

TILTED IMPLANTS
IMPLANT-PROSTHETIC REHABILITATION OF THE ATROPHIC PATIENT







TILTED IMPLANTS

IMPLANT-PROSTHETIC REHABILITATION OF THE ATROPHIC PATIENT

ENRICO AGLIARDI, MD, DDS, PhD

Director
Advanced Oral Surgery Unit
School of Dentistry
Vita-Salute San Raffaele University
Milan, Italy

DAVIDE ROMEO, DDS, PhD

Adjunct Assistant Professor
Advanced Oral Surgery Unit
School of Dentistry
Vita-Salute San Raffaele University
Milan, Italy

With contributions from Matteo Clericò, DDS

 QUINTESSENCE PUBLISHING

Berlin | Chicago | Tokyo
Barcelona | London | Milan | Mexico City | Moscow | Paris | Prague | Seoul | Warsaw
Beijing | Istanbul | Sao Paulo | Zagreb



This book was originally published in Italian under the title *Tilted implants: Riabilitazione implanto-protesica del paziente atrofico* by Quintessenza Edizione, S.r.l. in Milan, Italy, in 2018.

Library of Congress Cataloging-in-Publication Data

Names: Agliardi, Enrico, author. | Romeo, Davide, author.

Title: Tilted implants : implant-prosthetic rehabilitation of the atrophic patient / Enrico Agliardi, Davide Romeo.

Other titles: Tilted implants. English

Description: Batavia, IL : Quintessence Publishing, Co. Inc., [2020] | This book was originally published in Italian under the title *Tilted Implants: Riabilitazione Implanto-Protesica del Paziente Atrofico* by Quintessenza Edizione, S.r.l. in Milan, Italy, in 2018. | Includes bibliographical references and index. | Summary: "Methods for placing different types of tilted implants in different configurations (eg, All-on-4, V-II-V, transsinus, zygomatic) including step-by-step protocols from patient evaluation to surgery to provisional and definitive prosthesis fabrication, featuring dozens of detailed clinical cases"-- Provided by publisher.

Identifiers: LCCN 2019047551 (print) | LCCN 2019047552 (ebook) | ISBN 9780867158182 (hardcover) | ISBN 9780867159936 (ebook)

Subjects: MESH: Dental Implantation--methods | Dental Implants | Osseointegration | Case Reports

Classification: LCC RK667.I45 (print) | LCC RK667.I45 (ebook) | NLM WU 640 | DDC 617.6/93--dc23

LC record available at <https://lcn.loc.gov/2019047551>

LC ebook record available at <https://lcn.loc.gov/2019047552>



© 2020 Quintessence Publishing Co, Inc

Quintessence Publishing Co, Inc

411 N Raddant Road

Batavia, IL 60510

www.quintpub.com

5 4 3 2 1

All rights reserved. This book or any part thereof may not be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, or otherwise, without prior written permission of the publisher.

Editor: Marieke Zaffron

Design: Sue Zubek

Production: Christine Cianciosi & Angelina Schmelter

Printed in China



Preface	<i>vi</i>
Acknowledgments	<i>vii</i>
Contributors	<i>viii</i>
Introduction	<i>ix</i>
1	The Biology of Osseointegration <i>1</i>
2	Osseointegration in Immediate Loading <i>19</i>
3	Immediate Loading with Tilted Implants <i>39</i>
4	Advantages of Tilting Dental Implants <i>63</i>
5	Evaluation of Edentulous Patients <i>75</i>
6	Diagnostics and Planning for Complex Rehabilitation <i>107</i>
7	Rehabilitation of the Compromised Patient <i>143</i>
8	Rehabilitation Protocols for the Maxilla <i>159</i>
9	Rehabilitation Protocols for the Mandible <i>273</i>
10	Provisional Prosthetic Solutions <i>305</i>
11	Definitive Prosthetic Solutions <i>335</i>
Index	<i>417</i>

T*ilted Implants* is a book that arises from the desire to share with the highest number of colleagues over 15 years of experience on implant-prosthetic rehabilitations with tilted implants. These types of restorative solutions were initially considered as innovative methods, while today they are commonly used by many clinicians around the world. Years of commitment and enthusiasm for the revolution that tilted implants brought into implant dentistry, but also frustration for the initial ostracism we have seen, have allowed us to develop a profound surgical and prosthetic knowledge that we wanted to share in its entirety, without concealing anything from the reader. The main objective from our side was to provide clinicians not only with a practical guide for the available treatment options, but also to analyze the individual procedures, with a detailed description of each step.

The World Health Organization reports a progressive aging of the population and a growing number of patients who are completely edentulous in advanced age. Added to these are the patients with a previous implant rehabilitation that has failed, those with terminal periodontitis, and those who have severely compromised fixed or removable prostheses where it will not be possible to preserve any teeth for the new rehabilitation. Very often dentists must face situations of limited bone quantity, systemic conditions that are not ideal, and the need to reduce both biologic and financial costs.

To meet this growing need, treatment protocols have been used in the last decade that incorporate tilted implants, supported by an extensive scientific literature and with high success rates in the long term. The first of these protocols is undoubtedly the All-on-4. Its winning feature, which allowed its diffusion on a global scale, was the apparent simplicity of application, even in the most complicated clinical scenarios. In reality, the excellent survival rate, reported by the most accredited scientific publications, occurs only if precise surgical techniques, a proper prosthetic protocol, and biomechanics principles are adopted, leaving limited space

for improvisation. As with all surgical techniques, a good basic predisposition is therefore necessary, as well as a learning curve and a continuous critical review of what has been done.

This manuscript therefore includes a detailed description of treatment protocols that include the use of tilted implants, such as All-on-4, V-II-V, transsinus implants, and zygomatic implants.

Starting from a review of the scientific basis of immediate loading and the advantages deriving from implant inclination, we have addressed all the necessary diagnostic aspects for a correct treatment plan. We focus on presurgical planning, a fundamental starting point for the correct management of the immediate provisional prosthesis. The part dedicated to the surgical protocols—the true heart of the book—allows the reader to learn the ideal rehabilitative path, both for contained bone deficits and for extreme atrophy, guiding the operator in use of the patient's residual bone as a function of immediate loading. The work concludes with a step-by-step description of the provisional and definitive prosthetic protocols that have been developed over 15 years of clinical and research experience.

Tilted Implants is not just an implant surgery book but represents a practical guide and a daily resource for anyone who wants to approach these techniques and is looking for a point of reference to perform cutting-edge rehabilitative treatments in the interest of their patients. For those who already apply these techniques successfully, the wish is that they can find confirmation in what they do and maybe new ideas for further professional growth.

Finally, we would like to thank all our contributors for their excellent cooperation. Special thanks to the main contributor, Dr Matteo Clericò. Without his fundamental work, this book would still be a splendid project for the future. Thank you to Dr Parveen Virdee and Dr Kristen Frantz for their help with the linguistics.

In addition, many thanks to the entire team at Quintessenza Italia and Quintessence Publishing for their excellent support and patience during this time.

A very big thank you to Matilde, my wife, the love of my life, who with her silent intelligence has accompanied me over the years, always creating a safe haven, our family, where I can repair myself and rediscover the energy to write the book. A loving thanks to my beloved children Jacopo, Costanza, and Carlotta who, with their love and their joy of life, repay my every effort and make sense of it. To my father, Raffaele “Gigi,” a great man who passed away a few years ago, to whom I owe many of my abilities. I dedicate this book to him. A heartfelt thanks to my mother Franca and to my brother Mauro, a man and physician of great integrity who was a guide and an example for me to imitate. I hope you are proud of me.

To all my teachers. There are too many to remember them all, considering I have learned from all the people I have been lucky enough to meet. One exception—a special thanks to Paulo Maló, who gave me the honor of his friendship, his explosive desire to innovate, and his intellectual liveliness, to which I owe much of everything I managed to do in the field of rehabilitation of compromised patients.

Last but not least, a big thank you to my dental technicians Matteo Consonni, Stefano Rota, and Marco Ghisleni, who gave me the honor of working with them. Thanks again to the other contributors who helped us with their valuable scientific contributions: Raffaele Vinci, Riccardo Benzi, Alessandra Carrera, Federico Mandelli, Stefano Panigatti, Michele Manacorda, Vittoria Terraneo, Marco Vigoni, and the young doctors Daria Saporiti and Federica Grangia.

—EA

The biggest thanks goes to my parents, Elio and Lina, model of life and source of inspiration, for having guided and sustained my steps with their smile and for transmitting to me the values of honesty, perseverance, and sacrifice.

To my wife Michelle, for the infinite love and joy that fill my days, and for the patience and the strength with which, as a colleague, she supports my every professional choice. To my friend and teacher, Dr Enrico Agliardi, who has believed in me since I was a young student of dentistry and who gave me the honor of participating in his clinical and professional activities. Without envy or self-interest, he opened the doors of his practice, showing me the art of oral surgery. The teachings he has transmitted to me are innumerable, while he infected me with the passion he has for this profession. Being at his side is a privilege that few have had, and it is an honor that I find difficult to repay. My eternal gratitude goes to him for wanting to combine his name with mine in this book, which I hope will represent a starting point for many future projects. To the many colleagues, technicians, and assistants who also wanted to share with the undersigned just a moment of their life’s work.

—DR

Enrico Agliardi, MD, DDS, PhD

Director
Advanced Oral Surgery Unit
School of Dentistry
Vita-Salute San Raffaele University
Milan, Italy

Riccardo Benzi, MD, DDS

Private Practice Limited to Implant Dentistry and
Prosthetic Rehabilitation
Vigevano, Italy

Alessandra Carrera, DDS

Private Practice
Galbiate, Italy

Matteo Clericò, DDS

Private Practice
Bollate, Italy

Matteo Consonni, CDT

Dental technician
Bergamo, Italy

Michele Manacorda, MD, DDS

Adjunct professor
Department of Oral Surgery
School of Dentistry
Vita-Salute San Raffaele University
Milan, Italy

Federico Mandelli, DDS

Private Practice
Pioltello, Italy

Davide Romeo, DDS, PhD

Adjunct Assistant Professor
Advanced Oral Surgery Unit
School of Dentistry
Vita-Salute San Raffaele University
Milan, Italy

Stefano Rota, CDT

Dental technician
Bergamo, Italy

Raffaele Vinci, MD, DMD

Associate professor and Director of the Specialization
School
in Oral Surgery
School of Dentistry
Vita-Salute San Raffaele University
Milan, Italy

The All-on-4 concept is an immediate function rehabilitation protocol developed at the Maló Clinic in Lisbon, Portugal. The concept is based on the optimal number of four implants placed as cornerstones for supporting an edentulous arch with a complete-arch prosthesis and immediate loading. Tilted implants are key for this rehabilitation. Using implants in this way allows for the implant support to be moved posteriorly and for the implants to be longer. In the maxilla, the implant passes through a dense bone structure—the anterior wall of the maxillary sinus—and reaches high density in the anterior maxilla, enhancing the primary stability. Thus, an immediate provisional prosthesis can be delivered to provide function and esthetics.

The All-on-4 concept was proposed for the first time in 2003 with a clinical study in the mandible and in 2005 for the maxilla. Those pioneering publications were initially received with considerable skepticism and criticism from the dental community, although they were the result of years of preliminary analysis and experimental investigations conducted in the Maló Clinic. Nowadays, the protocol is accepted worldwide, and for many clinicians, it represents the first choice in some categories of patients for whom bone grafts are not possible or in which outcomes are questionable.

When I first met Enrico in 2004, I immediately understood that he has a clear mind regarding the advantages and benefits of this revolutionary approach, and he started to adopt it in his private practice and at the University of Milan. At the beginning, he faced the same difficulties I had, but his perseverance and belief in what he was doing allowed him to succeed. I can say that he is now one of my best references for these rehabilitations. We share the same passion for what we do.

The All-on-4 concept has undergone continuous development, from standard to extramaxillary approaches with the insertion of four zygomatic implants. Bone grafts can now be avoided even in severely atrophic maxillary arches. Each protocol is supported by clinical studies that report the outcomes and provide feedback for future improvements.

Enrico has always supported the same philosophy we have at the Maló Clinic. He didn't just limit his practice to performing surgeries—he has run prospective and experimental studies with the same critical eyes and has shared his experience in international venues. Our close collaboration in delivering zygomatic implants has overcome many complex clinical situations, providing benefits for a subset of patients who lost hope in implant therapies.

Enrico has taken the esthetics of the provisional and definitive rehabilitations into great consideration. The chapters dedicated to prosthetics are enriched by excellent photographs that guide the reader through each phase of the treatment. Enrico has extensive experience with All-on-4, as well as tilted implants.

This book contains 15 years of activity of Enrico and his team in this type of solution and defines the state of the art of rehabilitations supported by tilted implants with immediate function, from situations of recent edentulism to the most severely atrophic alveolar ridges. For all the aforementioned reasons, it is a great pleasure and honor for me to present this landmark text, which I'm sure will receive great acclaim not only in private practice, but in academic settings as well.

Paulo Maló, DMD, PhD

Clinical Director
Maló Clinic Worldwide
Lisbon, Portugal



The Biology of Osseointegration

Definition of Osseointegration

Implant dentistry is based on the fundamental principle of osseointegration, defined by Prof P-I Brånemark as “a direct structural and functional connection between ordered, living bone and the surface of a load-bearing implant.”¹ Prof Brånemark is without a doubt the founding father of modern implant dentistry. The concept of osseointegration began with a study published in 1959 when Prof Brånemark was observing rabbit bone marrow using a titanium chamber with a transilluminating optic system. At the end of the experiment, he realized that it was very difficult to remove the chamber from the rabbit’s fibula and that the mineralized tissue perfectly fitted the microirregularities of the titanium surface, showing no sign of inflammation.²

In light of these observations, Prof Brånemark began to further experiment with animals (specifically rats, rabbits, and dogs), and a study on dogs allowed him and his colleagues to analyze the factors influencing the stability of titanium screws supporting dental prosthetic components.^{3,4} The next step was human clinical trials, as is shown in the seminal 1977 publication that contained the results of 10 years of experience with full-arch implant-supported prostheses.¹

However, because it was technically impossible to prove this osseous integration with objective data, the scientific world was skeptical of this idea at the time. The first researcher who managed to scientifically prove the integration of endosseous implants was Dr André Schroeder. His team revealed the phenomenon of osseointegration histologically using innovative techniques that allowed simultaneous sectioning of the decalcified bone and the implant without losing anchorage.⁵

The first definitions of osseointegration (from the Greek word *ostéon*, meaning *bone*, and the Latin word *integratio*, meaning *growth/rearrangement*) were of a histologic nature: direct connection between bone (as a mineralized bone matrix) and implant with no interposition of the soft tissue.

Prof Brånemark’s definition is true at the optic microscopic level. Nowadays, it is known that the titanium implant surface undergoes oxidative processes when in contact with air, and that this oxide layer (TiO₂) interacts with certain noncollagenous osseous proteins (mainly osteopontin and bone sialoprotein) that are present in the hematologic fluid of the osteotomy, developing chemical and physical connections.⁶

Meffert et al⁷ divided the concept of osseointegration into *adaptable osseointegration* if the osseous tissue was adjacent to the implant surface and *biointegration* if it was possible to find a direct biochemical bone-to-implant connection. According to Boyne and Scheer,⁸ it is accurate to use the term *osseointegration* when the implant is entirely integrated in mature bone tissue with all its components (ie, vascular lacunae, hematopoietic tissue, adipose tissue, connective tissue, and calcified matrix). However, there will never be 100% anchorage between the bone matrix and the implant surface. After this study, a series of discussions occurred relating to the minimum bone-to-implant contact needed to consider an implant osseointegrated.

