall phenotype.

In conclusion, it is strongly encouraged to use strict selection criteria for immediate implant placement, most importantly a thick wall phenotype. All details of this attractive surgical approach are presented in chapter 7.

Partial extraction and immediate implant placement with the socket shield technique. The socket shield technique (SST) is a rather new surgical technique of immediate implant placement following partial extraction of the tooth, leaving a thin buccal portion of the root to avoid bundle bone resorption in the most critical area for the esthetic outcome (Fig 5-19).

The SST requires a fully intact buccal bone wall, but the thickness does not seem to be relevant. This

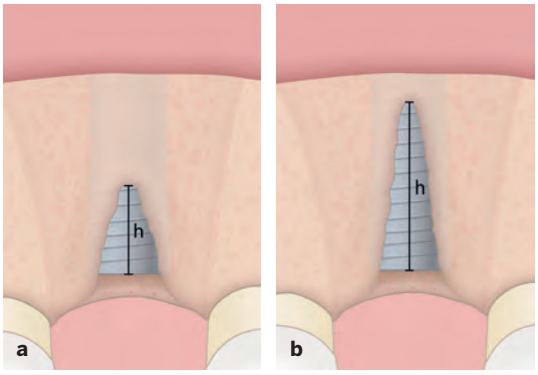


Fig 5-24 Crater-like defects are often seen in extraction sites with a thin wall phenotype. These defects have three dimensions. The first dimension is the vertical size of a defect; it ranges from short *(a)* to long *(b)*. This is not relevant for the regenerative outcome of a defect, because the bone formation is provided from the side, the mesial, and distal bone walls.

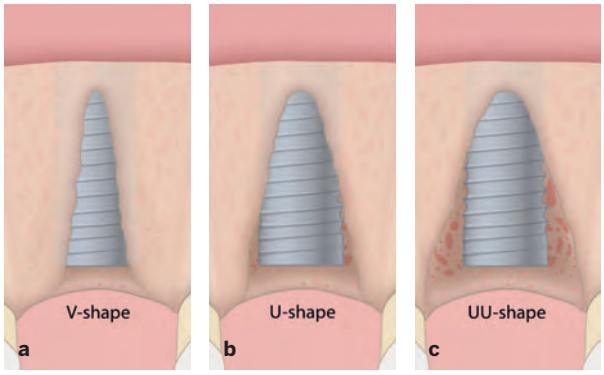


Fig 5-25 The second dimension, the mesiodistal extension of a crater-like defect in the crestal area, matters much more. A narrow defect is V-shape *(a)*, a wider one U-shape *(b)*, and a really wide one UU-shape *(c)*. V-shape defects are most favorable for regeneration. This classification was first used by Kan et al.[69]

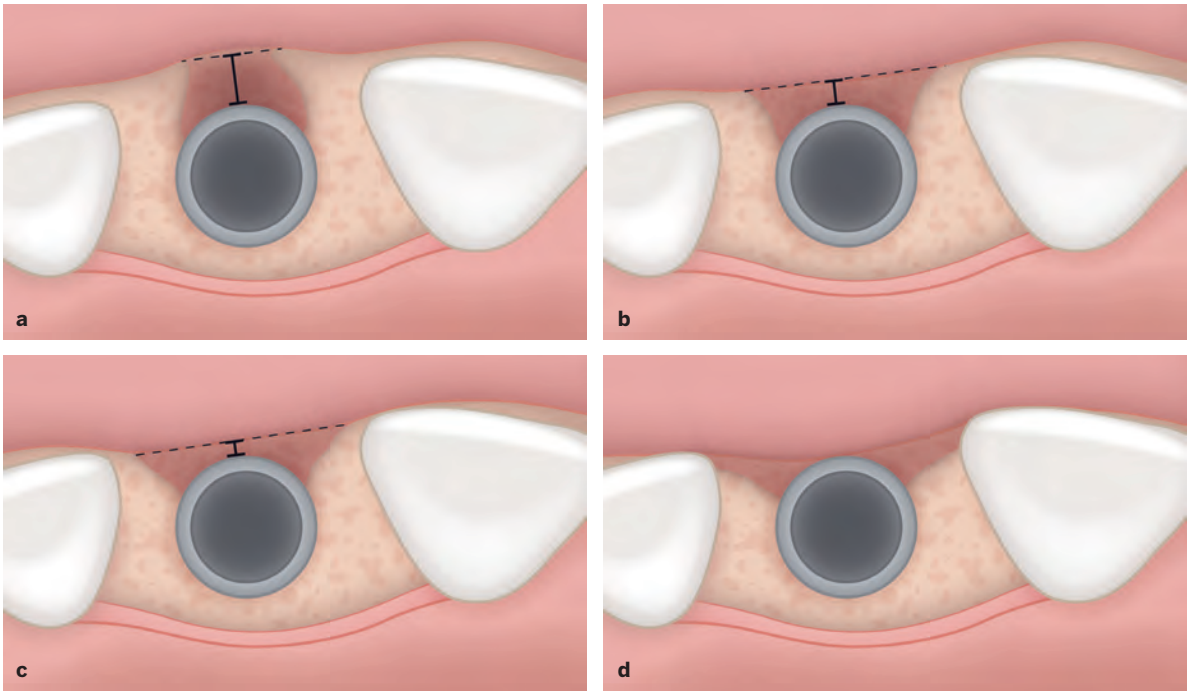


Fig 5-26 *(a)* The third dimension is the orofacial depth of a defect. Deep defects with a depth of ≥ 1 mm are most favorable. Combined with a V-shape defect, this defect morphology is most favorable for predictable regeneration. *(b)* The digital drawing shows a shallow defect (depth < 1 mm), but still with a two-wall defect morphology. *(c)* This is a borderline situation with the implant surface almost at the level of the bone surface. The defect depth is minimal. *(d)* In this situation, the exposed implant surface is outside the bony housing, and implant placement must be carefully considered. Implant placement with simultaneous GBR must be done with membrane tacks or miniscrews to optimize membrane and bone filler stability.

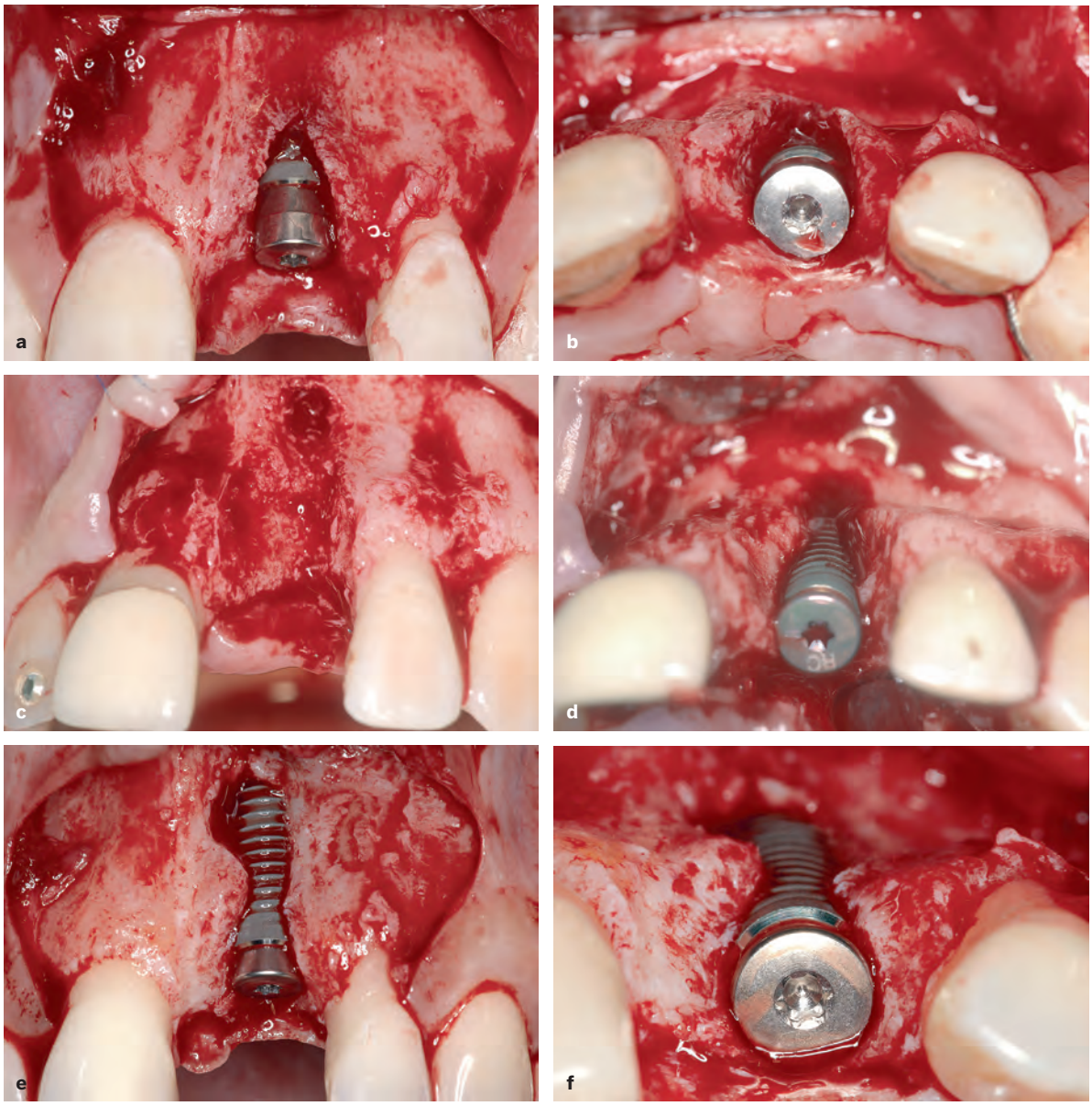


Fig 5-27 *(a)* Example of an implant with a V-shape defect 8 weeks following flapless extraction. *(b)* The occlusal view shows a deep defect, which is most favorable concerning its regenerative potential. The mesial and distal bone surface is large to provide angiogenic and osteogenic cells for bone regeneration. In addition, filler stability is optimal in such a defect. *(c)* The central incisor site has a UU-shape defect following a longstanding chronic infection at a central incisor. *(d)* The occlusal view confirms the UU-shape defect. However, the defect is deep, providing large areas of exposed, bleeding bone surfaces on the mesial and distal sides of the defect. *(e)* Lateral incisor site after implant placement 8 weeks following extraction. The buccal defect is quite extended. *(f)* The occlusal view shows a shallow defect, especially at the distal side.

and deep defect, whereas a UU-shape and shallow defect is most challenging (Fig 5-27).