The problem of defining the exact degree of bone-to-implant attachment led to a definition of osseointegration based on implant stability, which is a clinical criterion rather than a histologic criterion. Osseointegration thereby becomes a process that allows an alloplastic material under functional load to be rigidly fixated without any clinical symptoms.⁹ Osseointegration is not a characteristic of a material, but a condition in which there is no movement at the bone/implant interface.

In one publication,¹⁰ osseointegration was considered from the following different points of view:

1. Patient's point of view: An implant is osseointegrated if there is lack of mobility, stability of the prostheses under functional load, and absence of pain and inflammation.
2. Biologic point of view: Osseointegration is the apposition of newly formed bone along the implant surface without the interposition of fibrous tissue. There is a direct and functional connection that is able to sustain loads without deformation or rejection.
3. Biomechanical point of view: An implant is osseointegrated if there is no relative movement between the implant and the surrounding bone, and the deformation under loading is equal between the implant and the surrounding bone.
4. Microscopic/biophysical point of view: Osseointegration implies that under an electron microscope, the components of tissue around an implant are identified as normal bone and marrow components.

Some researchers consider osseointegration as a foreign body response to the implanted device, stating that only a biomechanical factor was responsible for the development of soft tissue integration or for an osseous covering.¹¹ Indeed, the authors behind these statements have demonstrated that even amalgam compounds can be embedded into bone.¹¹ However, there is documented evidence that the bone response is quantitatively different depending on the type of biomaterial and its surface roughness, which opposes the view of osseointegration as simply a foreign body reaction.^{12–16}

Osseointegration has clearly evolved as a concept and can be considered from different viewpoints, including anatomical, histologic, and ultrastructural.^{17–19} The concept of osseointegration in the scientific community has grown from the passive and blind acceptance of bone-to-implant contact to indisputable evidence supported by histologic data. Osseointegration and the stability of the implant are now used as definitive measures of clinical consequences in both the short and long term.

Today, where immediate loading of implants is a prevalent reality in many clinical situations (from single implants to full-arch rehabilitation), both in native bone and in postextraction sites, implant survival in the short term is often expected. The focus has now shifted to the long-term stability of peri-implant tissues (ie, bone and gingiva) due to the increasing esthetic need in the anterior zone for single and partial rehabilitations and for hygienic maintenance in complete fixed solutions.

Experimental Studies on the Intraosseous Anchorage of Dental Prostheses

Since the early 20th century, many authors have published techniques to substitute missing teeth in partially or completely edentulous patients. Those techniques required implants of different shapes and different materials: Maggiolo's gold implants (1809), Greenfield's platinum–iridium lattice cage (1909), Casto's (1914) and Kauffer's (1915) spiral platinum–iridium implants, Abel's porcelain screw (1934), Dahl's subperiosteal button (1942), Formiggin's steel and tantalum hollow spiral shape screw (1947), and more recently, Linkow's^{20,21} and Pasqualini's (1972) blades, Scialom's tantalum needle implant,²² and Tramonte's, Garbaccio's, Marini's, and Pierazzini's screw (**Fig 1-1**).

At those times, early failures were frequent due to the lack of sterility of the surgical field. Therefore, many authors assumed that the implant had to be surrounded by a layer of fibrous tissue (ie, fibroosseous integration) that ensured stability with some grade of mobility, mimicking the periodontal ligament. After 10 years of loading, the implant survival rate ranged from 40% to 70%.²³ A few implants showed no complications and worked well, but the majority of them required removal because of severe peri-implant infections²⁴ (**Figs 1-2** and **1-3**).

In 1969, Prof Brånemark performed an experimental study on dogs to analyze which factors may influence the stability of endosseous implants and the clinical success of dental prostheses.⁴ The endosseous implants consisted of a cylindrical titanium screw with perforations at the inferior end to allow for bone growth and to ensure solid anchorage in the mandible. A slot in the middle of the screw head connected the implant to the prosthetic structure.

The aim of the study was to analyze the biologic response of the bone around the implant at different time intervals without considering the long-term prognosis of the implants. The implant head was exposed after a healing period of 6 to 8 weeks to

Fig 1-1 Implant-supported prosthesis with various morphologies of fixtures. Note the infectious processes around the mandibular implants.

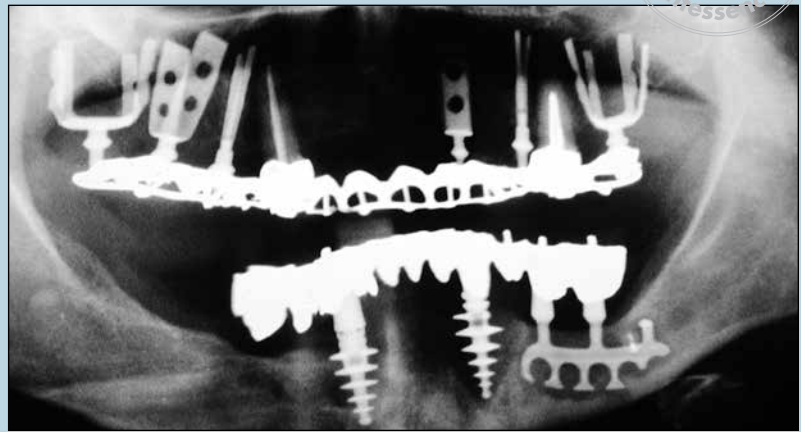


Fig 1-2 This complete mandibular fixed prosthesis failed 10 years after loading. (a to d) Note how the bone loss involved the entire length of both the teeth and the implants. (e to g) Panoramic radiographs taken during the treatment phases and at the 5-year follow-up. (Clinical case in collaboration with Dr Alessandra Carrera, Galbiate, Italy.)



allow a healing abutment to be placed. During the next 2 weeks, the prostheses were delivered and loaded. After the animals were sacrificed, the surgical sites were investigated clinically as well as with a stereomicroscope, radiograph, and optical microscope both before and after removal of the implants. The results showed how the hard and soft tissues accepted the implants

without any sign of inflammation. In nearly all cases, the bone grew around the threads without fibrous tissue interposition, and the prosthesis was well anchored to the implants. These encouraging results led Prof Brånemark to begin a clinical study in humans.

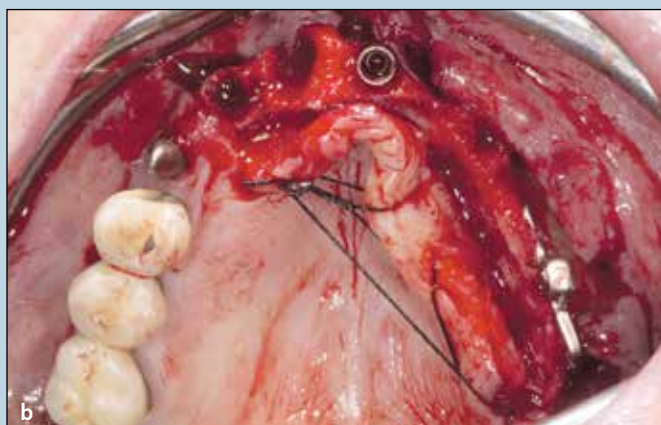
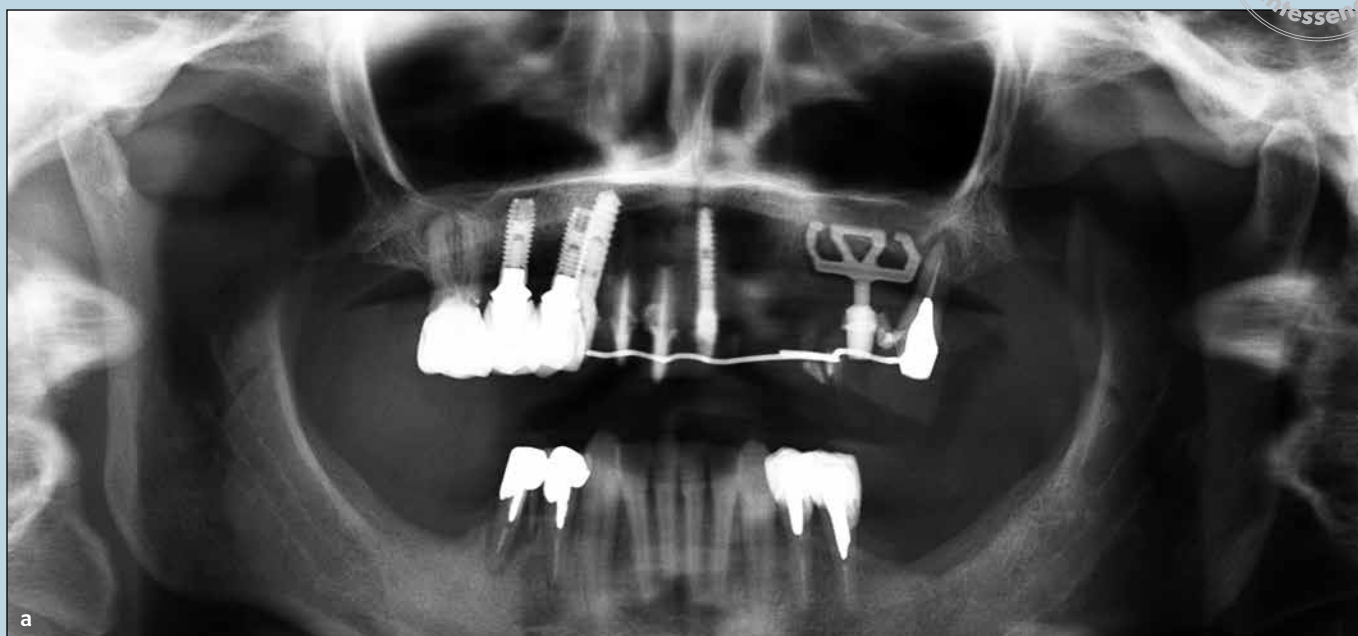


Fig 1-3 (a to e) After implants were removed from infected areas, extensive bone defects can be seen throughout the alveolar process. This complicates immediate implant placement. Thanks to the inclination of the implants, however, it is possible to achieve functional primary stability for immediate loading without the need for bone grafts.





Fig 1-3 cont. (f and g) The failing implants were carefully removed. (h) The panoramic radiograph after delivery of the immediate prosthesis showing the two axial implants and single tilted implant. (i) The follow-up radiograph after 1 year of loading demonstrates peri-implant bone stability. (j) Bone stability is still evident after 7 years. (k and l) A functional balance is maintained, and esthetics are not compromised.

Prof Brånemark's 10-Year Clinical Study

In 1977, Prof Brånemark published an article that can be considered one of the milestones of implant surgery.¹ From 1965 to 1975, together with his team, he treated a total of 128 maxillae and 107 mandibles in 211 patients, for a total of 1,618 implants supporting full-arch fixed prostheses. Of the 211 patients, 24 received treatment in both arches. The experimental time of 10 years was divided into three phases: the initial stage, the development stage, and the routine stage, with a few differences in surgical technique, prosthetic protocol, and healing time according to the acquired experience.

In the mandible, a full-thickness flap half the height of the alveolar process was raised on the labial aspect. The flap continued along the crest of the ridge distally to locate the mental foramen and the neurovascular bundle. In the maxilla, the incision was made along the crest to expose the incisive foramen and to isolate the nasopalatine nerve.¹

During the initial and development project periods, Prof Brånemark and his team raised fairly extensive flaps to clearly identify the noble neurovascular structures. Consequently, extensive hematomas often developed beneath the flaps, and postoperative bone loss was higher because the cortical bone was deprived of part of its periosteal blood supply. In the third project period (ie, the routine phase), better preoperative

planning (especially more accurate radiographic preoperative planning) and an improved clinical experience led to smaller and more conservative flaps, resulting in fewer postoperative problems, less bone resorption, and increased patient comfort.

Implant positioning was conditioned by bone quantity and the need to completely submerge the implants without leaving any threads exposed. In most cases, due to advanced mandibular atrophy, four to six implants were placed only in the interforaminal region because bone height in distal areas was insufficient to place implants with a minimum length of 10 mm. In cases of extreme atrophy, the lower mandibular cortex became part of the implant site. In severe atrophies of the maxilla, the floor of the nose and the sinus cavities posteriorly represented the biggest challenges.

The implants were placed fully submerged in bone and covered by the mucoperiosteal flap for a variable healing time, depending on the clinical experience of the practitioners as well as relevant studies on the healing processes of bone.^{3,25-30} When osseointegration was considered complete, the cover screw was replaced with a healing abutment of adequate height. The impression was taken, and the vertical dimension of occlusion was assessed to build a chrome-cobalt framework with acrylic teeth and pink gingiva. During the healing and remodeling period, no radiographs were taken because of the belief that radiation could impair newly forming bone at the bone/implant interface (Figs 1-4 and 1-5).