In the latter defects, the problem is not only the unfavorable defect morphology, but also the stability of the applied bone fillers, which is often compromised and might need special surgical measures to be improved.

One-wall defects

Horizontal one-wall defects are always healed ridges where tooth extraction has taken place more than 6 months ago—often years ago. As well documented today, ridge alterations primarily take place on the buccal aspect.[68] The amount of ridge atrophy is influenced by various factors such as surgical trauma

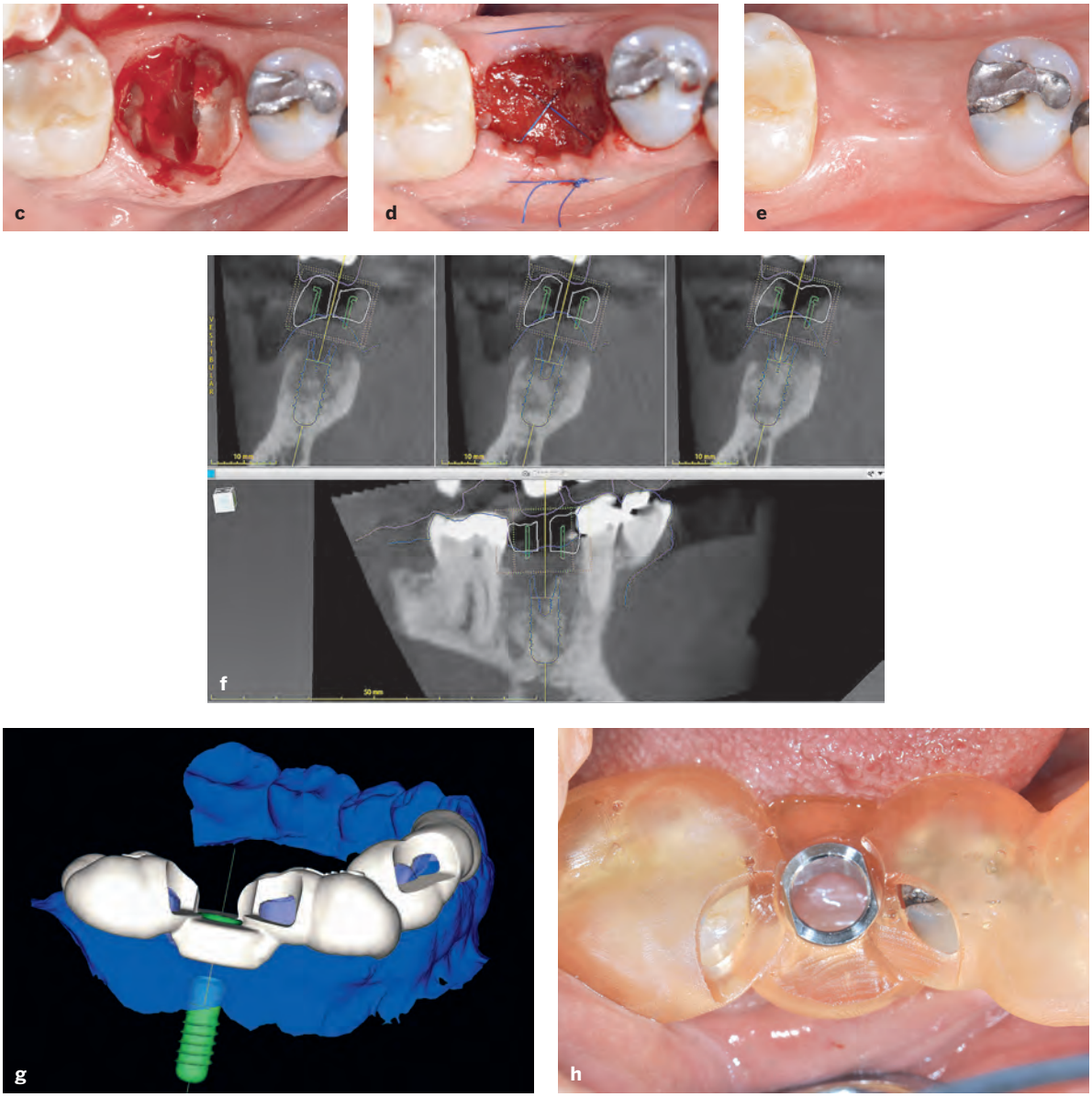


Fig 6-6 Case 1. *(cont) (c)* The extraction of the molar is done with a low-trauma technique using a horizontal decapitation, followed by a vertical root separation in a buccolingual direction. *(d)* The two root fragments are removed, and the socket rinsed and debrided. Then, the socket is filled with a bovine bone filler (deproteinized bovine bone mineral [DBBM]). *(e)* Clinical status 4 months later. The ridge is nicely healed. The ridge volume and the band of keratinized mucosa seem appropriate for a flapless implant surgery using digital technology. *(f)* The CBCT shows the planning for static CAIS (sCAIS) using a surgical stent. *(g)* The software program allows the production of the surgical stent with a sleeve by 3D printing. *(h)* Clinical try-in of the surgical stent prior to surgery. The stent has an excellent fit.

such as first molars in the mandible. This approach in posterior sites using implant placement 4 months following extraction and socket grafting is appealing for patients, because the implant can often be placed without GBR, and often with a flapless surgery using CAIS. This clearly offers a surgical approach with reduced invasiveness and better cost-effectiveness when compared to an open-flap implant placement with simultaneous GBR. A typical case is shown in Fig 6-6. This Type 3 approach is particularly attractive for elderly patients with multimorbidity, including medical risk factors such as anticoagulation medication.[76]

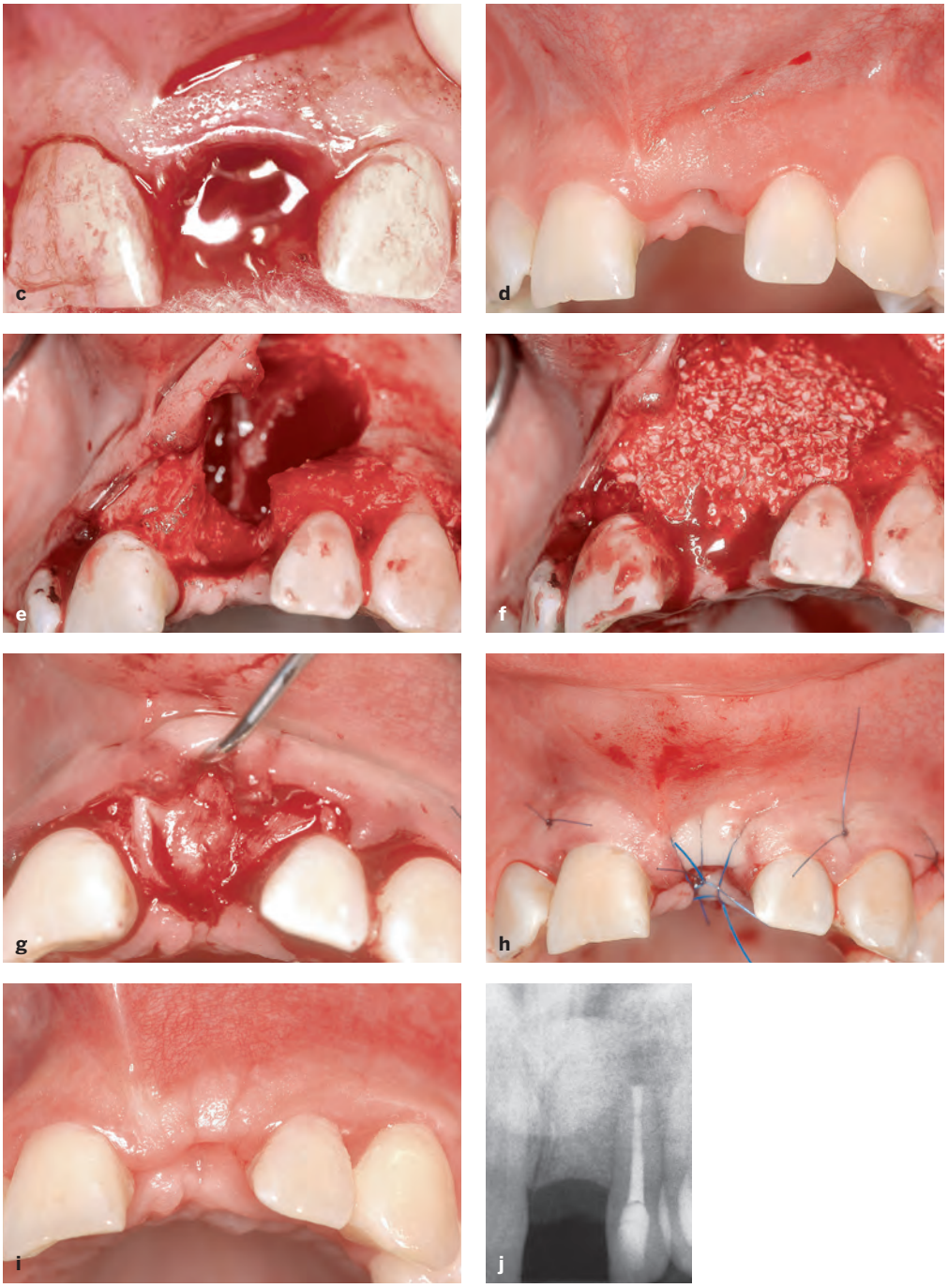


Fig 6-7 Case 2. *(cont) (c)* Clinical status following extraction of the central incisor. A lot of cystic fluid poured out of the cyst, which was thoroughly rinsed. The wound is left to heal by secondary intention. *(d)* After 4 weeks, the extraction has healed, and the patient has no symptoms. This allows the cyst to be surgically removed with a cystectomy and a simultaneous apicoectomy of the lateral incisor. *(e)* The intrasurgical view shows the large bone defect following cystectomy. The thin facial bone wall of the former extraction socket had been resorbed during the 4 weeks of healing. The crest width at adjacent teeth, however, is excellent and measures roughly 7 mm. *(f)* In the region of the left central incisor, a ridge augmentation procedure is performed with autogenous bone chips and DBBM particles (Bio-Oss, Geistlich) to augment the ridge volume for later implant placement. The apical portion of the cystic bone defect is filled with a collagen fleece. *(g)* The augmentation material is covered with a non-cross-linked collagen membrane (Bio-Gide, Geistlich). *(h)* The surgery is completed with a tension-free primary wound closure using mattress and single sutures. *(i)* Clinical status 6 months later. The site shows a complication-free wound healing. The single-tooth gap is now ready for late implant placement. *(j)* The periapical radiograph shows the local area where a ridge augmentation has been performed. The radiopaque bone filler (DBBM) can still be recognized in the central incisor region. The periapical area at the lateral incisor also shows a nice bone healing. →

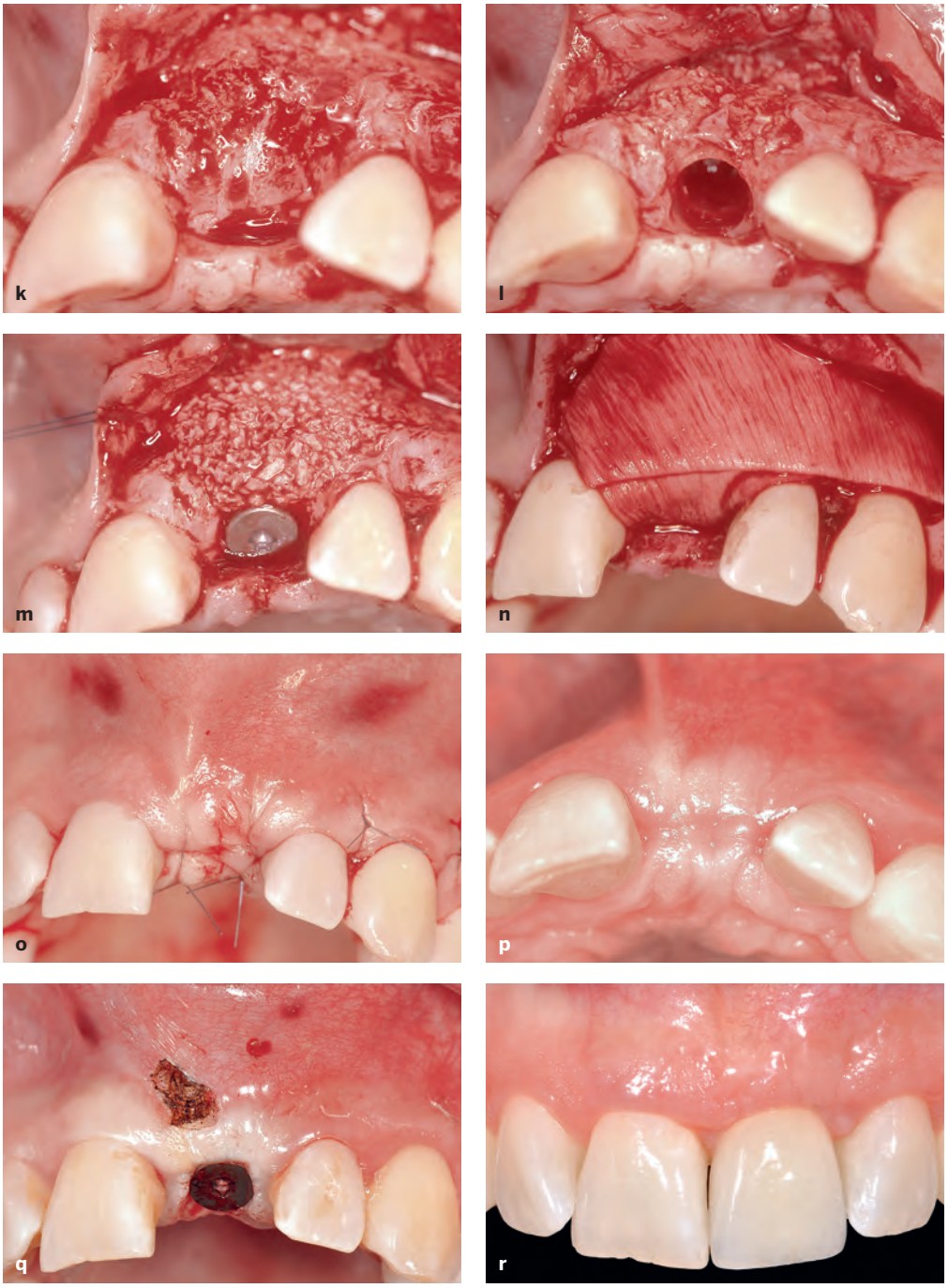
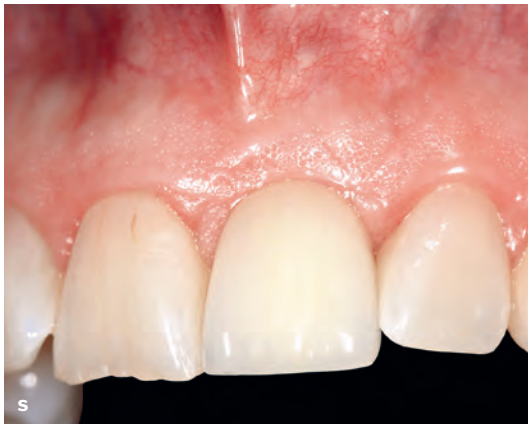
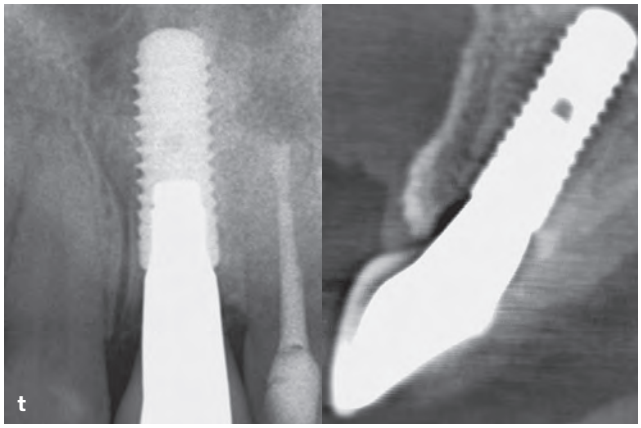
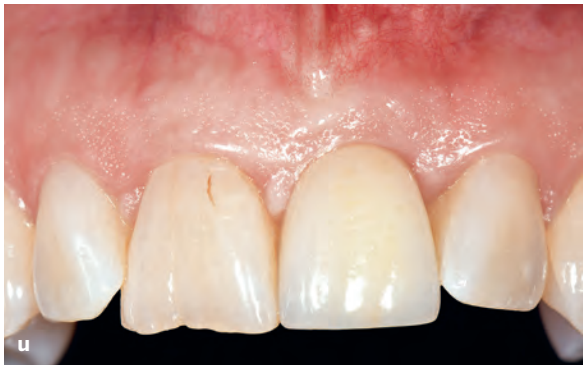
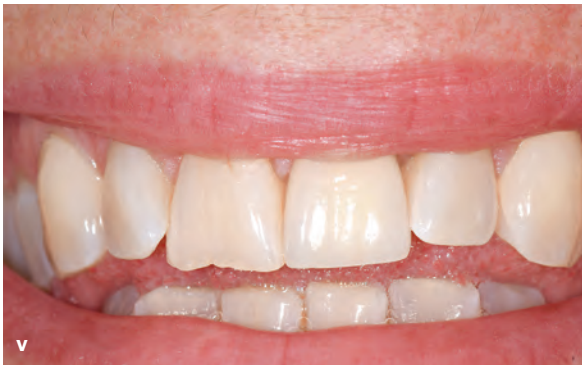


Fig 6-7 Case 2. *(cont) (k)* Following flap elevation, the occlusal view confirms a nicely healed alveolar ridge in the central incisor site. The ridge volume allows for the insertion of a standard-diameter bone-level implant. *(l)* Status following implant bed preparation. The facial bone wall is intact, but is only 1 mm thick. It was decided to perform a simultaneous contour augmentation with DBBM particles to overcontour the local ridge anatomy at the site. *(m)* Status following insertion of a bone-level implant (Straumann) and simultaneous contour augmentation with Bio-Oss DBBM. Bone augmentation is done to the rim of a 2-mm healing cap, which is left in place for the entire healing period. *(n)* The augmented area is covered with a non-cross-linked collagen membrane (Bio-Gide). *(o)* The surgery is completed with a tension-free primary wound closure. *(p)* Clinical status after 8 weeks of healing. The mucosa healed free of complications, and the ridge volume is excellent. *(q)* After 8 weeks, the implant site is reopened with a small punch, and the 2-mm healing cap is replaced with a 4.5-mm healing cap. In addition, the frenulum is cut with a CO_2 laser. *(r)* Clinical status following restoration with a full-ceramic crown. →









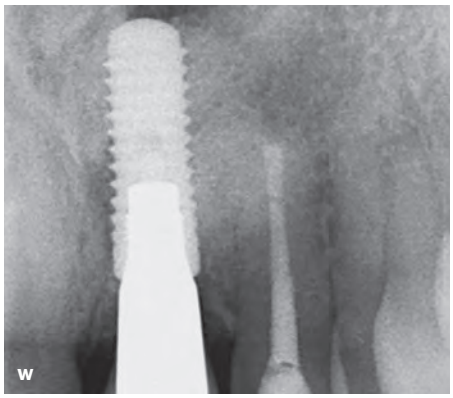


Fig 6-7 Case 2. *(cont) (s)* Clinical status at the 7-year examination (2016) demonstrating stable peri-implant mucosa. *(t)* The radiographic examination at 7 years shows stable bone crest levels. The CBCT demonstrates a thick and fully intact facial bone wall. The peak of the bone wall is located about 3 mm coronally to the implant shoulder. *(u)* Clinical status at the 10-year examination (2020) demonstrates an excellent esthetic outcome with stable peri-implant mucosa. The patient has excellent home care. *(v)* The lip line shows a pleasing esthetic outcome, and the patient is very satisfied. The prognosis for long-term stability over 30+ years is excellent. *(w)* The periapical radiograph shows stable bone crest levels. The platform-switched bone-level implant shows absolutely no bone loss after 10 years of function. (Prosthodontics performed by Dr Julia Wittneben.)