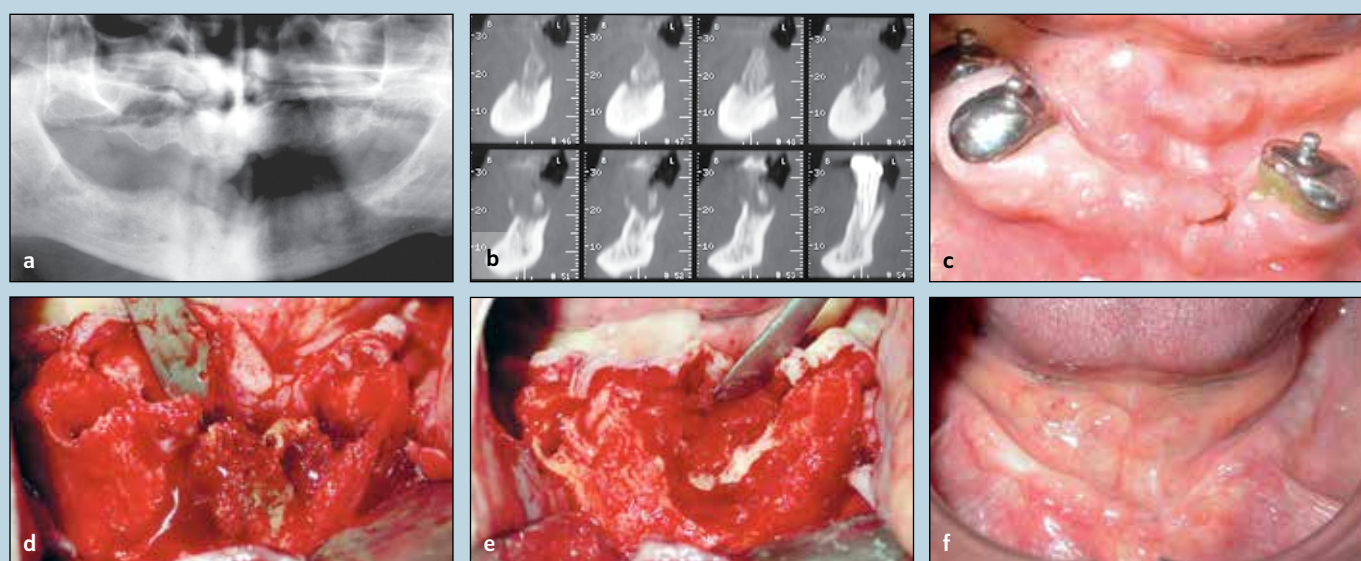


Fig 1-4 Mandibular rehabilitation with delayed loading according to the original Brånemark protocol. (a to c) The radiograph, CBCT scan, and clinical examination demonstrate osteonecrosis in the region of the mandibular left incisors. (d to f) The area is debrided and left to completely heal for 4 months. →

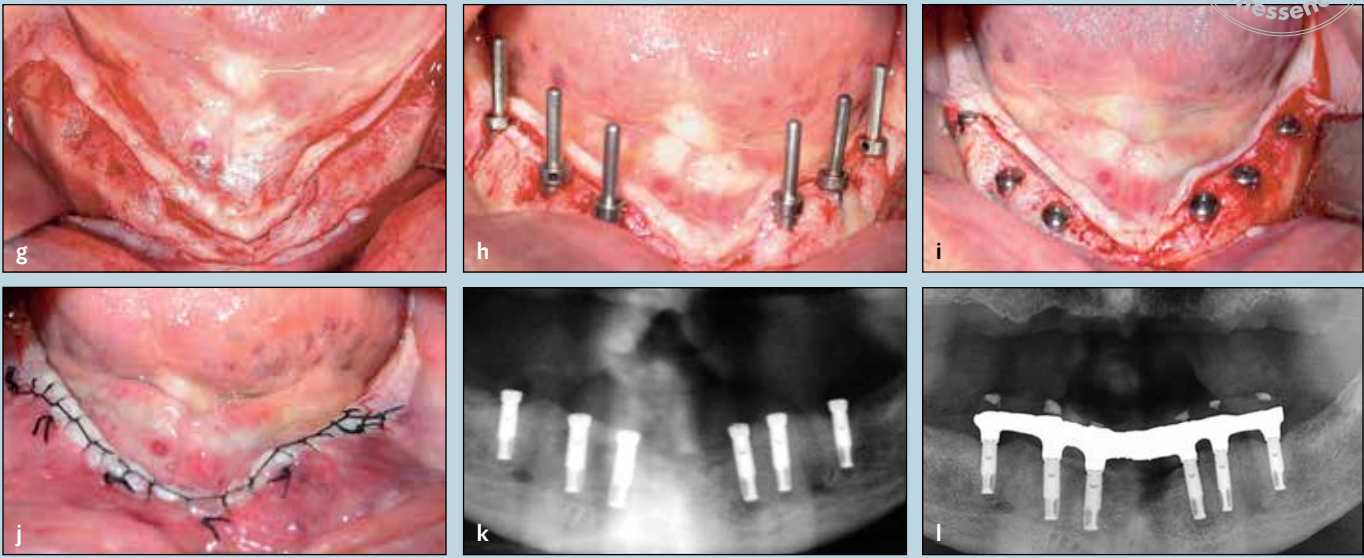


Fig 1-4 cont. (g to k) Once the site had healed, implants were placed. Loading with a definitive prosthesis occurred 6 months later. (l and m) Radiograph and clinical view after 15 years. The original definitive prosthesis had been replaced with a new definitive prosthesis 12 years after the implants were placed.

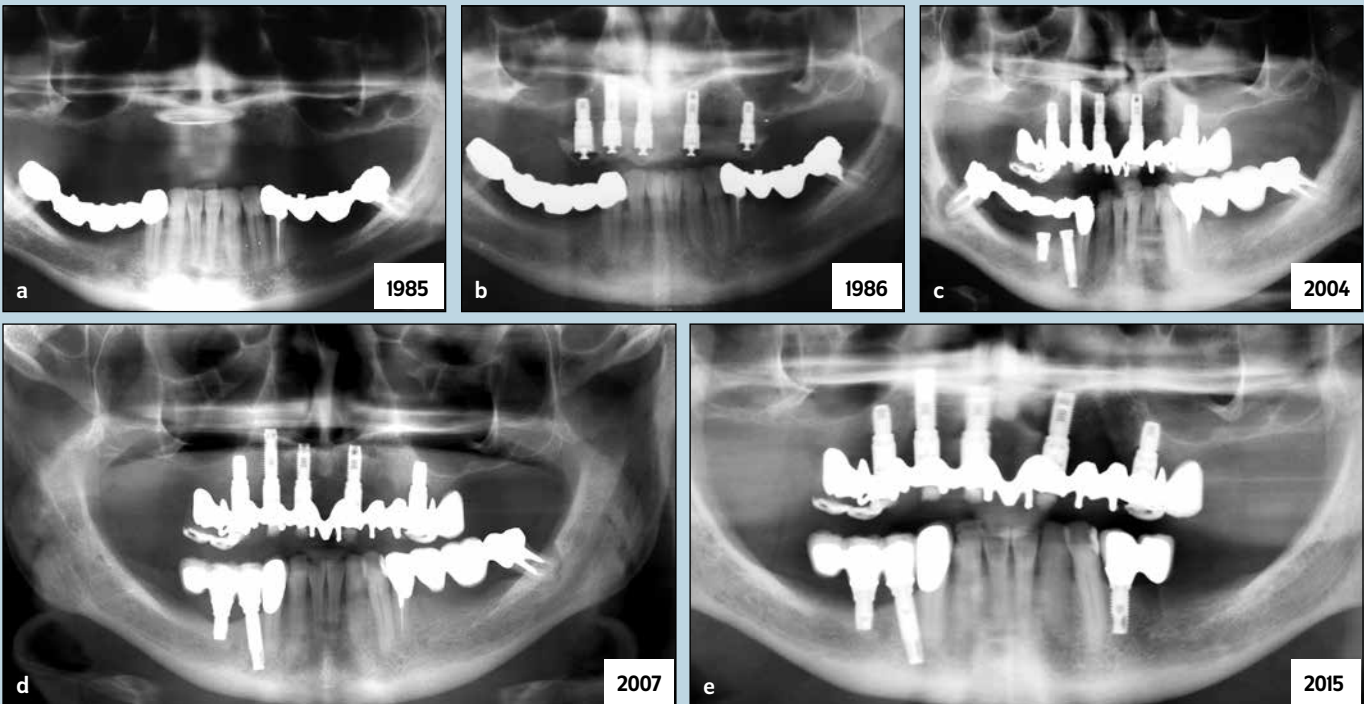


Fig 1-5 (a to e) Panoramic radiographs show 30 years of follow-up of a patient treated with a Toronto-Brånemark maxillary prosthesis. Over the years, the mandible has undergone various interventions, such as the replacement of dental-supported fixed prostheses with implant-supported fixed partial dentures. (Courtesy of Dr Federico Gualini, Bergamo, Italy.)

Reevaluation of the Brånemark Protocol

In their long-term prospective study, Brånemark et al¹ proved that it was possible to achieve predictable results and stable bone-to-implant integration following a scrupulous surgical and prosthetic protocol that can be summarized in nine points:

1. The use of a biocompatible material, such as titanium
2. Two-stage surgical protocol
3. Stress-free healing time of at least 3 months for the mandible and 5 to 6 months for the maxilla
4. Minimally invasive surgical technique, paying particular attention not to overheat the bone when drilling
5. Performing either a vestibular or mucobuccal incision
6. Surgery under sterile conditions
7. Using titanium instruments where needed
8. Avoiding radiographs during the integration phase
9. Placement of prostheses with acrylic occlusal surfaces

Before the introduction of this protocol, implants were regularly loaded at the time of placement because it was commonly thought that immediate stimulation could prevent crestal bone resorption and promote bone growth around the implants.^{20,21} The interposition of fibrous connective tissue, evidenced in many situations, was regarded as an ideal response to the implant because it resembled the natural periodontal ligament.^{20,21} However, the idea of immediate loading was abandoned when it became evident that a fibrous layer between the implant and the bone threatened the long-term stability of the implant. A stable situation could have been obtained only with direct contact between implant and bone.^{1,4}

The Brånemark school rejected the idea of connective anchorage in that the direct contact between the bone and the implant was the fundamental requirement for long-term success. The surgical protocol adopted by Prof Brånemark was made up of a two-stage approach. In the first stage, an implant made of inert and carefully cleaned material was inserted with minimal trauma into a suitable surgical site and left to heal for at least 3 months without any external communication. Postinsertion immobility, total absence of loading during the healing period, and elimination of occlusal interferences and masticatory overloads were essential requirements.³¹

One of the most controversial points of the protocol is undoubtedly the waiting time before prosthetic loading. In fact, different loading times were tested during the experimentation, ranging from 84 days in 1968 to 45 days in 1970, with some borderline cases of 2 to 4 weeks. It was noted that insufficient healing time increased the risk of early or late mobility of the implant. Therefore, the healing time was altered to 174 days in

1974, and a slight reduction to 89 days was introduced in 1977 (Table 1-1).¹ After 10 years of experience, the period of time without loading was reduced to 3 months in the mandible and 5 to 6 months in the maxilla, based on the different bone densities.^{1,9,27}

The stages of Prof Brånemark's study and the decision to have a long waiting period before the routine stage were made as a result of careful observation of some key parameters. The first parameter was about patient selection: 80% of patients presented with advanced mandibular atrophy, with a thin layer of cortical bone containing low-density trabecular bone marrow that could not guarantee good mechanical retention for the implants. The second parameter was about the implant design in terms of dimensions and microstructure, with a total of 22 different implant morphologies that were tested and discarded before the final period. The third parameter was the surgical protocol that underwent many changes: in the routine stage, more conservative flaps were raised that not only avoided exposing the bone too much, but also did not interrupt the blood supply, decreasing the healing period and postoperative complications. In the first phase, shorter implants were placed associated with site tapping, while in the third phase, implants were longer and were placed deeper. The fourth parameter regarded the prosthetic components. Very often, because of the patients' bone resorption, prostheses had unfavorable loading conditions due to long abutments and nonaxial loading directions.

In conclusion, it was impossible for Prof Brånemark's team to set scientifically accurate data about the correct healing period because of the heterogeneous composition of the sample and the continuous changes in the protocol.¹ Furthermore, data about the relationship between the different parameters with the healing times were missing. As a result, these parameters were established empirically. Brånemark et al considered the proposed time as completely empirical and not based on scientific evidence. They were not a fundamental requirement for the final success, but a therapeutic precaution for the clinician.³²

Histodynamics of Endosseous Wound Healing

As a means of structural and functional connection between implant and bone, osseointegration is an essential prerequisite for the long-term stability of implants and implant-supported restorations. The biology of this process can be influenced by many variables, such as characteristics of the bone site, the drilling protocol and extent of surgical trauma, and macroscopic and microscopic features of the implant.³³ Many of these parameters have been extensively analyzed in animal models to understand how they influence osseointegration.³⁴⁻³⁸

TABLE 1-1 | Mean healing periods of Prof Brånemark's study¹

Year	Mean healing time (days)	Phase of the study	Evolution of the protocol
1965	No loading	Initial stage	Implant design modifications, surgical protocol changes, negative selection of patients
1966	No loading		
1967	NA		
1968	84	Development stage	
1969	68		
1970	45		
1971	77		
1972	116	Routine stage	Definitive implant design, improved surgical and prosthetic protocols, negative selection of patients
1973	124		
1974	174		
1975	89		

NA, not applicable.

In 1980, the terms *contact osteogenesis* and *distance osteogenesis* were introduced by Osborn and Newsley³⁹ to distinguish the phenomenon of osseointegration based on different implant surfaces rather than in relation to biologic processes. Later on, Davies et al^{6,40-47} conducted in vitro studies to explain the sequence of events that occur at the bone/implant interface.

In distance osteogenesis, the bone formation starts from the walls of the osteotomy: the cells with osteogenic potential lay a new bone matrix that surrounds the implant⁴⁷ (**Fig 1-6a**). In contact osteogenesis, the surface is colonized by osteogenic cells that deposit a bone matrix that extends from the implant to the walls of the surgical site⁴⁷ (**Fig 1-6b**).

Even if both processes lead to the deposition of new bone around the implants, the biologic process is different, and the role of implant morphology and implant surface is crucial in this regard. In fact, distance osteogenesis is more common with smooth surfaces, while both types of osteogenesis are present with rough surfaces.

According to Davies,⁴⁵ contact osteogenesis can be divided into the following three stages:

- Osteoconduction
- Formation of new bone
- Arrangement of the newly formed bone

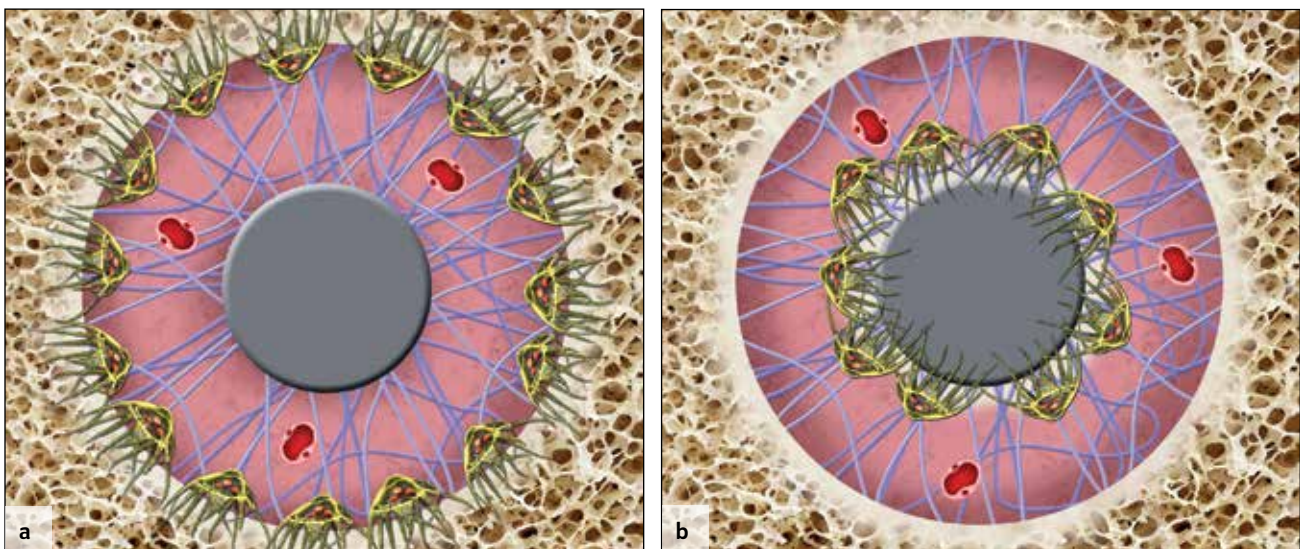


Fig 1-6 (a) Illustration of distance osteogenesis. (b) Illustration of contact osteogenesis.