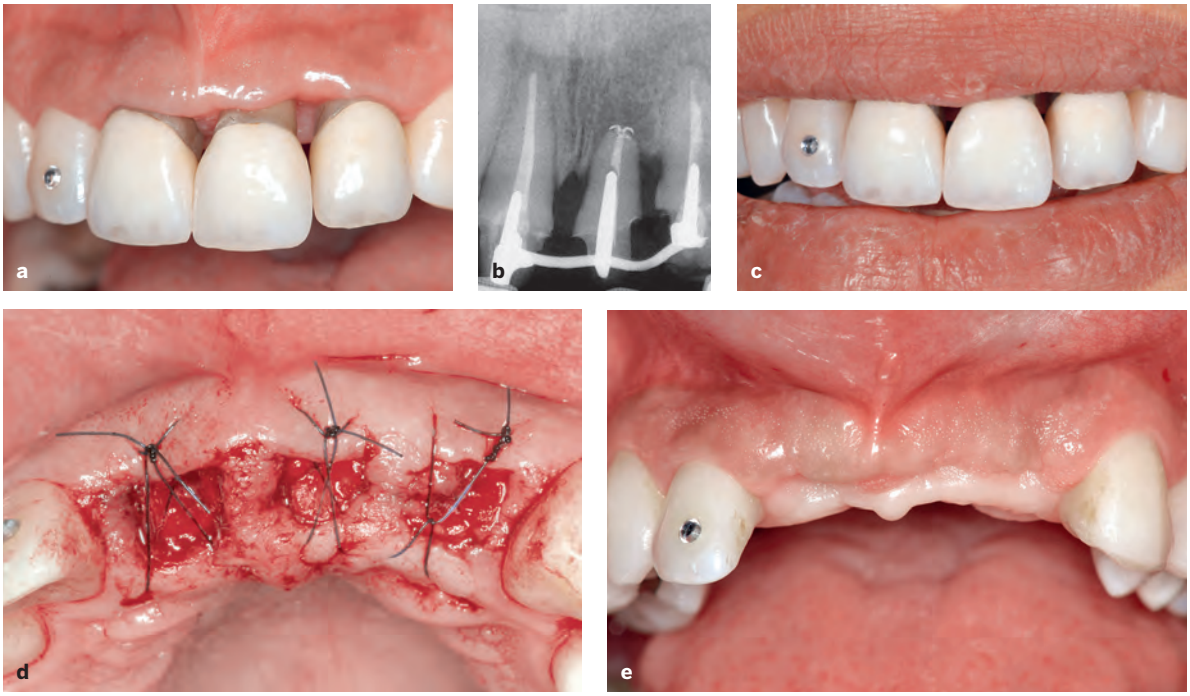


Fig 8-18 Case 4. *(a)* Initial status of a woman 10 years after a serious car accident. The three teeth involved have an extended hard and soft tissue defect. *(b)* The periapical radiograph documents the vertical bone loss, in particular around the left central incisor. *(c)* The esthetic zone is heavily compromised with two large black triangles. *(d)* Status following extraction of all three teeth. Following application of collagen plugs, the wound margins are stabilized with sutures. *(e)* Two months later, the soft tissues are well healed. The facial atrophy in the area of the left incisors is clearly visible. *(f)* The typical translucent surgical stent is tried in to be used during implant surgery for a correct 3D insertion of two TL implants.

missing maxillary lateral incisors without interfering with embrasure space toward the adjacent central pontics. Since the introduction of Roxolid (Straumann) implants featuring a titanium-zirconium (Ti-Zr) alloy, concerns about questionable mechanical resistance properties (ie, two NDIs having to support two central pontics) have been dispelled.[40]

The second principle is the routine use of local contour augmentation as previously described. Besides the augmentation of both implant sites, bone augmentation is extended to the future pontic and—if present—to the cantilever area. Bone augmentation is performed not only in a horizontal direction, but also slightly in a vertical direction to optimize soft tissue height in these areas. With regard to the fact that the soft tissue thickness in the pontic area only measures 3 to 4 mm,[41] it is obvious that the esthetic outcome is always slightly compromised, because these pseudo papillae in the pontic area are reduced in height and feature a so-called "blunt" morphology. If the resulting vertical soft tissue deficiency results in an unacceptable esthetic outcome, the use of pink ceramics must be considered.[42,43]

Three typical case reports are shown in Figs 8-18 to 8-20.

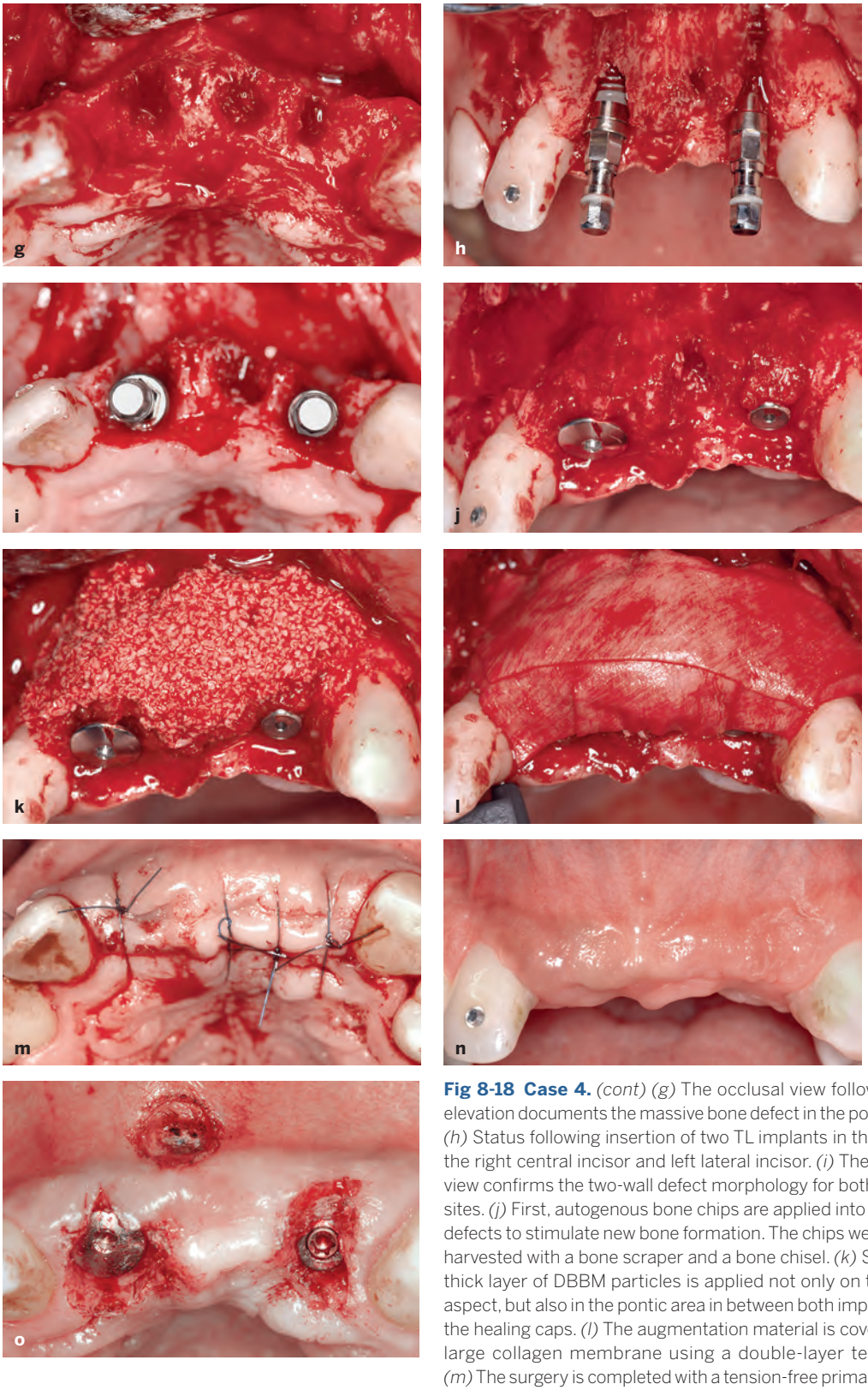


Fig 8-18 Case 4. *(cont) (g)* The occlusal view following flap elevation documents the massive bone defect in the pontic area. *(h)* Status following insertion of two TL implants in the sites of the right central incisor and left lateral incisor. *(i)* The occlusal view confirms the two-wall defect morphology for both implant sites. *(j)* First, autogenous bone chips are applied into the bone defects to stimulate new bone formation. The chips were locally harvested with a bone scraper and a bone chisel. *(k)* Second, a thick layer of DBBM particles is applied not only on the facial aspect, but also in the pontic area in between both implants and the healing caps. *(l)* The augmentation material is covered by a large collagen membrane using a double-layer technique. *(m)* The surgery is completed with a tension-free primary wound closure. *(n)* Soft tissue status following complication-free wound healing. *(o)* Both implant sites are reopened and the short healing caps replaced by longer ones. →

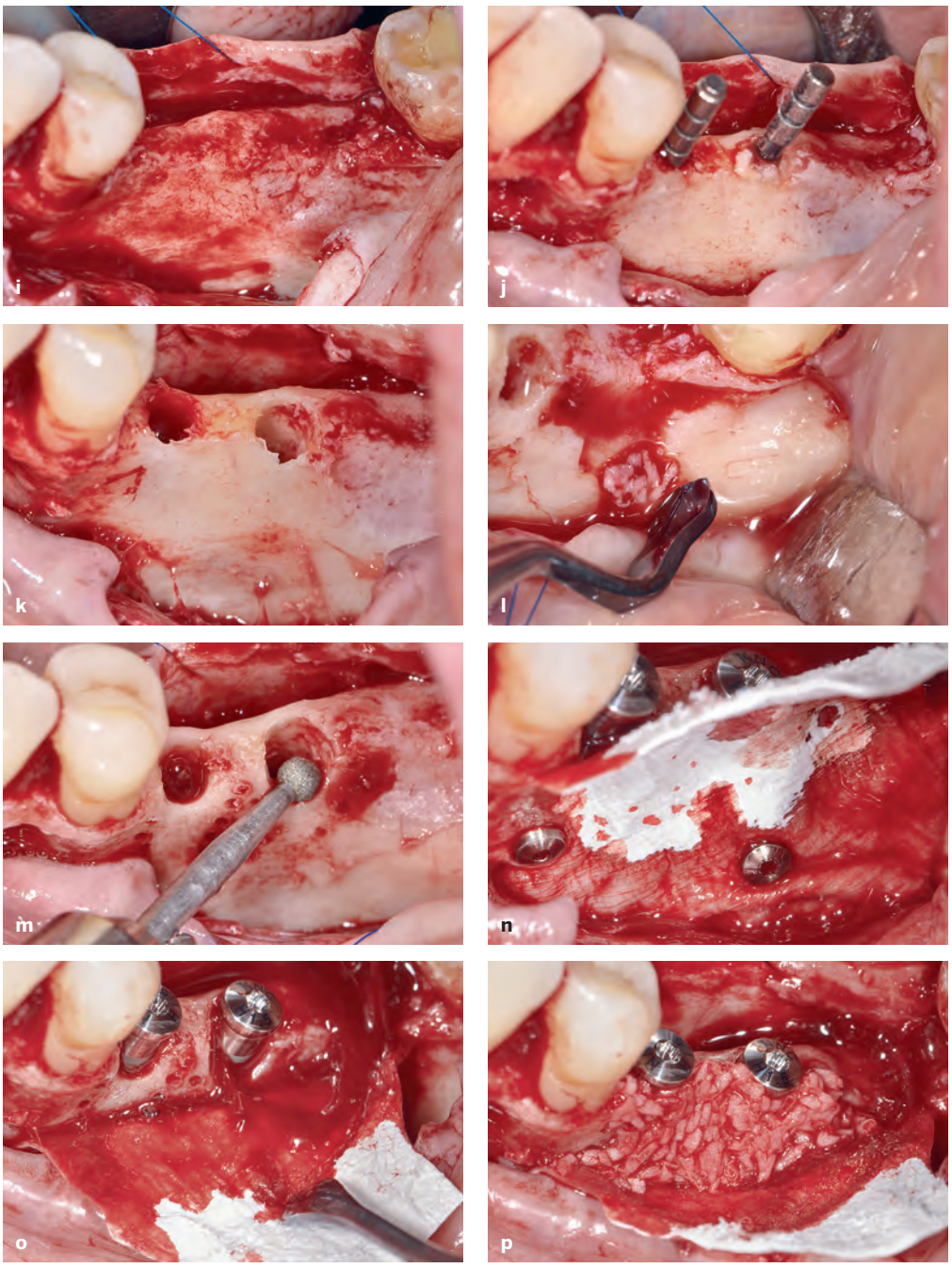


Fig 9-15 Case 5. *(cont) (i)* Intraoperative view following elevation of the mucoperiosteal flap. The horizontal bone atrophy is apparent. *(j)* Status following initial preparation with the first spiral drill. The small depth gauges are in place to check implant position and implant axis. *(k)* Upon completion of implant bed preparation, the two buccal bone walls have a thin, knife-edge anatomy. Both need to be removed, otherwise osteoclastic activity would be triggered due to avascular necrosis. *(l)* Autogenous bone chips are harvested in the distal area with a Hu-Friedy Buser Bone Scraper. The scraper must be sharp. The chips are stored in a solution of blood and sodium chloride to cause the spontaneous release of growth factors in order to get a bone-conditioned medium (BCM). *(m)* The thin buccal bone walls are reduced in height with a diamond round bur to eliminate the risk of a massive osteoclastic activity during early healing due to avascular necrosis. This bone preparation creates a horizontal bottom for both defects. *(n)* Following insertion of the two NNC implants, a collagen membrane is applied and fixed with two fixation screws. *(o)* This view shows the two NNC implants, both with a 1.5-mm healing cap, buccal bone defects with an exposed microrough implant surface, perforated buccal cortex to stimulate bleeding, and collagen membrane fixed with tacks. *(p)* The first layer of bone chips is applied and covers the entire augmentation area. →

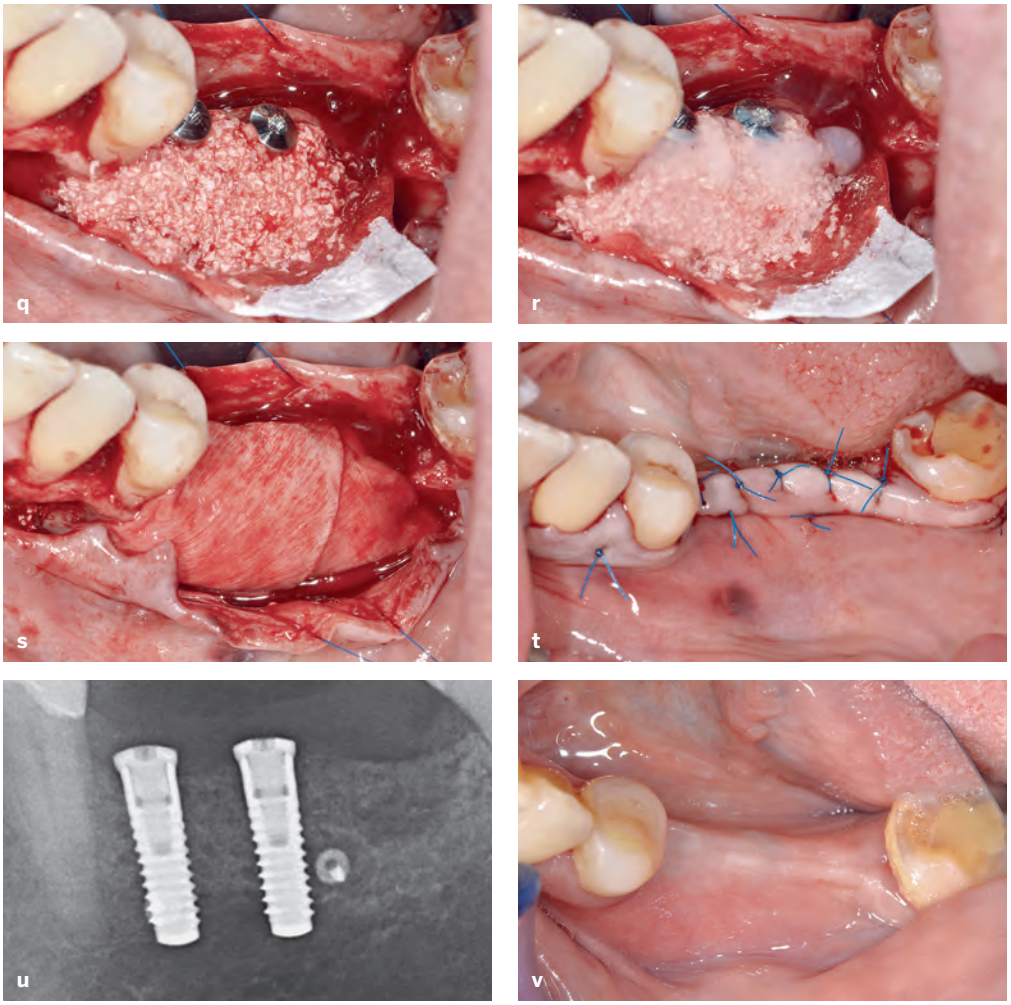
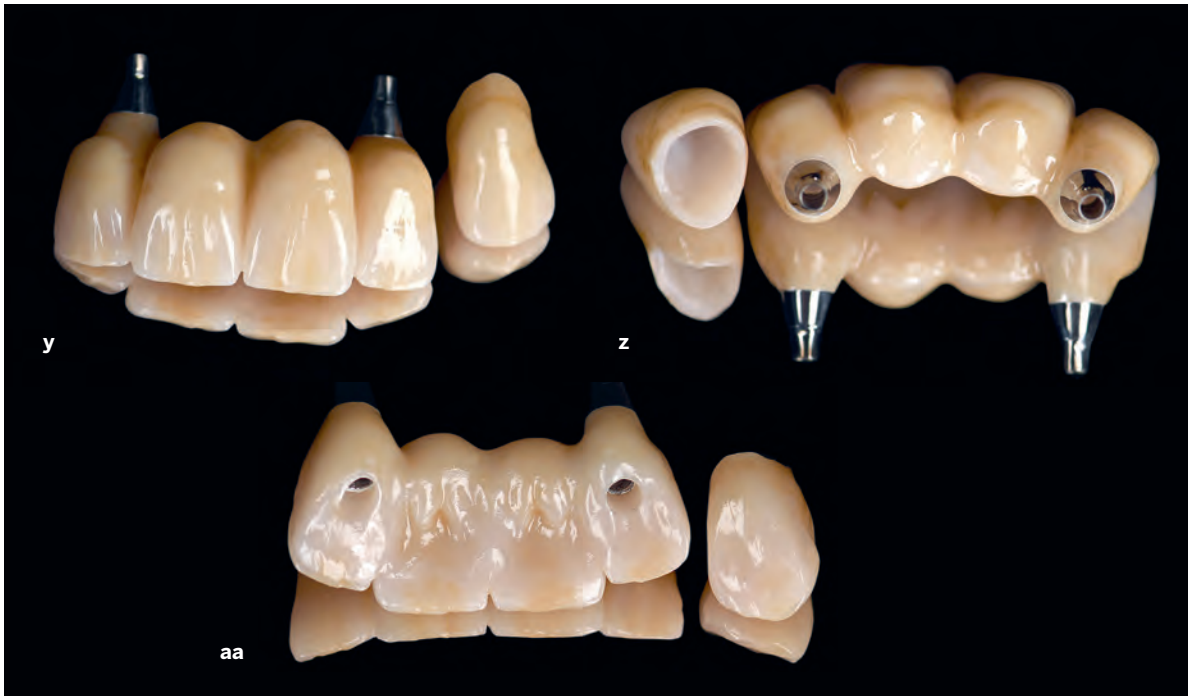
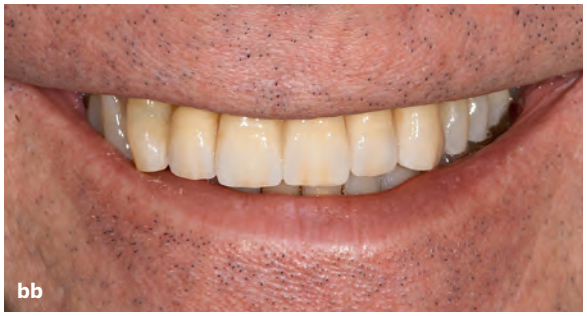
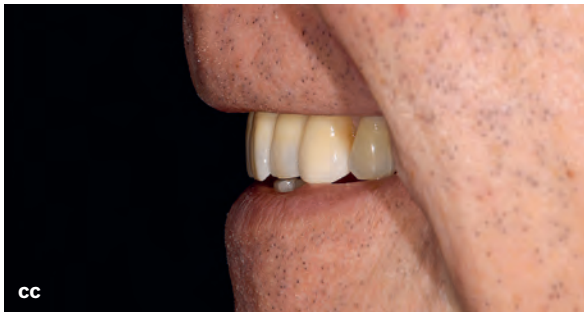
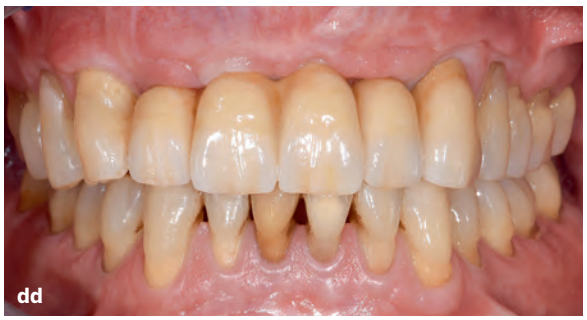