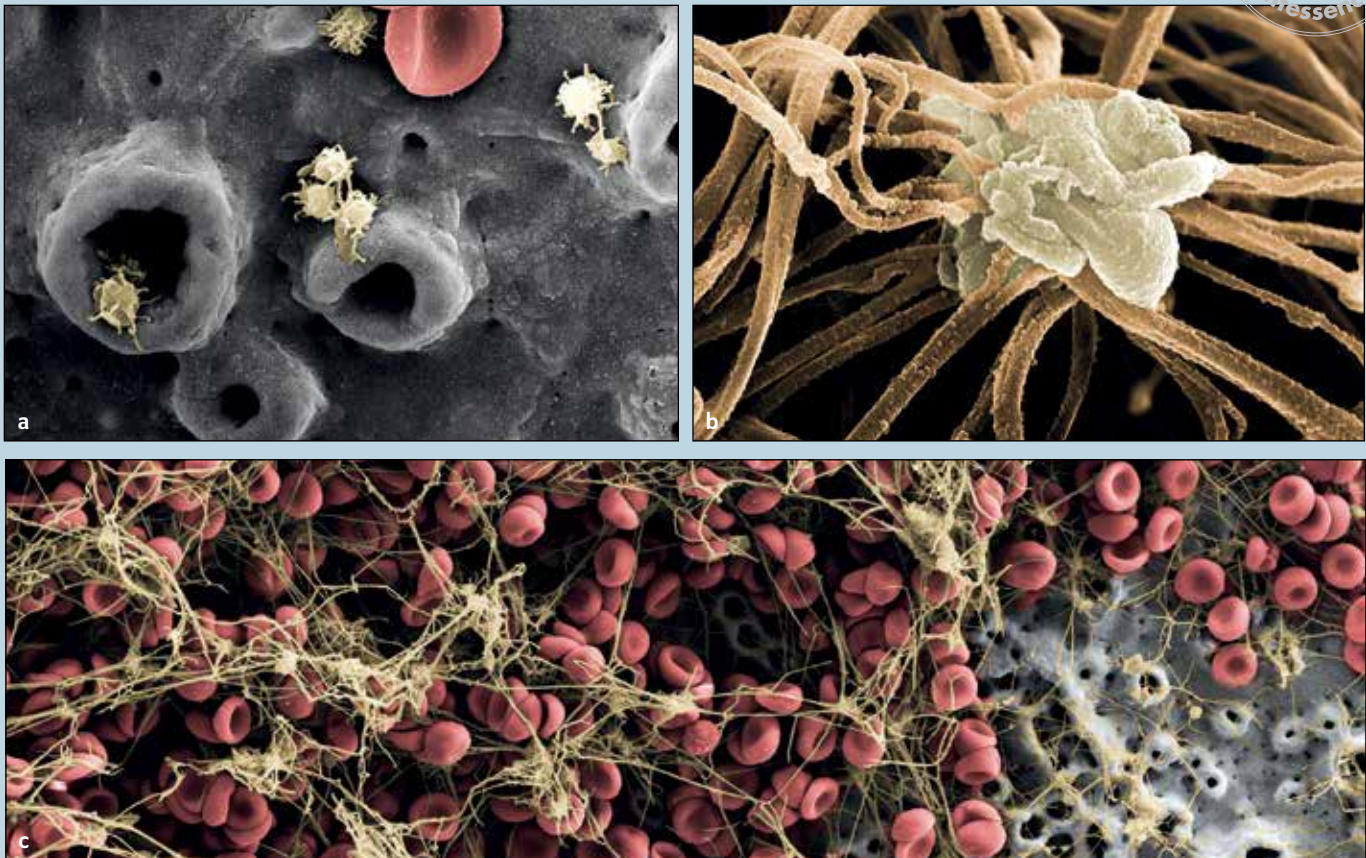


Fig 1-7 (a to c) Scanning electron microscope (SEM) images show the interaction between the TiUnite surface (Nobel Biocare), the red blood cells, and the activated platelets trapped in the fibrin network.

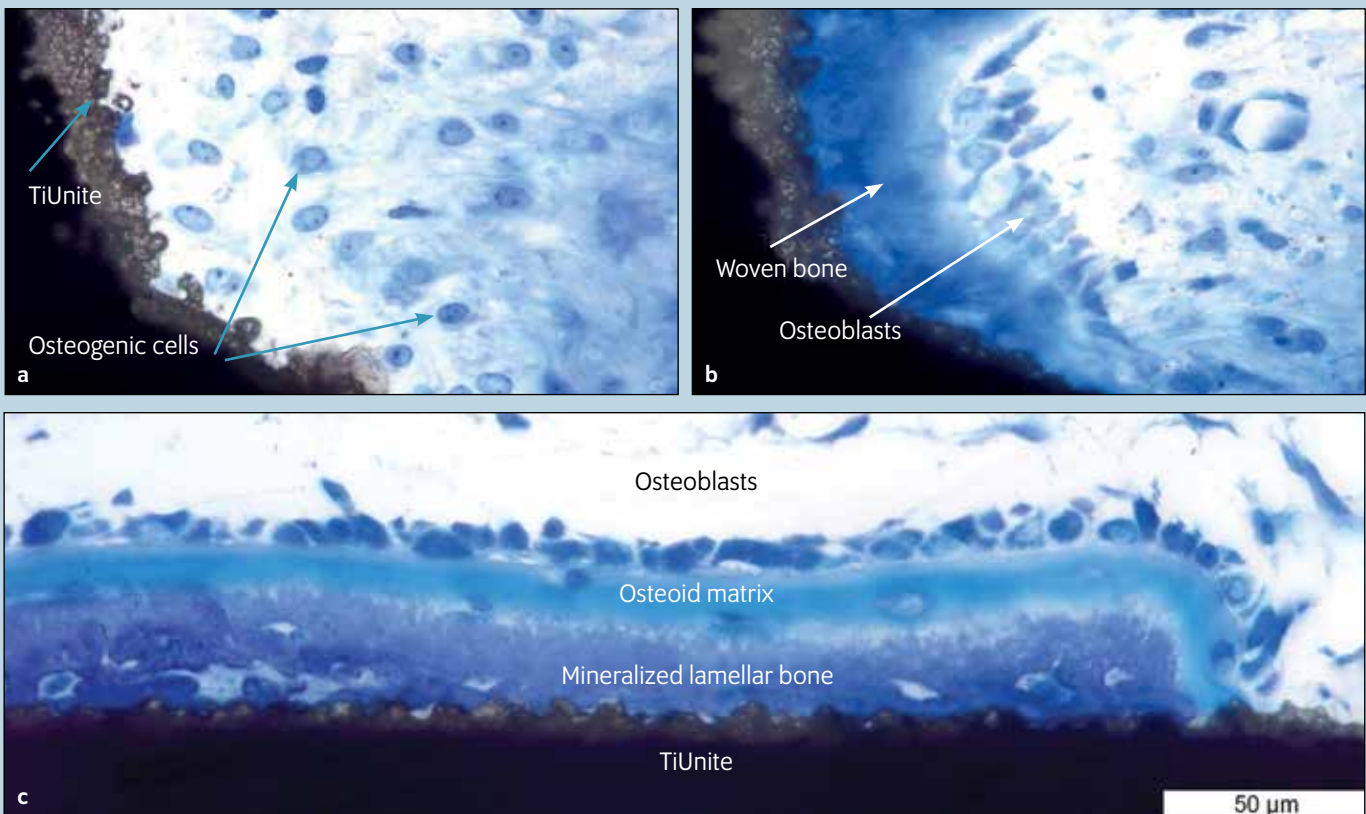
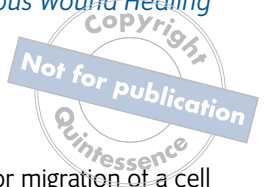


Fig 1-8 (a to c) The osteogenic cells make contact with the TiUnite surface and then migrate, producing an osteoid matrix. The newly formed bone is distributed on the osteoconductive surface, forming a thin band of trabecular bone. This thin layer will grow and through subsequent adaptations become lamellar bone. (Courtesy of Dr Peter Schüpbach, Langenthal, Switzerland.)



Osteoconduction

Osteoconduction is based on the migration of mesenchymal stem cells (MSCs) toward the surface of the implant. These cells are in the process of differentiation as they approach the osteogenic line, and they move through the fibrin clot formed in the surgical site between implant and bone.⁴⁵

During the drilling phase, a small hemorrhage is produced in the microcirculation, and this initiates the coagulation process and the formation of a fibrin clot.⁴⁵ Furthermore, as a consequence of hemostasis, local ischemia will occur with necrosis of the bone component located no more than 0.1 mm from a capillary.⁴⁸ In the clot, leukocytes converge, attracted by chemotactic factors (eg, platelet-derived growth factor [PDGF] and transforming growth factor β [TGF- β]), thrombin, and products of tissue degradation.^{49–52} Initially, a large number of neutrophils are present in the healing site, but macrophages soon become numerically predominant.⁵³ Cytokines play an important role not only in the resolution of inflammation, but also in wound repair⁵⁴; PDGF can accelerate the mitosis of fibroblasts and bone cells, while TGF- β acts on the formation of collagen type I.^{55–57} The first components that interact with the implant surface are proteins and other macromolecules present in the blood fluid, whereas the cellular component operates after this.^{45,58} An implant with a rough surface promotes osteoconduction, first favoring the absorption and retention of macromolecules (especially thrombin and fibrinogen) and subsequently increasing the surface area available for the fibrin matrix to anchor.^{59,60} Furthermore, the surface roughness affects the number and the activation degree of platelets as well as the level of adhesion of red blood cells⁶¹ (Fig 1-7).

Cells with osteogenic potential and mature fibroblasts migrate to the implant, generating contraction forces and causing a reorganization and deformation of the fibrin matrix as well as wound contraction.⁶ Macrophages and polymorphonuclear leukocytes have a negligible traction compared with platelets and fibroblasts.⁶ If the contraction forces of the fibrin clot exceed the adhesive forces of the fibrin clot, this process may cause the clot to detach from the implant surface, resulting in a discontinuity that can slow the osseointegration process. Therefore, the retention of the clot by the implant is an essential prerequisite for the migration of osteogenic cells, and the microstructure of the implant surface has a very important role in the retention of the fibrin clot and preventing its detachment.^{6,62} An in vitro study showed that there are no statistically significant differences in fibrin retention values passing from one surface treatment with mild airborne-particle abrasion up to a very aggressive etching, while there is a difference between a titanium plasma-sprayed surface and a machined surface.⁴⁷

Formation of new bone

Bone formation requires the recruitment or migration of a cell population with osteogenic potential, and this population must also differentiate into mature cells that are able to secrete osteoid⁴⁷ (Fig 1-8).

Osteoblasts are the cells responsible for bone formation, and they have the following characteristics⁶³:

- Osteoblasts are derived from osteoprogenitor cells of mesenchymal origin. They end their differentiation cycle as osteocytes.
- These cells have a high secretory capacity; they synthesize a matrix composed mainly of collagen type I and bone proteins, adjusting the mineralization of the matrix in a highly specialized tissue.
- Osteoblasts demonstrate autocrine regulation. They synthesize and deposit growth factors in the bone matrix and respond to these factors during repair and remodeling phases.
- Osteoblasts mediate systemic and local signals for the recruitment and activity of osteoclasts, which are involved in the processes of peri-implant bone repair and remodeling.

Before bone formation can begin, these cells have to face various stages⁶⁴: recruitment, adhesion, proliferation, and differentiation.

Recruitment

It is essential that a sufficient number of osteoblasts reach the implant surface. These cells originate from the pool of mesenchymal cells of bone marrow and from cellular layers between the periosteum and the endosteum.⁶⁵ They are recruited through the direct action of cytokines on progenitor cells, particularly bone morphogenetic proteins (BMPs).^{66–68}

Adhesion

The characteristics of each biomaterial (eg, the microscopic appearance of its surface, chemical composition, and surface energy) play a fundamental role in osteoblast adhesion, affecting the proliferation process and cell differentiation in proximity with the implant surface.⁶⁷

The adhesion to a biomaterial consists of two stages: (1) a stage of aggregation that occurs rapidly and includes short-term events such as physiochemical bonds between cells and material (ie, ionic bonds and van der Waals forces); and (2) a stage of adhesion, which takes place over a longer period of time and

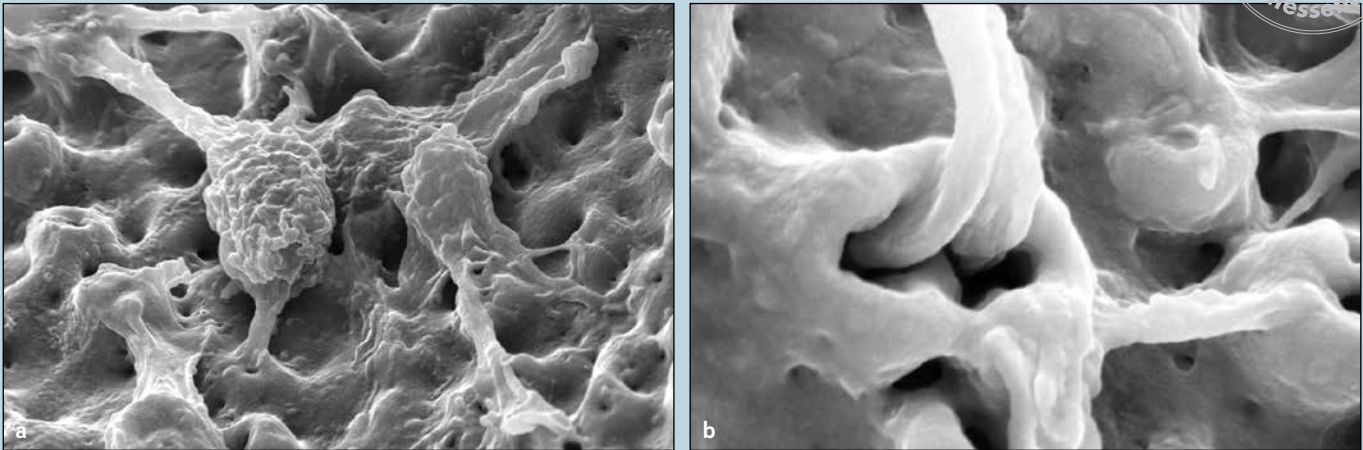


Fig 1-9 (a and b) The bone-depositing osteoblasts attach to the titanium surface using their pseudopodia and covering the orifices of the open pores. (Courtesy of Dr Peter Schüpbach, Langenthal, Switzerland.)

involves different biologic molecules, such as proteins of the extracellular matrix. These proteins interact with each other and induce translation signals to promote transcription factors and to regulate gene expression.⁶⁹

Surface characteristics (eg, microstructure, surface chemistry, and free energy) also determine how biologic molecules will be adsorbed and in which orientation. This first contact between cells and material is allowed by these molecules, and this will affect the morphology of the osteoblasts and their capacity for proliferation and differentiation.⁷⁰ In the context of osseointegration, these bone matrix proteins are components of the bone/implant interface, and the cellular adhesion to the implant occurs indirectly via these proteins⁷¹ (**Fig 1-9**).