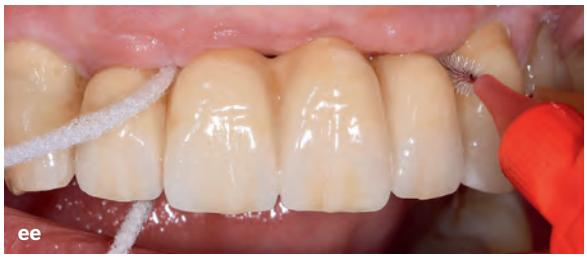
Fig 9-15 Case 5. *(cont) (q)* The second layer with BCM-activated DBBM particles improves the augmentation volume significantly. With the BCM technique, the entire augmentation volume is enriched with growth factors. *(r)* To further stabilize the applied bone fillers, fibrin sealant (Tisseel) is used. *(s)* Finally, the large membrane is flipped over to the lingual side and nicely adapted deep underneath the lingual flap on the lingual bone surface of the mandible. The membrane nicely falls in place and is very stable. This type of augmentation is often called the *sausage technique*. *(t)* Following incision of the periosteum, the surgery is completed with a tension-free primary wound closure. Two horizontal mattress sutures (size 4-0), and multiple interrupted single sutures (size 5-0) are used. *(u)* The postoperative radiograph shows the two NNC implants, the two fixation screws, and the small perforations in the buccal cortex. *(v)* Clinical status 2 months later. The soft tissues have healed without any complications. *(w)* The implant sites are reopened with a midcrestal incision to maintain the keratinized mucosa. An Osstell SmartPeg is inserted. The ISQ values measure 74 and 78. →











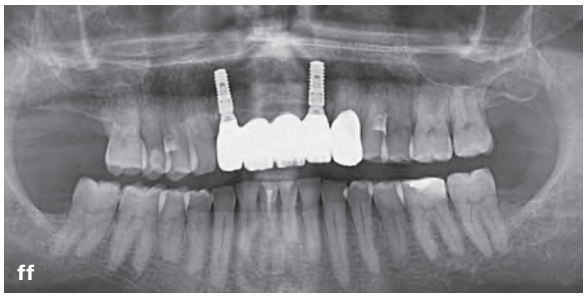


Fig 10-2 *(cont) (y to aa)* The definitive prosthetic restorations have an ovate pontic with an emergence profile. *(bb and cc)* Maximum smile line. *(dd)* Frontal intraoral view. *(ee)* The reconstructions allow optimal access for oral hygiene. *(ff)* Radiographic situation at 1-year follow-up. (Restoration prepared by Nadin Al-Haj Husain, Bern, Switzerland.)

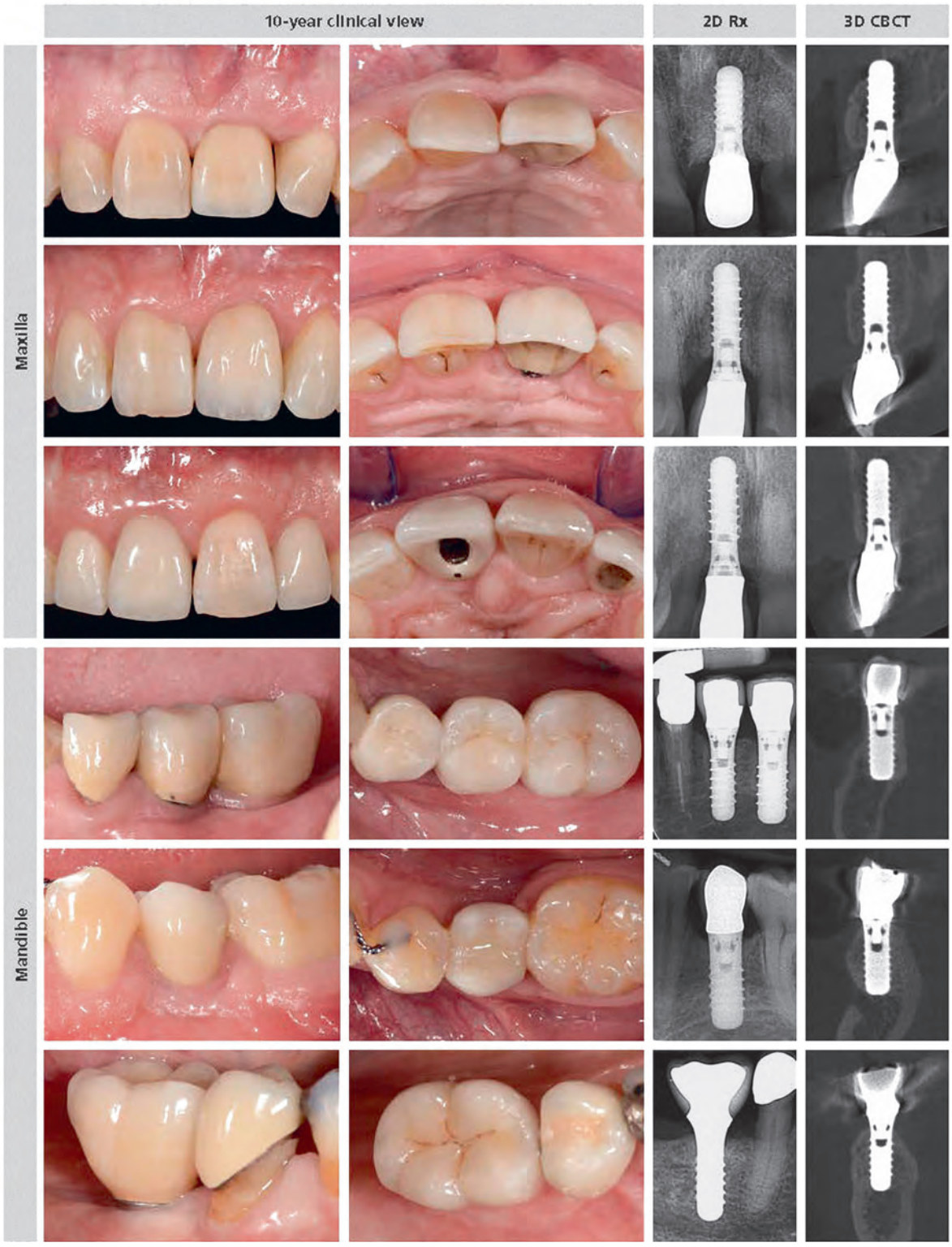


Fig 10-3 Three representative case series for the maxilla and the mandible, showing only minor graft resorption at the 10-year examination. (Reprinted with permission from Chappuis et al.[142])