Proliferation

Cellular proliferation is influenced by many factors. Among the main factors are cytokines and growth factors located around cells, hormones, growth factors present in the bloodstream, and physical or biochemical stimuli.^{72,73}

Differentiation

Osteoblasts have to complete a differentiation process before producing bone matrix; these cells are required to acquire specific phenotypic characteristics of secreting cells.⁷⁴ Given a certain number of osteoblasts, from 65% to 85% are lost as a result of programmed cell death (ie, apoptosis), while only a small percentage survive and end their cycle as an osteocyte (14% in cortical bone and 29% in trabecular bone).⁷⁵ This differentiation

process is not spontaneous; evidence demonstrates that it is regulated by hormones, growth factors, cytokines, mechanical stimulation, and physical deformation.^{76,77} The clot that is formed around the implant in the first hours after surgery will tend to mature over the following days, forming a granulation tissue that is rich in neutrophils and macrophages. The proliferation of small vessels and the production of growth factors by osteoid cells will allow the formation of connective tissue in the peri-implant area. Subsequently, the combined osteoclastic, fibroblastic, and osteoblastic actions will transform the connective tissue into an osteoid tissue, which will be replaced with the mature lamellar bone tissue after about 8 weeks.

The formation of new bone is divided into various stages, summarized as follows^{6,43,47}:

1. Noncollagenic bone proteins adsorb on the implant surface, especially osteopontin and bone sialoprotein along with proteoglycans.⁴⁶
2. The first calcium phosphate crystals form, which begins the mineralization of the bone proteins.
3. A first mineralized state without collagen fibers is created that joins directly to the implant. This is called the *cement line*. It is about 0.5 μm thick and contains calcium, phosphorus, osteopontin, and bone sialoprotein.
4. The collagen fibers join the cement line to form a continuum with the marrow compartment. These fibers have no direct connection with the implant surface.⁷⁸

The bone growth determined by an appositional process is regulated by polarized osteoblasts. As a result of matrix accumulation at their basal side, the cells passively drop out in a more apical direction. During the calcification process, osteoblasts succeed to migrate quickly and avoid being incorporated into the matrix; osteoblasts trapped in bone gaps are called *osteocytes*.^{6,78}

Arrangement of newly formed bone

During the first postoperative weeks, the osteogenic response is high, with mitosis and differentiation of MSCs into osteogenic cells reaching its highest activity during the first 15 to 20 days. At first, woven bone tissue is formed with collagen fibers arranged in a completely random fashion, with low mineralization density and numerous irregularly organized osteocytes. The function of this immature bone is to restore the continuity between the walls of the surgical site and the implant surface. Its mechanical properties are lower than those of organized lamellar bone. The formation of woven bone allows for a bone anchor that corresponds to the biologic fixation of the implant; this process begins 10 to 14 days after surgery and is different from the primary stability, which is a purely mechanical fixation.⁷⁹

The formation of new bone continues for another 6 weeks while the initial remodeling processes lead to a gradual adaptation of the newly formed bone. At 8 weeks, the neo-osteogenic activity is drastically reduced, while the remodeling and the morphostructural adaptation of newly formed bone reaches its peak. The bone tissue changes its structure, becoming more elaborate and acquiring a lamellar structure in addition to increasing its degree of mineralization⁸⁰⁻⁸² (Figs 1-10 and 1-11).

Author's note

When biomechanical conditions stimulate the skeletal mass and the occlusal loads are properly distributed and transmitted to the implant, bone remodeling is initiated, leading to the formation of a lamellar bone layer along the entire surface of the implant.⁸¹ The bone in contact with implant surface undergoes morphologic adaptation to stress and mechanical loading.⁸² This is confirmed by the presence of medullary spaces containing osteoblasts, osteoclasts, MSCs, blood vessels, and lymph vessels. The remodeling region can be extended up to 1 mm from the implant surface (see Fig 1-10).^{60,79}

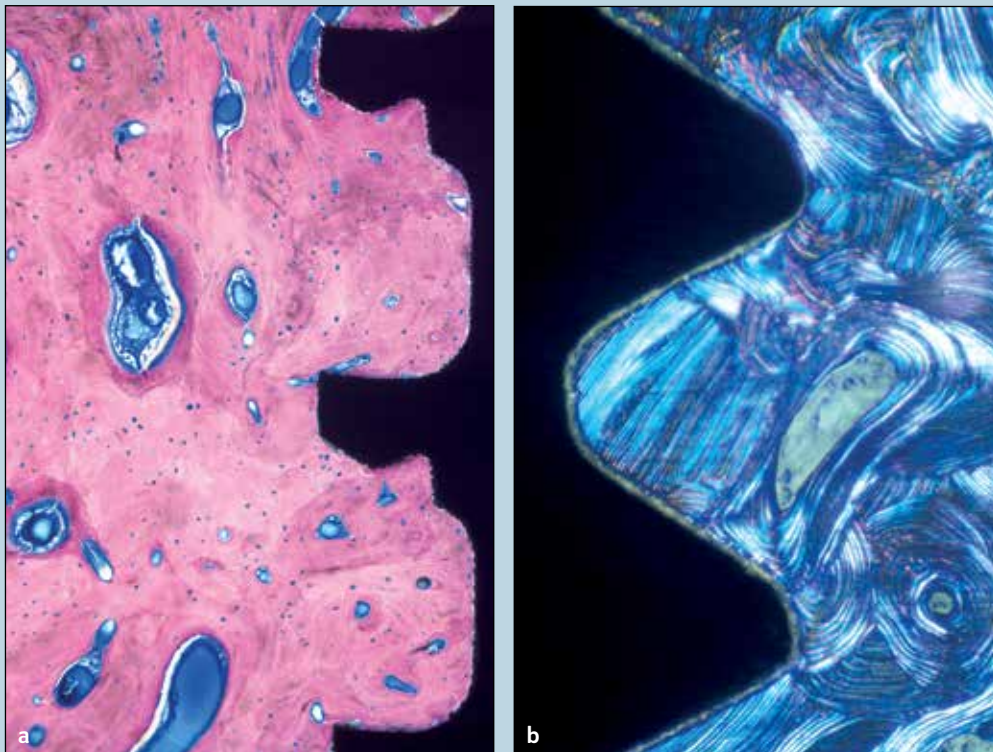


Fig 1-10 (*a and b*) Histologic and polarized light images show bone formation 6 months after implant placement. (Courtesy of Dr Peter Schüpbach, Langenthal, Switzerland.)

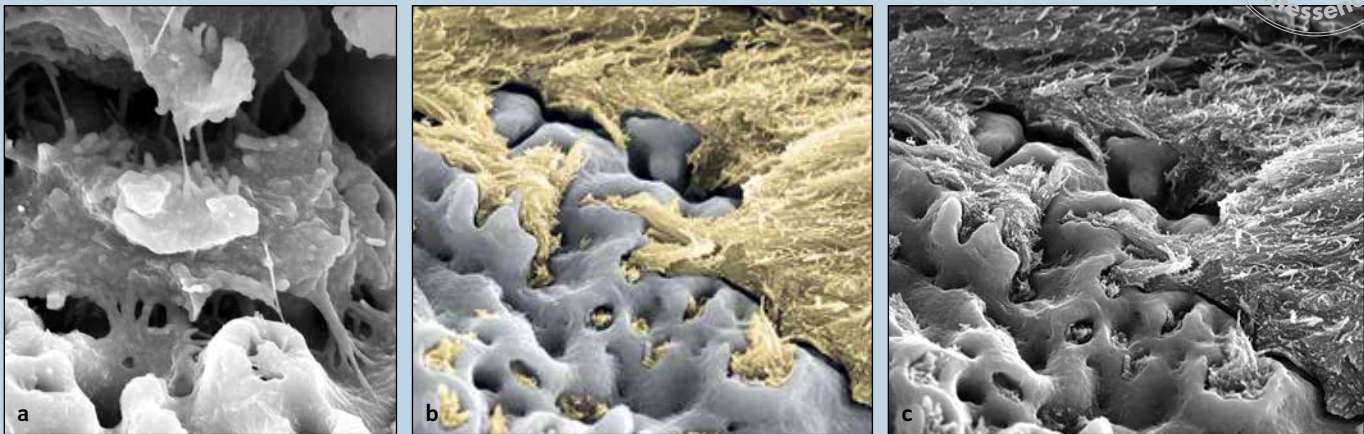


Fig 1-11 (a to c) Osteoconductive bone formation. The SEM images at 6 months after implant placement highlight the interaction between the newly formed bone and the TiUnite surface. The bone was removed to expose the implant surface. Note the presence of bone anchored in the orifices of the pores. (Courtesy of Dr Peter Schüpbach, Langenthal, Switzerland.)

Implant Morphology and Bone Healing Dynamics

It is known that the initial or primary stability is given by pure mechanical interlock between bone and implant without any biologic boundary.⁸³ The clinician generally evaluates the level of this primary stability based on the implant insertion torque. The torque, expressed in Ncm, reflects the stress level at the bone/implant interface added to the friction forces generated during seating.³⁴ It is generally assumed that the bone is an elastic tissue and that there is a linear relationship between implant stability and bone deformation.³⁴ In reality, stability decreases if microfractures converge into a macrofracture, and bone necrosis can be a consequence of vascular damage and ischemia.⁸⁴ Both microfracture formation and bone necrosis by compression are evident at different levels when there is a difference between the outer diameter of the implant threads and the inner diameter of the osteotomy drill.³³

Author's note

Davies⁴⁵ described how the success of immediate implant loading is based on three factors: (1) obtaining primary stability, ensuring that the micromobility of the implant is avoided during and immediately after positioning; (2) having good secondary stability (commonly called *biologic stability*) based on osteogenesis in the peri-implant area; and (3) being able to control bone resorption resulting from abnormal forces that destabilize the implant during the healing period.

In a recent publication, Coelho and Jimbo³³ analyzed how the relationship between implant macrogeometry and osteotomy size could drive the osseointegration process. According to the authors, it is not advisable to achieve high levels of torque because the excessive deformation not only leads to a decrease in biomechanical stability, but depending on implant thread design, it may cause adverse biologic effects, resulting in a degree of bone compression.³³

This type of scenario is well illustrated in an animal model (dog mandible) where an implant with V-shaped threads was placed in a site prepared with a drill with a diameter equivalent to the inner part of the threads.³³ The histologic image shows the continuity of the bone/implant interface, which represents a mechanical index of the connection between the two components, with a high level of primary stability within 2 weeks (**Fig 1-12a**). There are microfractures due to stress concentration at the tips of the threads and bone remodeling as a result of tissue necrosis. After 4 weeks, a remodeling area emerges due to the union of bone remodeling sites created after necrosis by compression and formation of microfractures (**Fig 1-12b**). In a time between 2 and 4 weeks, primary stability decreases because of bone resorption; the resorbed volume will be filled with new woven bone that will reestablish the contact with the implant surface (ie, secondary stability). According to this scheme of osseointegration that Coelho and Jimbo³³ define as *interfacial remodeling*, the bone that surrounds this type of implant is mature lamellar bone with few small marrow spaces.

By placing implants in sites made with a drill with a diameter equivalent to the external part of the threads, empty spaces were created between the implant and the osteotomy walls,

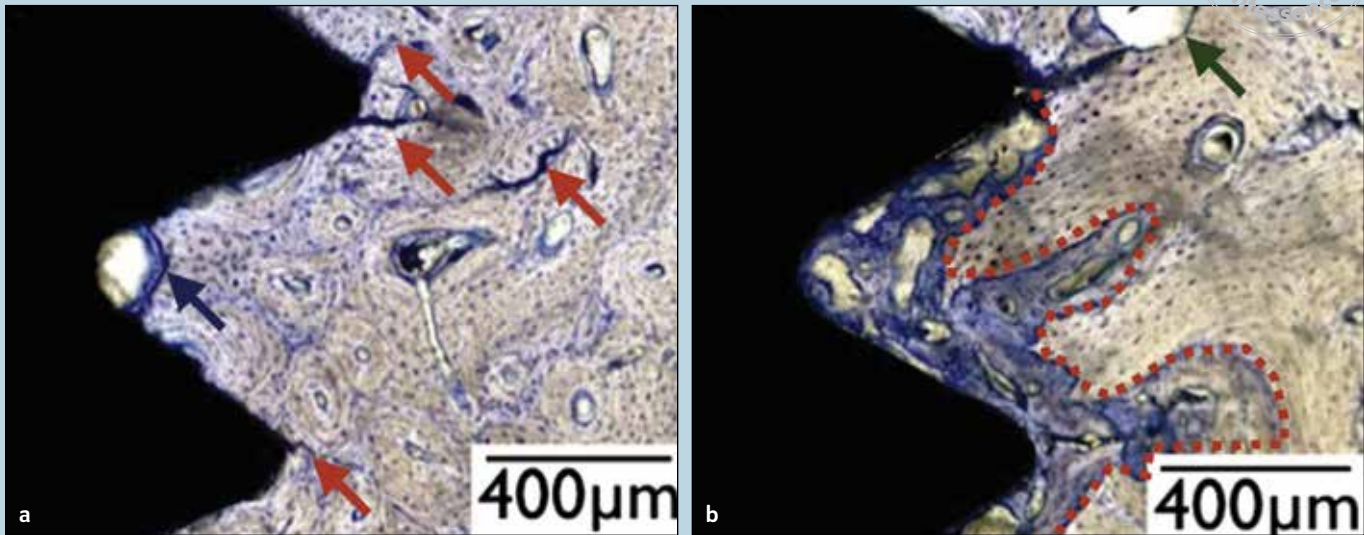


Fig 1-12 Optical micrographs of V-threaded implants placed in sites surgically instrumented to the inner diameter of the implant thread in vivo in a beagle dog model. (a) At 2 weeks in vivo, the almost continuous bone/implant interface reveals mechanical interlocking between components, which is responsible for primary stability. The red arrows depict microcracks at regions where the yield strength of bone has been exceeded due to high stress concentration; the blue arrow depicts initial remodeling taking place between the implant threads due to compression necrosis. (b) At 4 weeks, substantial remodeling has occurred at the interface, where cell-mediated processes resorbed the region encompassed between the dashed line and the implant. The green arrow shows a remodeling site at the extension of a microcrack. (Reprinted with permission from Coelho and Jimbo.³³)

leading to healing that is referred to as *intramembranous-like* healing.⁵⁸ These areas, called *healing chambers*, will be filled with a blood clot and will not contribute to primary stability but will play a key role in secondary stability.^{85,86} In these healing chambers, the bone formation process begins according to a model of intramembranous ossification that results in direct bone formation on the implant surface without removal of necrotic bone. The woven bone will be replaced with lamellar bone that surrounds the osteons.⁸⁵ Although this model does not require high levels of primary stability, good fixation in the bone can be guaranteed by the implant apex. It is therefore possible to have a stable blood clot inside the healing chambers to start osteogenesis.^{87,88}

Studies were conducted using implants with an external thread design to ensure primary stability while the internal part and the osteotomy size allows for the formation of healing chambers. In fact, there is no bone resorption in the healing chambers, but only the process of immature bone formation that can compensate for the loss of primary stability due to the bone compression zone located in the implant thread extremities.⁸⁹

However, instead of altering the preparation of the osteotomy to accommodate the implant threads, it is better to have an implant morphology that promotes hybrid healing, with a thread

design that ensures primary stability. This allows for a combination of compact lamellar bone structure (due to the interfacial remodeling) together with bone with a haversian-like structure due to the intramembranous-like healing. Currently, there are not many implants with this configuration, so there is no available long-term evaluation of this hybrid osseointegration model.⁹⁰

References

1. Brånemark PI, Hansson BO, Adell R, et al. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. *Scand J Plast Reconstr Surg Suppl* 1977;16:1–132.
2. Brånemark PI. Vital microscopy of bone marrow in rabbit. *Scand J Clin Lab Invest* 1959;11:1–82.
3. Breine U, Johansson B, Roylance PJ, Roeckert H, Yoffrey JM. Regeneration of bone marrow. A clinical and experimental study following removal of bone marrow by curettage. *Acta Anat* 1964; 59:1–46.
4. Brånemark PI, Adell R, Breine U, Hansson BO, Lindström J, Ohlsson A. Intra-osseous anchorage of dental prostheses. I. Experimental studies. *Scand J Plast Reconstr Surg* 1969;3:81–100.
5. Schroeder A, Pohler O, Sutter F. Tissue reaction to an implant of a titanium hollow cylinder with a titanium surface spray layer [in German]. *SSO Schweiz Monatsschr Zahnheilkd* 1976;86:713–727.
6. Davies JE, Hosseini MM. Histodynamics of endosseous wound healing. In: Davies JE (ed). *Bone Engineering*. Toronto: Em Squared Inc, 2000:1–14.

7. Meffert RM, Block MS, Kent JN. What is osseointegration? *Int J Periodontics Restorative Dent* 1987;4:9–21.
8. Boyne PJ, Scheer PM. Comparison of interface osseointegration of different designs of intraosseous implants. *J Dent Res* 1988;67:182.
9. Zarb GA, Jansson T. Prosthodontic procedures. In: Brånemark PI, Zarb GA, Albrektsson T (eds). *Tissue Integrated Prostheses: Osseointegration in Clinical Dentistry*. Chicago: Quintessence, 1985: 241–282.
10. Esposito M, Hirsch JM, Lekholm U, Thomsen P. Biological factors contributing to failures of osseointegrated oral implants. (I). Success criteria and epidemiology. *Eur J Oral Sci* 1998;106:527–551.
11. Donath K, Laass M, Gunzl HJ. The histopathology of different foreign-body reactions in oral soft tissue and bone tissue. *Virchows Archiv A Pathol Anat Histopathol* 1992;420:131–137.
12. Johansson C. On tissue reactions to metal implants [thesis]. Goteborg: University of Goteborg, 1991.
13. Gottlander M. On hard tissue reactions to hydroxyapatite-coated titanium implant [thesis]. Goteborg: University of Goteborg, 1994.
14. Wennenberg A. On surface roughness and implant incorporation [thesis]. Goteborg: University of Goteborg, 1996.
15. Albrektsson T, Berglundh T, Lindhe J. Osseointegration: Historic background and current concepts. In: Lindhe J, Thorkild K, Lang NP. *Clinical Periodontology and Implant Dentistry*, ed 4. Oxford: Blackwell, 2003:809–820.
16. Mavrogenis AF, Dimitriou R, Parvizi J, Babis GC. Biology of implant osseointegration. *J Musculoskelet Neuronal Interact* 2009;9:61–71.
17. Adell R, Lekholm U, Rockler B, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg* 1981;10:387–416.
18. Brånemark PI. Osseointegration and its experimental studies. *J Prosthet Dent* 1983;50:399–410.
19. Linder L, Albrektsson T, Brånemark PI, et al. Electron microscopic analysis of the bone-titanium interface. *Acta Orthop Scand* 1983;54:45–52.
20. Linkow L. The age of endosseous implants. *Dent Concepts* 1966;8:4–10.
21. Linkow L, Chérchève R. *Theories and Techniques of Oral Implantology*. St Louis: CV Mosby, 1970:74–76.
22. Scialom J. Editorial Implantologie [in French]. *Rev Odontoplastol* 1970;33:10–12.
23. Kapur KK. Veterans Administration Cooperative Dental Implant Study—Comparisons between fixed partial dentures supported by blade-vent implants and removable partial dentures. Part II: Comparisons of success rates and periodontal health between two treatment modalities. *J Prosthet Dent* 1989;62:685–703.
24. Bodine RL Jr. Construction of the mandibular implant denture superstructure. *J Oral Implantol* 2001;27:262–266.
25. Brånemark PI, Breine U, Hallén O, Hanson B, Lindstrom J. Repair of defects in mandible. *Scand J Plast Reconstr Surg* 1970;4: 100–108.
26. Brånemark PI, Lindström J, Hallén O, Breine U, Jeppson PH, Ohman A. Reconstruction of the defective mandible. *Scand J Plast Reconstr Surg* 1975;9:116–128.
27. Albrektsson T, Jansson T, Lekholm T. Osseointegrated dental implants. *Dent Clin North Am* 1986;30:151–174.
28. Lundskog J. Heat and bone tissue. An experimental investigation of the thermal properties of bone and threshold levels for thermal injury. *Scand J Plast Reconstr Surg* 1972;9:1–80.
29. Adell R, Breine U, Brånemark PI, Hansson BO. Intra-osseous anchorage of dental prostheses. Review of clinical approaches. *Scand J Plast Reconstr Surg* 1970;4:19–34.
30. Adell R. Regeneration of the periodontium. An experimental study in dogs. *Scand J Plast Reconstr Surg Suppl* 1974;11:1–177.
31. Garrington GE. Clinical response to dental implant materials. *Oral Implantol* 1974;5:33–43.
32. Henry P, Rosenberg I. Single-stage surgery for rehabilitation of the edentulous mandible: Preliminary results. *Pract Periodontics Aesthet Dent* 1994;6:15–22.
33. Coelho PG, Jimbo R. Osseointegration of metallic devices: Current trends based on implant hardware design. *Arch Biochem Biophys* 2014;561:99–108.
34. Halldin A, Jimbo R, Johansson CB, et al. The effect of static bone strain on implant stability and bone remodeling. *Bone* 2011;49: 783–789.
35. Yeniol S, Jimbo R, Marin C, Tovar N, Janal MN, Coelho PG. The effect of drilling speed on early healing to oral implants. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2013;116:550–555.
36. Jimbo R, Giro G, Marin C, et al. Simplified drilling technique does not decrease dental implant osseointegration: A preliminary report. *J Periodontol* 2013;84:1599–1605.
37. Giro G, Tovar N, Marin C, et al. The effect of simplifying dental implant sequence on osseointegration: An experimental study in dogs. *Int J Biomater* 2013;2013:230310.
38. Jimbo R, Tovar N, Yoo DY, Janal MN, Anchieta RB, Coelho PG. The effect of different surgical drilling procedures on full laser-etched microgrooves surface-treated implants: An experimental study in sheep. *Clin Oral Implant Res* 2014;25:1072–1077.
39. Osborn JF, Newesley H. Dynamics aspects of the implant-bone interface. In: Heimke G (ed). *Dental Implants: Materials and Systems*. Munich: Hanser, 1980:111–123.
40. Davies JE, Chernecky R, Lowenberg B, Shiga A. Deposition and resorption of calcified matrix in vitro by rat bone marrow cells. *Cells Mater* 1991;1:3–15.
41. Davies JE, Ottensmeyer P, Shen X, Hashimoto M, Peel SAF. Early extracellular matrix synthesis by bone cells. In: Davies JE (ed). *The Bone-Biomaterial Interface*. Toronto: University of Toronto, 1991:214–228.
42. Davies JE, Nagai N, Takeshita N, Smith DC. Deposition of cement-like matrix on implant materials. In: Davies JE (ed). *The Bone-Biomaterial Interface*. Toronto: University of Toronto, 1991:285–294.
43. Davies JE. In vitro modeling of the bone/implant interface. *Anat Rec* 1996;245:426–445.
44. Davies JE, Baldan N. Scanning electron microscopy of the bone-bioactive implant interface. *J Biomed Mater Res* 1997;36: 429–440.
45. Davies JE. Mechanisms of endosseous integration. *Int J Prosthodont* 1998;11:391–401.
46. Hosseini MM, Sodek J, Franke RP, Davies JE. The structure and composition of the bone-implant interface. In: Davies JE (ed). *Bone Engineering*. Toronto: Em Squared Inc, 2000:296–304.
47. Davies JE, Park JY. Critical issues in endosseous periimplant wound healing. In: Ellingsen JK (ed). *Bio-implant Interface: Improving Biomaterials and Tissue Reactions*. Boca Raton, FL: CRC, 2003.
48. Søballe K. Hydroxyapatite ceramic coating for bone implant fixation. Mechanical and histological studies in dogs. *Acta Orthop Scand Suppl* 1993;255:1–58.
49. Gallit J, Clark RA. Wound repair in the context of extracellular matrix. *Curr Opin Cell Biol* 1994;6:717–725.
50. Bar-Shavit R, Kahn A, Wilner GD, Fenton JW. Monocyte chemotaxis: Stimulation by specific exosite region in thrombin. *Science* 1983; 220:728–731.
51. Postlethwaite AE, Kang AH. Collagen and collagen peptide-induced chemotaxis of human blood monocytes. *J Exp Med* 1976; 143:1299–1307.
52. Norris DA, Clark RA, Swigart LM, Huff JC, Weston WL, Howell SE. Fibronectin fragment(s) are chemotactic for human peripheral blood monocytes. *J Immunol* 1982;129:1612–1618.
53. Thomsen P, Ericsson LE. Inflammatory cell response to bone implant surfaces. In: Davies JE (ed). *The Bone-Biomaterial Interface*. Toronto: University of Toronto, 1991:153–164.

54. Probst A, Spiegel HU. Cellular mechanisms of bone repair. *J Invest Surg* 1997;10:77–86.
55. Scher CD, Shepard RC, Antoniades HN, Stiles CD. Platelet-derived growth factor and the regulation of the mammalian fibroblast cell cycle. *Biochim Biophys Acta* 1979;560:217–241.
56. Canalis E. Effect of growth factors on bone cell replication and differentiation. *Clin Orthop Relat Res* 1985;193:246–263.
57. Joyce ME, Jingushi S, Bolander ME. Transforming growth factor- β in the regulation of fracture repair. *Orthop Clin North Am* 1990; 21:199–209.
58. Berglundh T, Abrahamsson I, Lang NP, Lindhe J. De novo alveolar bone formation adjacent to endosseous implants. *Clin Oral Implant Res* 2003;14:251–262.
59. Boyan BD, Bonewald LF, Paschalis EP, et al. Osteoblast-mediated mineral deposition in culture is dependent on surface microtopography. *Calcif Tissue Int* 2002;71:519–529.
60. Franchi M, Fini M, Martini D, et al. Biological fixation of endosseous implants. *Micron* 2005;36:665–671.
61. Park JY, Davies JE. Red blood cell and platelet interactions with titanium implant surfaces. *Clin Oral Imp Res* 2000;11:530–539.
62. Brett PM, Harle J, Salih V, et al. Roughness response genes in osteoblasts. *Bone* 2004;35:124–133.
63. Puzas JE. The osteoblast. In: Flavus MJ (ed). *Primer on the Metabolic Bone Diseases and Disorders of Mineral Metabolism*, ed 2. New York: Raven Press, 1993:15–21.
64. Cooper LF. Biologic determinants of bone formation for osseointegration: Clues for future clinical improvements. *J Prosthet Dent* 1998;80:439–449.
65. Owen M. Marrow stromal stem cells. *J Cell Sci Suppl* 1988;10: 63–76.
66. Mundy GR, Boyce B, Hughes D, et al. The effects of cytokines and growth factors on osteoblastic cells. *Bone* 1995;17:S71–S75.
67. Lan J, Wang Z, Wang Y, Wang J, Cheng X. The effect of combination of recombinant human bone morphogenetic protein-2 and basic fibroblast growth factor or insulin-like growth factor-I on dental implant osseointegration by confocal laser scanning microscopy. *J Periodontol* 2006;77:357–363.
68. Huang YH, Polimeni G, Qahash M, Wikesjö UM. Bone morphogenetic proteins and osseointegration: Current knowledge—Future possibilities. *Periodontol* 2000 2008;47:206–223.
69. Anselme K. Osteoblast adhesion on biomaterials. *Biomaterials* 2000;21:667–681.
70. Boyan BD, Hummert TW, Dean DD, Schwartz Z. Role of materials surfaces in regulating bone and cartilage cell response. *Biomaterials* 1996;17:137–146.
71. Shen X, Roberts E, Peel SA, Davies JE. Organic extracellular matrix components at the bone cell/substration interface. *Cell Mater* 1993;3:257–272.
72. Goldring SR, Goldring MB. Cytokines and skeletal physiology. *Clin Orthop Relat Res* 1996;324:13–23.
73. Buckley MJ, Banes AJ, Levin LG, et al. Osteoblasts increase their rate of division and align in response to cyclic, mechanical tension in vitro. *Bone Miner* 1988;4:225–236.
74. Balloni S, Calvi EM, Damiani F, et al. Effects of titanium surface roughness on mesenchymal stem cell commitment and differentiation signaling. *Int J Oral Maxillofac Implants* 2009;24:627–635.
75. Parfitt AM. Bone-forming cells in clinical condition. In: Hall BK (ed). *The Osteoblast and Osteocyte*. Caldwell: Telford, 1990:351–430.
76. Adams JC, Watt FM. Regulation of development and differentiation by the extracellular matrix. *Development* 1993;117:1183–1198.
77. Baylink DJ, Finkelman RD, Mohan S. Growth factors to stimulate bone formation. *J Bone Miner Res* 1993;8:S565–S572.
78. Murai K, Takeshita F, Ayukawa Y, Kiyoshima T, Suetsugu T, Tanaka T. Light and electron microscopic studies of bone-titanium interface in the tibiae of young and mature rats. *J Biomed Mater Res* 1996;30:523–533.
79. Chappard D, Aguado E, Huré G, Grizon F, Basle MF. The early remodeling phases around titanium implants: A histomorphometric assessment of bone quality in a 3 and 6-month study in sheep. *Int J Oral Maxillofac Implants* 1999;14:189–196.
80. Frost HM. Some ABC's of skeletal pathophysiology. The growth/modelling/remodelling distinction. *Calcif Tissue Int* 1991;49: 301–302.
81. Albrektsson T, Wennerberg A. Oral implant surfaces: Part 1—Review focusing on topographic and chemical properties of different surfaces and in vivo responses to them. *Int J Prosthodont* 2004;17: 536–543.
82. Carter DR, Giori NJ. Effect of mechanical stress on tissue differentiation in the bony implant bed. In: Davies JE (ed). *The Bone-Biomaterial Interface*. Toronto: University of Toronto, 1991:367–375.
83. Meyer U, Joos U, Mythili J, et al. Ultrastructural characterization of the implant/bone interface of immediately loaded dental implants. *Biomaterials* 2004;25:1959–1967.
84. Verborgt O, Gibson GJ, Schaffler MB. Loss of osteocyte integrity in association with microdamage and bone remodeling after fatigue in vivo. *J Bone Miner Res* 2000;15:60–67.
85. Leonard G, Coelho P, Polyzois I, Stassen L, Claffey N. A study of the bone healing kinetics of plateau versus screw root design titanium dental implants. *Clin Oral Implants Res* 2009;20:232–239.
86. Coelho PG, Suzuki M, Guimaraes MV, et al. Early bone healing around different implant bulk designs and surgical techniques: A study in dogs. *Clin Implant Dent Relat Res* 2010;12:202–208.
87. Marin C, Granato R, Suzuki M, Gil JN, Janal MN, Coelho PG. Histomorphologic and histomorphometric evaluation of various endosseous implant healing chamber configurations at early implantation times: A study in dogs. *Clin Oral Implants Res* 2010;21:577–583.
88. Suzuki M, Calasans-Maia MD, Marin C, et al. Effect of surface modifications on early bone healing around plateau root form implants: An experimental study in rabbits. *J Oral Maxillofac Surg* 2010;68:1631–1638.
89. Coelho PG, Marin C, Teixeira HS, et al. Biomechanical evaluation of undersized drilling on implant biomechanical stability at early implantation times. *J Oral Maxillofac Surg* 2013;71:e69–e75.
90. Iezzi G, Piattelli A, Mangano C, et al. Peri-implant bone tissues around retrieved human implants after time periods longer than 5 years: A retrospective histologic and histomorphometric evaluation of 8 cases. *Odontology* 2014;102:116–121.