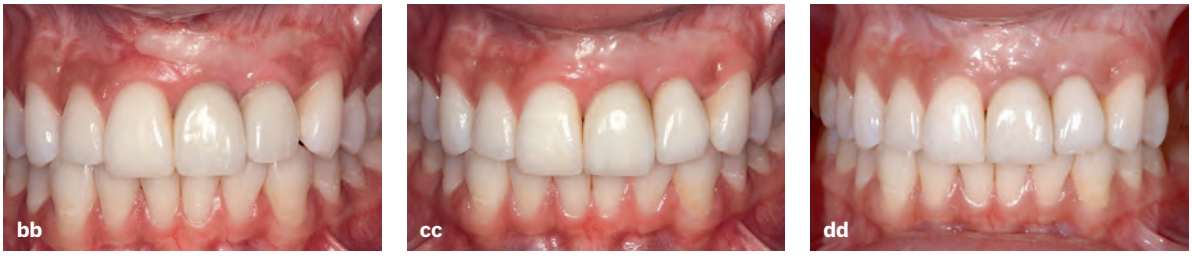


Fig 12-5 Case 5. *(cont) (bb and cc)* Clinical view of the positive coronal fill and soft tissue healing after 2 months and after 6 months of a perioplasty laser procedure to blend in the soft tissue graft margins. *(dd)* Three-year follow-up of two zirconia layered ceramic crowns cemented on the one abutment–one time placed zirconia abutments. Note the positive fill of the papilla between the central and lateral implant incisors and the increase of keratinized buccal tissue, resulting in a pleasing gingival smile design with natural crown contour and length. (Prosthetics: Dr Kyle Stanley, Los Angeles, California.)

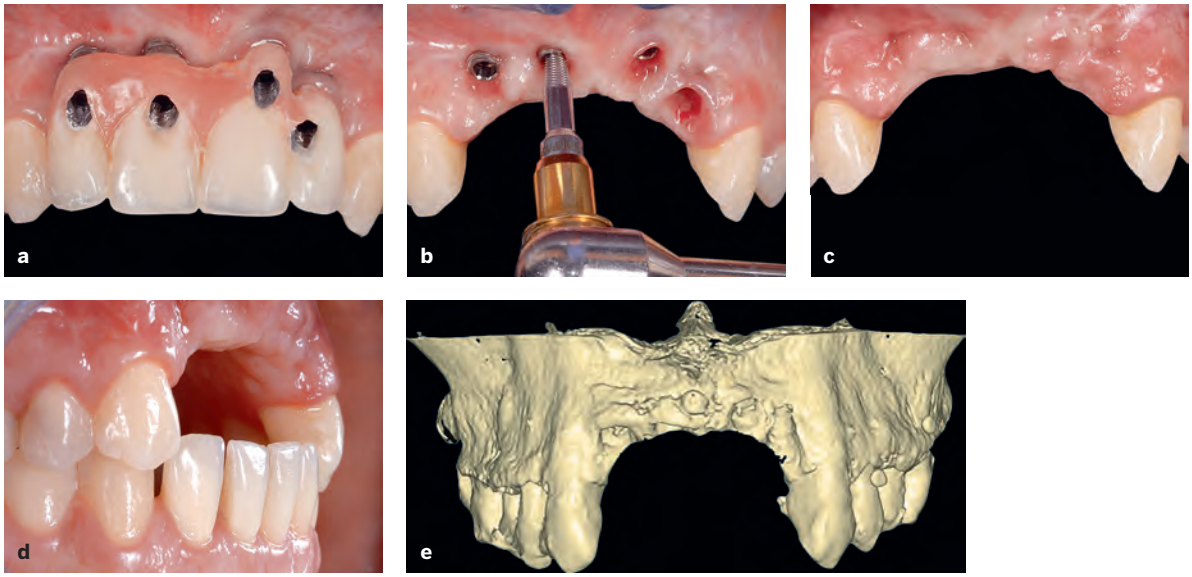


Fig 12-6 Case 6. *(a and b)* Clinical view of a compromised anterior maxilla with an unesthetic implant prosthesis treated with four malpositioned implants. Note the close proximity and deep placements of the implants, resulting in inflammation, bleeding, and painful peri-implant mucosa. The implants were removed atraumatically with an implant removal tool and reverse torque. *(c and d)* Buccal and lateral views of the healed ridge 2 months after implant placement. Note the healthy soft tissue coverage but severe atrophy of the anterior maxilla in the horizontal and vertical dimensions. *(e)* CBCT buccal view of the severe loss of hard tissue in the anterior maxilla.

Case 6

Figure 12-6 shows an example of replacement of a severely compromised anterior ridge and existing implant-supported prosthesis with new implants and regenerated hard and soft tissue volume.

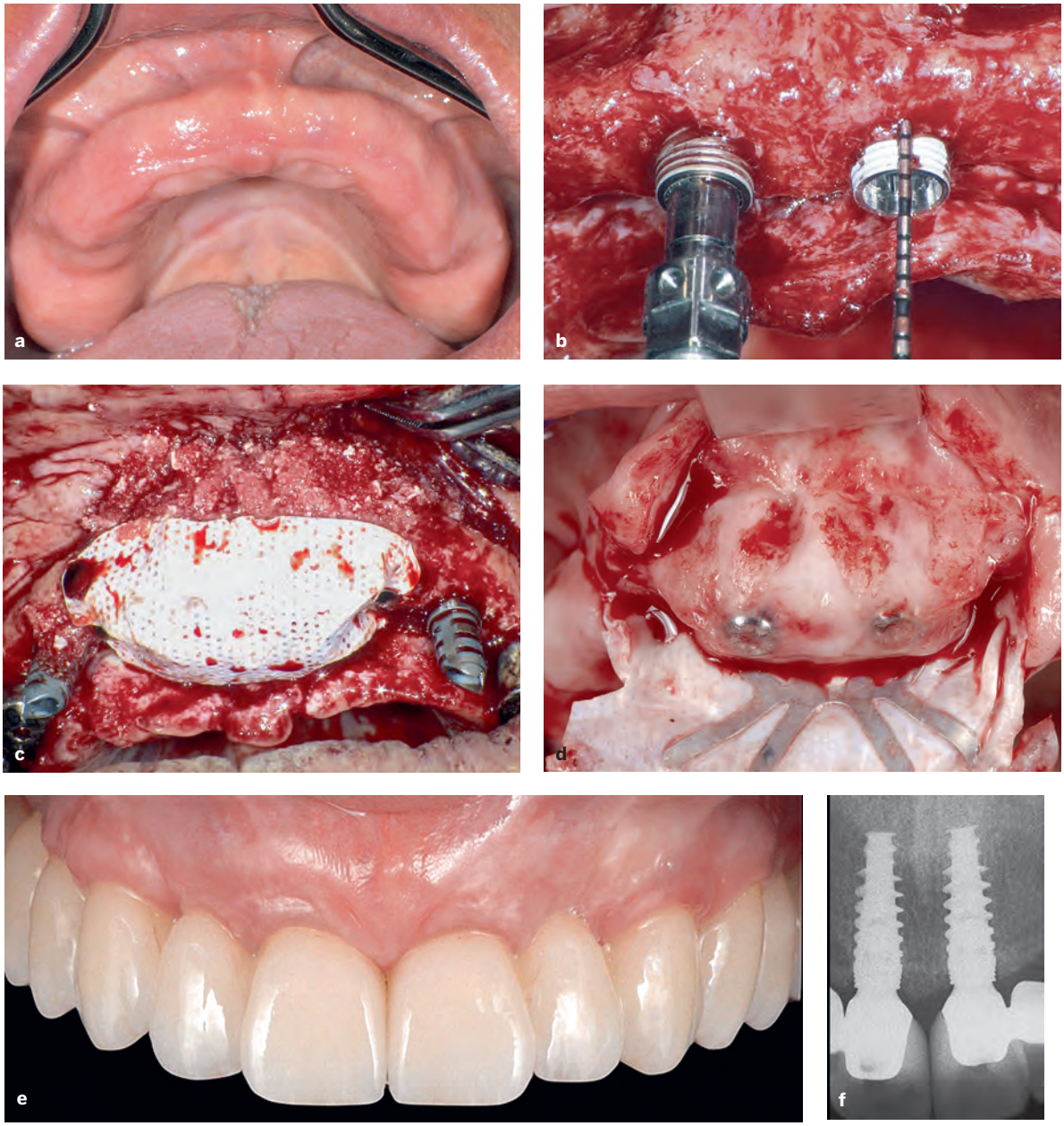


Fig 12-7 Case 7. *(a and b)* Edentulous case with deficient anterior maxilla treated with eight dental implants. The two central incisor implants were placed 3 mm supracrestally for ideal implant crown length and soft tissue margin development. *(c and d)* The two anterior implants were treated with a simultaneous vertical submerged GBR procedure using an immobilized titanium-reinforced PTFE membrane and a mixed auto/xenograft. After an uneventful 9-month healing period, the membrane was removed and demonstrated a full vertical and buccal ridge augmentation around the two anterior implants. *(e and f)* Five-year clinical follow-up of a fully restored maxilla with four three-unit zirconia/ceramic partial dentures with stable crestal bone and soft tissue stability. Note the fully restored marginal gingiva around the two central incisor implants. (Prosthetics: Dr Francesco Mintrone, Modena, Italy.)

Case 7

Figure 12-7 shows an example of an edentulous case with a deficient anterior maxilla treated with anterior vertical GBR and posterior bilateral sinus augmentation with simultaneous implant placement, resulting in an optimal esthetic rehabilitation.