Page numbers followed by “f” denote figures; those followed by “t” denote tables.

A

- A-point, 121, 122f, 123
- AFG. *See* Anatomic functional geometry.
- Airborne-particle abrasion, 35, 366, 367f, 387f, 393f
- Alkaline phosphatase, 35
- All-on-4 protocol/technique
 - advantages of, 63
 - angulated abutments with, 179, 185, 185f
 - benefits of, 152, 154
 - bone defects with, 231, 241f-242f
 - case study of, 125, 126f-141f, 247f
 - description of, 33
 - edentulism treated with, 152, 154, 154f-156f
 - history of, 68
 - hybrid, 231, 260f-263f
 - hygienic maintenance benefits of, 154
 - illustration of, 24f, 69f
 - lateral radiograph of, 87, 87f
 - long implants with, 231, 237f-240f
 - in mandible
 - alveolar crest preparation, 281, 281f
 - anesthesia for, 279
 - case study of, 383, 411f-416f
 - description of, 69f, 235f, 383, 411f-416f
 - drill sequence, 285t
 - esthetics, 277f
 - flap elevation, 279, 280f
 - implant placement, 284, 286, 286f
 - implant site preparation, 282-284, 283f
 - incision for, 279, 279f
 - inferior alveolar nerve, 280, 280f
 - Nobel Biocare bone mill, 286, 286f
 - prosthetic abutments, 286, 287f
 - radiographic examination before, 279, 279f
 - results, 301f
 - summary of, 278t
 - surgical guide for, 281, 283f
 - suturing, 286, 287f
 - in maxilla, 69f, 383, 411f-416f
 - maxilla and mandible with skeletal class correction, 125, 126f-141f
 - objectives of, 154, 155f-156f
 - in posterior maxilla, 171t-172t, 174-185, 175f-185f
 - radiographic examination before, 279, 279f
 - studies of, 69-70
 - surgical guide for, 176, 177f, 281, 283f
 - suturing, 286, 287f
 - Toronto-Brånemark maxillary prosthesis versus, 71f
 - transsinus tilted implants with, 187, 187f, 231, 234f-236f
- All-on-6 protocol, 171t, 173
- Alveolar crest, 281, 281f
- Alveolar ridge atrophy, 39
- Alveoloplasty, 176, 256f, 281, 288f
- Analog-digital workflow, 345
- Anatomic functional geometry, 115
- Angulated abutments, 179, 185, 185f, 223f, 286f
- Anterior loop of inferior alveolar nerve/mental nerve, 93-94, 93f, 280f
- Anterior symphysis, intraoral palpation of, 82
- Articulator
 - mounting casts on, 313, 338-341, 340f
 - provisional prostheses mounted on, 389f
- Atrophic mandible. *See* Mandible, atrophic.
- Atrophic maxilla. *See* Maxilla, atrophic.
- Axial implants
 - anterior, 179, 183f
 - in anterior maxilla, 263f
 - description of, 50-51
 - insertion axis of, 179, 182f

- in posterior maxilla, 170t-171t, 179, 182f
- survival of, 52t
- tilted implants versus, 288

B

- Bicorticalism, 23
 - Biomaterials, 11-12
 - BMPs. *See* Bone morphogenetic proteins.
 - Bone
 - age-related changes in, 28
 - dense, 28
 - Lekholm and Zarb's classification, 21, 21b
 - medium, 28
 - Misch classification of, 21, 21b
 - soft, 28
 - type D1, 29
 - type D2 and D3, 29
 - type D4, 29-31
 - Bone deformation, 26
 - Bone density
 - classification of, 22t
 - corticosteroid effects on, 66f
 - determination of, in implant site preparation, 28-31
 - implant success and, 22
 - low levels of, 187, 231
 - primary stability affected by, 22
 - Bone formation
 - adhesion stage of, 11-12, 12f
 - arrangement of bone after, 13, 13f-14f
 - differentiation stage of, 12-13
 - histology of, 13f
 - osteoblasts in, 11, 12f
 - osteogenic cells in, 10f
 - proliferation stage of, 12
 - recruitment stage of, 11
 - Bone grafts, for atrophic posterior maxilla, 159, 160f-167f
 - Bone healing, implant morphology and, 14-15
 - Bone-implant interface, micromovements at, 19-20
 - Bone loss, 76f
 - Bone modeling, 26. *See also* Bone remodeling.
 - Bone morphogenetic proteins, 11
 - Bone quality
 - heat production during implant site preparation affected by, 28
 - primary stability affected by, 22
 - Bone regeneration, 159
 - Bone remodeling
 - cellular activity of, 19
 - description of, 13, 26
 - Bone stress, implant length effects on, 25, 26f
 - Bone-to-implant contact, for osseointegration, 1-2
 - Brachycephalic facial type, 110, 112
 - Brånemark, P-I
 - osseointegration discovery by, 1
 - protocol developed by, 8
 - 10-year clinical study by, 6, 6f-7f
 - Brånemark Novum, 31, 31f, 275, 275f
- ## C
- CAD/CAM titanium framework, 335, 335f, 344f, 414f
 - CBCT. *See* Cone beam computed tomography.
 - CBJR. *See* Cranial base and jaw relationship.
 - Centric occlusion, 113
 - Centric relation, 110-111, 113
 - Centripetal resorption, 79
 - Ceramic crowns, 370, 371f-372f, 383
 - Chewing, 113

Index



Chronic periodontitis, 197f
 CO. See Centric occlusion.
 Complete-arch rehabilitation, number of implants in, 31
 Complete dentures
 construction of, 75
 edentulism treated with, 145-147, 153t
 implants to support, 146
 Complete prosthesis, resorption associated with, 147
 Composite resin teeth
 prefabricated, definitive prosthesis with
 casts, 338
 esthetic try-in, 347, 348f
 intermaxillary relationship, 338-341, 339f-340f
 metal framework, 342-347
 passive fit, 345, 347
 patient assessment, 336-338
 prosthesis delivery, 351, 352f-355f
 prosthesis finalization, 347-351
 wax setup, 341-342, 342f
 titanium framework with, 401f
 Computed tomography
 cone beam, 87-89, 89f
 in edentulism evaluations, 87f, 87-88
 fan beam, 87f, 87-88, 89t
 implant planning evaluation using, 127f
 Computer-assisted planning, for edentulism, 95, 96f-105f
 Cone beam computed tomography, 87-89, 89f
 Contact osteogenesis
 bone formation in, 10f, 11-13, 12f
 definition of, 9
 illustration of, 9f
 osteoconduction in, 10f, 11
 stages of, 9, 11-13
 Cortical anchorage, in primary stability, 23-25, 24f-25f
 Cortical bone
 primary stability affected by, 23
 trabecular bone and, 23
 CR. See Centric relation.
 Cranial base and jaw relationship, 110-113, 110f-113f
 Crestal bone level, tilted implants effect on, 50-51, 58
 Crown and partial denture design, in mandible, 276, 277t
 "Curtain effect," 122, 122f
 Cutback, 367, 369, 369f, 387f

D

Definitive prostheses
 airborne-particle abrasion, 366, 367f, 387f, 393f
 CAD/CAM titanium framework for, 335, 335f, 344f
 cementing of single crowns, 373, 373f
 ceramic crowns, 370, 371f-372f
 cleaning of, 355f
 complications of, 377, 379, 379f
 construction of, 335
 cutback, 367, 369, 369f
 "disilivision" technique for, 356-379, 357f-379f
 esthetic try-in, 358
 framework passivity, 364, 364f
 occlusion in, 379-380, 381f-382f
 passive fit of, 358
 photographs of, 359, 359f
 placement of, 375-377, 376f
 porcelain layering, 367, 369, 369f
 with prefabricated composite resin teeth
 casts, 338
 esthetic try-in, 347, 348f
 intermaxillary relationship, 338-341, 339f-340f
 metal framework, 342-347
 passive fit, 345, 347
 patient assessment, 336-338
 prosthesis delivery, 351, 352f-355f
 prosthesis finalization, 347-351
 wax setup, 341-342, 342f
 prototype, 360
 screw-retained, 335
 silicone index, 356, 360, 361f, 365
 Delayed loading, Brånemark protocol regarding, 8
 Dense bone, 28

Dental prostheses
 definitive. See Definitive prostheses.
 intraosseous anchorage of, 2-3, 3f-5f
 provisional. See Provisional prosthesis/restoration.
 Diagnostic planes, 107-108, 108b
 Direct technique, for provisional prosthesis
 mandibular, 324, 330f-331f
 maxillary, 324, 325f-329f
 steps involved in, 305-311, 306f-311f
 "Disilivision" technique, 356-379, 357f-379f
 Distal cantilever
 short implants with, in posterior maxilla, 170f7
 tilted implants for reduction in use of, 69, 71, 71f
 Distance osteogenesis, 9, 9f
 Dolichocephalic facial type, 110
 Double-scan technique, 362
 Drilling, heat production in implant site preparation affected by, 27-28
 Dysmorphism, 80f

E

Edentulism
 All-on-4 protocol for, 152, 154, 154f-156f
 alveolar bone resorption in, 79
 anatomical considerations for
 anterior loop of mental nerve, 93-94
 inferior alveolar nerve, 92, 92f, 97f
 mandibular canal, 92
 mandibular incisive canal, 95, 95t
 maxillary sinus, 91
 mental foramen, 92-93, 93t-94t
 appearance of patient with, 75f
 atrophy in, 124
 bone resorption patterns, 76
 clinical examination of, 80-83
 complete dentures for, 145-147, 153t
 computer-assisted planning for, 95, 96f-105f
 diagnostic prosthesis for, 109
 dysmorphism associated with, 80f
 evaluation of, 75-76
 extraoral inspection of, 80-81
 facial changes associated with, 75f, 80, 80f
 global prevalence of, 145
 health effects of, 143b, 143-144, 144t
 implant-retained overdenture for, 153t
 implant-supported overdenture for, 153t
 implants for
 complete dentures versus, 145-147
 immediate loading of, 146f
 masticatory force improvements using, 145
 preliminary considerations for, 147-148
 intraoral inspection of, 81-83, 82f-83f
 intraoral palpation in, 82
 mastication effects of, 144
 maxillary sinus in, 91
 nutrient intake and, 144t
 pathophysiology of, 76-79, 77f-79f
 prosthetic solutions for, 118b
 radiologic examinations of, 83-91, 84b, 84f-90f
 computed tomography, 87f, 87-88
 lateral cephalometric radiograph, 87, 87b, 87f
 panoramic radiographs, 85b, 85f-86f, 85-86
 periapical radiographs, 84f, 84-85
 Edentulous maxilla
 Marius bridge for, 68
 posterior
 All-on-4 technique for, 171t-172t, 174-185, 175f-185f
 All-on-6 technique for, 171t, 173
 fixed implant-supported prosthesis for, 170-174
 retrocanine triangle in, 168, 168f
 Endosseous implants, 2, 21
 Endosseous wound healing
 contact osteogenesis in. See Contact osteogenesis.
 histodynamics of, 8-13, 9f-13f
 Extraoral patient analysis, 311-313, 312f, 336

F

Facebow record, 131f, 316, 338f, 412f
 Facial analysis

description of, 107
in frontal plane, 108b
photographic report in, 108-109, 109f
in sagittal plane, 108b
in transverse plane, 108b

Facial types, 110, 112

Fan beam computed tomography, 87f, 87-88, 89t

FBCT. *See* Fan beam computed tomography.

Fibrin clot, 11

Fibroblasts, 11

Fixed implant-supported prosthesis
complete, 153t
immediate loading of, 274-275
for posterior maxilla, 159-169, 160f-169f
zygomatic implant, 191f

Fixed partial denture
with 45-degree tilted implant, 193, 196f-197f
implant-supported, 240f
in mandible, 276, 277t
with 30-degree tilted implant, 193, 195f
with transsinus tilted implants, 194, 198f-204f

Freeway space
description of, 112
determination of, 113-114, 114t
movements occurring in, 114

Frontal plane
facial analysis in, 108b
gingival exposure, 116
horizontal lines on, 110f
maxillary incisal edge position in, 115f-116f, 115-116
smile line, 116, 116t, 117f
upper lip position, 116, 116t, 117f
vertical dimension of occlusion reductions on, 112f

Full-arch rehabilitation, 148-149

FWS. *See* Freeway space.

G

Gingiva
excessive exposure of, 116
facial, 349, 350f
keratinized, 151, 279, 287f, 330f
modeling of, 370
pink, 403f

Gummy smile
causes of, 116
definition of, 116
illustration of, 117f
interventions for, 117-118
osteotomy for, 118, 120f
partial denture prosthesis with ridge lap contour for, 118, 119f

H

Healing
bone, implant morphology and, 14-15
after implant placement, 8, 9t

Healing chambers, 15

High smile line, 116

Horizontal canting, 124, 125f

Hourglass morphology, 95

Hybrid prosthesis, 151f

I

Immediate loading
of fixed implant-supported prosthesis, 274-275
of implant-supported overdenture, 274
of implants in completely edentulous patients, 146f
inclination of implants for, 4f
primary stability for, 19
success of, 14
of tilted implants
applications of, 59
complications, 51, 53
conclusions regarding, 58-59
crestal bone level, 50-51, 58
factors that affect, 59
failure of, 43
marginal bone loss after, 50, 53t

outcome variables, 55-56
screw loosening after, 51
studies of, 43, 44t-50t
survival after, 43, 50, 52t
systematic review of, 40-58

Implant(s)
axial. *See* Axial implants.
characteristics of, 31f-33f, 31-35
diameter of, 34
dimensions of, 33-34
failure of. *See* Implant failure.
inclination of, 4f
insertion torque for, 14, 22, 26
length of, bone stress affected by, 25, 26f
machined, 34
morphology of, bone healing and, 14-15
number of, 31f-32f, 31-33
placement of. *See* Implant placement.
postextraction, 288f-289f, 288-290
site preparation of. *See* Implant site preparation.
splinting of, 30, 56
stability of. *See* Implant stability.
submerging of, 6
surface of
airborne-particle abrasion of, 35
modifications to, 34-35
roughness of, 11, 35
surgery. *See* Implant surgery.
tilted. *See* Tilted implants.
zygomatic. *See* Zygomatic implants.

Implant failure
case studies of, 231, 232f-233f
illustration of, 5f, 156f
longer implants for correction after, 231f, 243f-245f
surgical retreatment for, 185, 187
tilted implants, 43
timing of, 21

Implant placement
All-on-4 technique for, 133f. *See also* All-on-4 protocol/technique.
bone grafting for, 39
finalizing of, 29
healing time after, 8, 9t
manual, 30, 30f

Implant-prosthetic treatment, 109-110

Implant-retained overdenture, 153t, 193

Implant site preparation
bone density determinations in, 28-31
heat production during, 27b
instrument-related factors in, 27b, 27-28
operator-related factors in, 27, 27b
patient-related factors in, 27b, 28
surgical site factors in, 27b, 28

Implant stability
bone deformation and, 26
primary. *See* Primary stability.
secondary. *See* Secondary stability.

Implant-supported overdenture
description of, 153t
immediate loading of, 274

Implant-supported prostheses, 3f

Implant surgery, 90-91

Impression, 315, 317f

Incisor angle, 122-124, 123f

Indirect technique, for provisional prosthesis
mandibular, 324, 332f-333f
steps involved in, 311-323, 312f-323f

Inferior alveolar nerve
anterior loop of, 280f
in edentulous patients, 86, 92, 92f, 97f

Interalar distance, 115, 116f

Interfacial remodeling, 14

Interforaminal axial implants, 73f

Interforaminal implants, 276

Interincisive angle, 123, 123f

Interincisive line, 124, 125f

Interpupillary line, 109, 124

Intramembranous-like healing, 15

Intraoral patient analysis, 311-313, 312f, 336

Index

K

Keratinized gingiva, 151, 279, 287f, 330f

L

Labial nose angle, 122, 122f
 Lamellar bone, 10f
 Lateral cephalometric radiograph, in edentulism evaluations, 87, 87b, 87f
 Lekholm and Zarb's classification of bone, 21, 21b
 Lip support, 121-122, 121f-122f
 Lithium disilicate crowns, 367, 368f, 395f
 Low smile line, 116

M

Machined implants, 34
 Mandible
 All-on-4 technique in
 alveolar crest preparation, 281, 281f
 anesthesia for, 279
 case study of, 383, 411f-416f
 drill sequence, 285t
 esthetics, 277f
 flap elevation, 279, 280f
 implant placement, 284, 286, 286f
 implant site preparation, 282-284, 283f
 incision for, 279, 279f
 inferior alveolar nerve, 280, 280f
 Nobel Biocare bone mill, 286, 286f
 prosthetic abutments, 286, 287f
 radiographic examination before, 279, 279f
 results, 301f
 summary of, 278t
 surgical guide for, 281, 283f
 suturing, 286, 287f
 atrophic
 case study of, 290, 294f-302f
 computer-assisted planning for, 95, 96f-105f
 composite resin teeth rehabilitation in, 383, 389f-410f
 crown and partial denture in, 276, 277t
 direct technique with intraoral finalization in, 324, 330f-331f
 fixed implant-supported prosthesis in, 274-275
 fixed prostheses for, 273-274
 implant-supported complete prostheses for, 276, 277t-278t
 implant-supported overdenture in, 274
 indirect technique in, 324, 332f-333f
 lateral deviation of, 111f
 postextraction implants in, 288f-289f, 288-290
 rehabilitation protocols for, 273-304
 removable prostheses for, 273-274
 short posterior implants in, 278t
 Mandibular canal, 85f, 85-86
 Mandibular cast, 313, 313f
 Mandibular implants, maxillary implants versus, 23
 Mandibular incisive canal, 95, 95t
 Mandibular incisor margin, under maximum intercuspation, 130f
 Mandibular prognathism, 110f
 Marius bridge, 68
 Masticatory forces, 77
 Maxilla
 All-on-4 protocol/technique in, 171t-172t, 174-185, 175f-185f, 383, 411f-416f
 atrophic
 advanced, 194, 206f-210f
 centripetal path of resorption in, 81
 intraoral palpation of, 82, 83f
 prosthesis for, 150f
 tilted implants for, 66-67
 zygomatic implants for, 264f-265f
 bone resorption of, 147f
 ceramic crown rehabilitation in, 383, 389f-410f
 direct technique with extraoral finalization in, 324, 325f-329f
 edentulous, fixed implant-supported prosthesis for, 170-174
 occlusal load dissipation benefits of, 146
 posterior. *See* Posterior maxilla.
 rehabilitation protocols for, 159-269
 V-II-V technique in, 383, 384f-388f
 Maxillary implants
 bone loss around, 232f
 case study of, 212f
 mandibular implants versus, 23
 Maxillary incisors

cervical margin of, 115
 edge position of, 115f-116f, 115-116
 vestibularization of, 130f
 Maxillary overdenture, 175f
 Maxillary prognathism, 110f
 Maxillary sinus
 in edentulism, 91
 elevation procedure for
 description of, 39
 failure of, 40f
 pneumatization of, 70f, 91f, 160f, 187f, 219f-220f, 231, 234f
 Maxillofacial complex, 3D reconstruction of, 77f
 Maxillomandibular relationship, 150
 Maximum intercuspation, 110-111, 113, 124
 Mental foramen
 anatomy of, 92-93, 93t-94t
 description of, 82
 panoramic radiograph of, 86
 security zone from, 94
 Mental nerve
 anterior loop of, 93-94
 panoramic radiograph of, 86, 86f
 in tilted implant placement, 222f
 Menton line, 110f
 Mesenchymal stem cells, 11, 13
 MI. *See* Maximum intercuspation.
 Microfractures, 14, 15f
 Micromotion, 56
 Midcrestal incision, 174
 Misch classification of bone, 21, 21b

N

Nasolabial angle, 122, 122f
 Nobel Biocare bone mill, 179, 286, 286f
 NobelProcera 2G scanner, 391f

O

Occlusal contacts, 351
 Occlusal envelope, 123, 123f
 Occlusal plane positioning, 124, 125f
 Occlusal table, 356
 Occlusion
 in definitive prosthesis, 379-380, 381f-382f
 terminology associated with, 113
 vertical dimension of
 anatomy involved in, 110
 cephalometric parameters in, 112, 113f
 definition of, 111
 description of, 53
 new, patient adaptation to, 114
 reduced, 111, 112f
 reestablishment of, 380
 registering of, 316-318, 317f
 Odontophobia, 210f, 217f
 Ophric line, 110f
 Osseointegration
 adaptable, 1
 bone-to-implant contact for, 1-2
 definition of, 1-2
 micromovement effects on, 20, 56
 overview of, 1-2
 points of view regarding, 2
 Osteoblasts, 11-12, 12f
 Osteoconduction, 10f, 11
 Osteogenesis. *See* Contact osteogenesis, Distance osteogenesis.
 Osteogenic cells, 10f, 11
 Osteotomy
 drill for, 285f
 for gummy smile, 118, 120f
 Overbite, 122-123
 Overjet, 122-123

P

Panoramic radiographs, in edentulism evaluations, 85b, 85f-86f, 85-86
 Partial dentures
 implant-supported, 160f
 with ridge lap contour, for gummy smile, 118, 119f
 Partial edentulism, 194, 195f
 Passive fit, 348f



Patient
 psychological health of, 150
 treatment planning involvement in, 149-150

Peri-implant bone, 21

Peri-implant mucositis, 53

Peri-implantitis, 53

Periapical radiographs
 advantages of, 84
 in edentulism evaluations, 84f, 84-85
 limitations of, 84-85

Periodontal disease, 201f, 234f, 246f

Periosteal elevators, 176, 279

Periotest, 275

Photographic report, 108-109, 109f

Pneumatization of maxillary sinus, 70f, 91f, 160f, 187f, 219f-220f, 231, 234f

Porcelain layering, 367, 369, 369f

Posterior maxilla
 anatomy of, 65f
 atrophic
 bone grafts for, 159, 160f-167f
 distal cantilever for, 168
 axial implants for, 170t-171t
 basal bone, 174
 edentulous
 All-on-4 technique for, 171t-172t, 174-185, 175f-185f
 All-on-6 technique for, 171t, 173
 fixed implant-supported prosthesis for, 170-174
 retrocanine triangle in, 168, 168f
 fixed implant-supported prosthesis for, 159-169, 160f-169f
 tilted implants for, 168, 169f
 transsinus tilted implants for, 169, 170t
 treatment options for, 170t-172t

Posterior tilted implants, 55

Postextraction atrophy, 76

Postextraction implants, 288f-289f, 288-290

Primary stability
 All-on-4 rehabilitation for, 71f
 bone quality and quantity in, 21b, 21f, 21-23
 cortical anchorage in, 23-25, 24f-25f
 definition of, 19
 determinants of, 21-28
 insertion torque and, 26
 micromovement reductions with, 26
 surgical technique and, 27
 tilted implants for, 67, 68f

Prognathism, 110f

Prosthetic abutments, 306-307, 362

Prosthetic screws, 351

Prosthetic space, 150

Provisional prosthesis/restoration
 articular mounting of, 389f
 case studies of, 209f, 236f, 324, 325f-333f
 cylinders fixed to, 308, 309f
 direct technique
 mandibular, 324, 330f-331f
 maxillary, 324, 325f-329f
 steps involved in, 305-311, 306f-311f
 illustration of, 100f
 immediate
 illustration of, 132f, 134f-135f, 296f
 positioning of, 321, 322f-323f
 indirect technique for
 mandibular, 324, 332f-333f
 steps involved in, 311-323, 312f-323f
 removal of, 336, 338, 338f
 soft tissue profile, 308, 310f, 311
 wax duplicate of, 357f
 zygomatic implants with, 269f

Pterygoid process, implant placement in, 66f

Pterygomaxillary implants, 64, 65t

R

Reductive osteoplasty, 99f

Remodeling. *See* Bone remodeling.

Removable partial denture, 147

Residual ridge, 146

Resorbable collagen membrane, 162f, 167f

Retrocanine triangle, 168, 168f

Ricketts analysis, 112

Rule of 10, 281, 282f

S

Sagittal plane
 facial analysis in, 108b
 horizontal lines on, 110f
 incisor angle in, 122-124, 123f
 lip support in, 121-122, 121f-122f
 vertical dimension of occlusion reductions on, 112f

Secondary stability, 19

Sheffield test, 347

Silicone index, 356, 360, 361f, 365, 412f

Single-tooth replacement, 33

Sinus cavity grafting, 239f

Sinus membrane, 161f

Skeletal class
 All-on-4 maxilla and mandible with correction of, 125, 126f-141f
 illustration of, 110, 110f

Smile
 gummy. *See* Gummy smile.
 width of, 124

Smile line, 116, 116t-117t, 117f

Soft bone, 28

Splanchnocranium, 76, 77f

Straight implants, inclined implants versus, 68f

Subnasale line, 110f

Surgical site
 implant site preparation affected by, 27b, 28
 underpreparation of, 29-30

Surgical technique, primary stability affected by, 27

T

Temporomandibular disorders, 274

Tilted implants
 advantages of, 63-73, 288
 in All-on-4 protocol, 68f
 anatomical considerations for
 anterior loop of mental nerve, 93-94
 inferior alveolar nerve, 92, 92f, 97f
 mandibular canal, 92
 mandibular incisive canal, 95, 95t
 maxillary sinus, 91
 mental foramen, 92-93, 93t-94t
 mental nerve, 93-94, 222f
 in atrophic mandible, 302f
 atrophic maxilla treated with, 66-67
 axial implants versus, 288
 case studies of, 222f, 226f-231f
 clinical protocols with, 64-68
 description of, 39-40
 distal cantilever reduction using, 69, 71, 71f
 edentulous maxilla treated with, 68
 force affected by, 25
 history of, 67
 immediate loading of
 applications of, 59
 complications, 51, 53
 conclusions regarding, 58-59
 crestal bone level, 50-51, 58
 factors that affect, 59
 failure of, 43
 marginal bone loss after, 50, 53t
 outcome variables, 55-56
 screw loosening after, 51
 studies of, 43, 44t-50t
 survival after, 43, 50, 52t
 systematic review of, 40-58
 implant dimensions for, 34
 indications for, 70, 70f
 insertion axis of, 178, 179f
 insertion of, 178, 180f-181f
 limitations of, 56
 osteotomy of, 178, 293f
 partially edentulous arch treated with, 67
 posterior, 55, 174, 289f, 291f
 primary stability with, 67, 68f
 pterygomaxillary implants, 64, 65t
 rationale for, 68
 rehabilitation with, 379-380
 splinting of, 56
 straight implants versus, 68f
 stress on, 55, 55f

Index



success rates for, 67
 survival rate of, 43, 50, 52t, 69
 transsinus
 All-on-4 technique with, 187, 187f
 case study of, 240f, 253f
 fixed partial denture with, 194, 198f-204f
 in posterior maxilla, 169, 170t
 primary stability of, 231
 Titanium CAD/CAM framework, 335, 335f, 344f, 414f
 Titanium implant
 bone resorption around, 233f
 osteoblast attachment to, 12f
 surface of, 1, 12f
 TiUnite implant, 10f
 Toronto-Brånemark prosthesis
 mandibular, 278t
 maxillary
 All-on-4 technique versus, 71f
 description of, 63
 illustration of, 7f, 57f
 radiograph of, 33f, 64f
 rule of 10, 281, 282f
 Trabecular bone
 cortical bone and, 23
 illustration of, 10f
 Transforming growth factor β , 11
 Transmucosal implants, 274
 Transsinus tilted implants
 All-on-4 technique with, 187, 187f
 case study of, 240f, 253f
 fixed partial denture with, 194, 198f-204f
 in posterior maxilla, 169, 170t
 primary stability of, 231
 Transsinus V-II-V technique, 231, 251f-255f
 Transverse plane
 facial analysis in, 108b
 horizontal canting, 124, 125f
 interincisive line, 124, 125f
 occlusal plane positioning, 124, 125f
 smile width, 124
 Treatment planning
 algorithm for, 149b
 anatomy in, 150-151
 clinical examination in, 174, 175f
 finances in, 151-152
 patient's involvement in, 149-150
 radiographic evaluation in, 174, 175f
 Trichion line, 110f
 Tricorticalism, 23
 Tuberosity implants, 64, 65t

U

Upper lip
 length of, age-related changes in, 117f
 position of, 116, 116t, 117f

V

V-II-V technique
 case studies of, 231, 246f-259f
 description of, 66, 66f, 152, 188f-189f, 188-189
 maxillary rehabilitation with, 383, 384f-388f
 transsinus, 231, 251f-255f
 V-threaded implants, 14, 15f
 VDO. See Vertical dimension of occlusion.
 VDR. See Vertical dimension at rest.
 Verification jig, 338, 339f
 Vertical dimension at rest, 113, 114t
 Vertical dimension of occlusion
 anatomy involved in, 110
 cephalometric parameters in, 112, 113f
 definition of, 111
 description of, 53
 new, patient adaptation to, 114
 recording of, 174, 279
 reduced, 111, 112f
 reestablishment of, 380
 registering of, 316-318, 317f
 Vertical releasing incision, 295f
 Voxel size, 88

W

Working cast, 315, 317f
 Woven bone, 21

X

Xenograft, 167f

Z

Zygomatic implants
 atrophic maxilla treated with, 264f-265f
 description of, 70, 144
 double, 231, 264f-269f
 extramaxillary approach to, 192, 261f-262f
 in maxilla, 189-193
 with provisional restoration, 269f
 surgical techniques for, 191-193