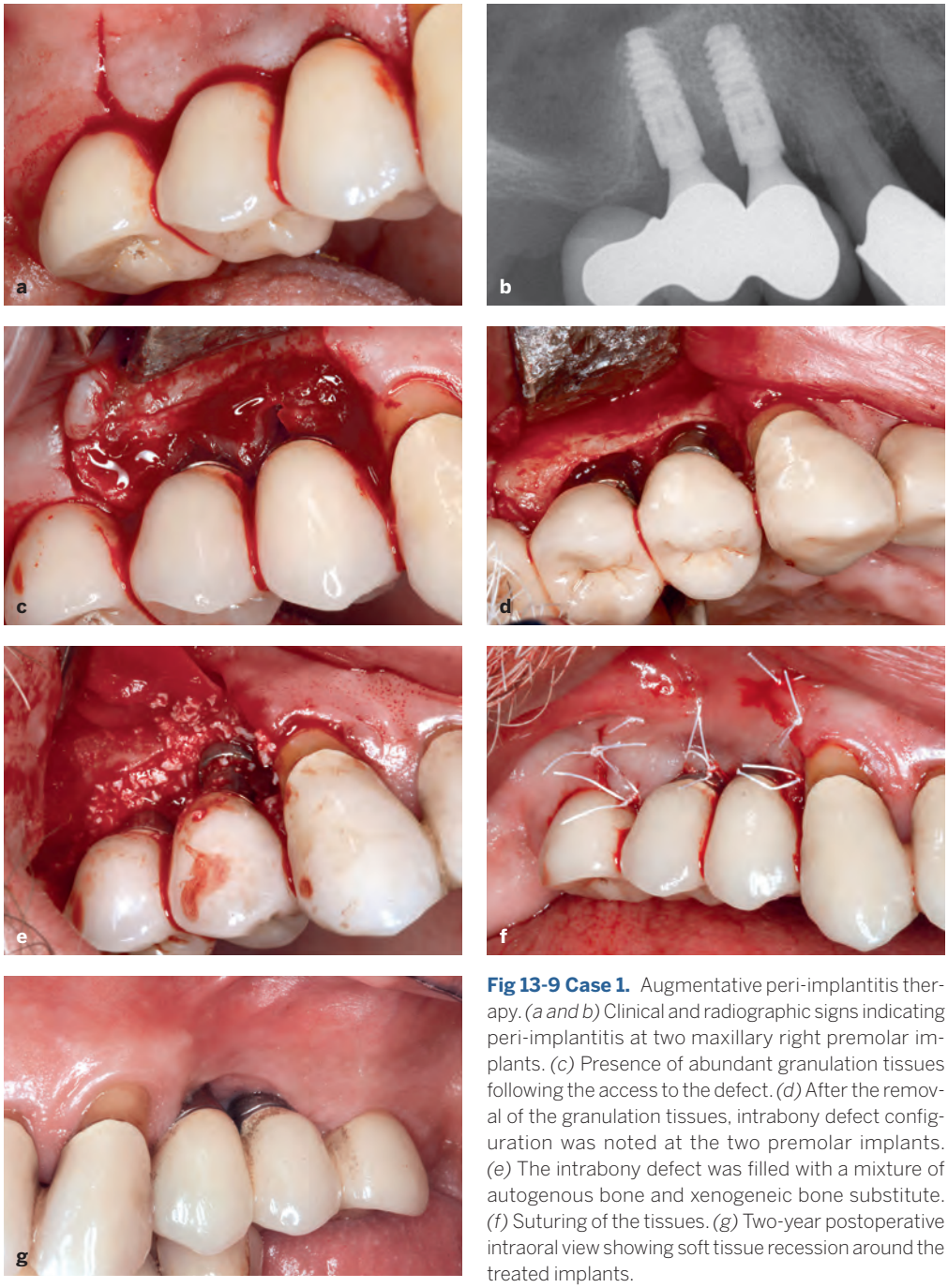


Fig 13-9 Case 1. Augmentative peri-implantitis therapy. *(a and b)* Clinical and radiographic signs indicating peri-implantitis at two maxillary right premolar implants. *(c)* Presence of abundant granulation tissues following the access to the defect. *(d)* After the removal of the granulation tissues, intrabony defect configuration was noted at the two premolar implants. *(e)* The intrabony defect was filled with a mixture of autogenous bone and xenogeneic bone substitute. *(f)* Suturing of the tissues. *(g)* Two-year postoperative intraoral view showing soft tissue recession around the treated implants.

Outcomes of combined therapy

Compared with baseline, combined peri-implantitis therapy significantly reduced signs of soft tissue inflammation (ie, BOP, PD, and suppuration) and resulted in a mean radiographic intrabony defect fill of 87% to 93%.[26–28] The majority of the patients (60%) presented with peri-implant tissue health (ie, absence of BOP) 7 years after the combined therapy[26] (Figs 13-9 to 13-12).

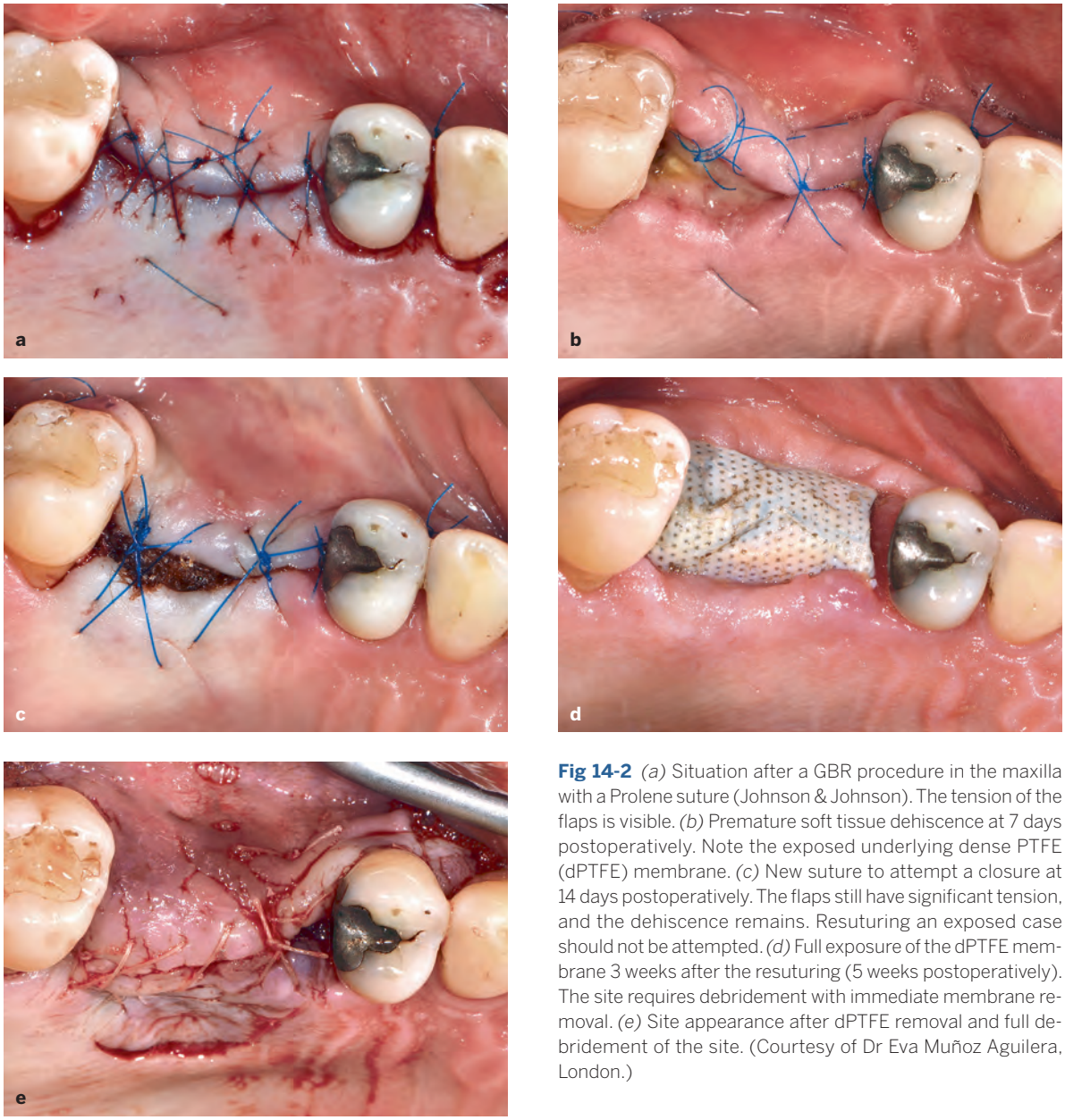


Fig 14-2 *(a)* Situation after a GBR procedure in the maxilla with a Prolene suture (Johnson & Johnson). The tension of the flaps is visible. *(b)* Premature soft tissue dehiscence at 7 days postoperatively. Note the exposed underlying dense PTFE (dPTFE) membrane. *(c)* New suture to attempt a closure at 14 days postoperatively. The flaps still have significant tension, and the dehiscence remains. Resuturing an exposed case should not be attempted. *(d)* Full exposure of the dPTFE membrane 3 weeks after the resuturing (5 weeks postoperatively). The site requires debridement with immediate membrane removal. *(e)* Site appearance after dPTFE removal and full debridement of the site. (Courtesy of Dr Eva Muñoz Aguilera, London.)

wounds should never be attempted. This is a common mistake that worsens the consequences of a premature membrane exposure (Fig 14-2).

Complications by alteration of anatomical landmarks

As mentioned earlier, when providing GBR therapy, there is a risk of neurosensory and vascular complications. A recent review reported that serious vascular complications due to damage in the floor of the mouth are infrequent but have potentially serious consequences that will require urgent and specialized management.[28] Based on the published case reports, controlling these complications will require maintaining airway patency (through naso- or orotracheal intubation or tracheostomy) and arresting the bleeding. Exploratory surgery in the floor of the mouth is required in the majority of the individuals to evacuate