Oreste Iocca
Editor

Evidence-Based Implant Dentistry

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Preface

The information provided in this book are the result of an evidence-based approach to the dental implant literature with the aim to analyze the most common dilemmas faced by the clinicians who adopt dental implants in their practice.

Our work is directed to the students, the general practitioners, and the implant specialists who wish to have an update on various implantology topics.

The *first two chapters* are intended to describe the bibliographic tools used for literature searches and the most common statistical concepts necessary to fully understand the medical and dental literature.

Chapter 3 analyzes the old dilemma in regard to extraction or implant placement. A schematic approach is adopted in the analysis of the various clinical scenarios. Finally, treatment algorithms are drawn in order to facilitate the decision-making process.

Chapter 4 focuses on bone response to implant surfaces, bone remodeling after dental extraction and subsequent implant placement, the processes of osseointegration, and the definition of implant stability and its clinical implications. A review of the outcomes of implants placed in infected sites is also provided.

Chapter 5 provides a description of the various placement and loading protocols in order to establish if any difference exists in terms of survival and success rates between the various protocols.

Chapters 6 and 7 give an organized classification of implant designs, implant length, and platform configurations in an attempt to establish their impacts on clinical outcomes.

Chapters 8 and 9 examine the various prosthetic solutions for implant restoration. The materials and designs of abutments and prostheses are analyzed in a way to facilitate the clinical decision-making.

Chapter 10 covers the topic of pre-implant surgery. Careful review of all the possible surgical options for the edentulous patient is performed and is accompanied by a rich iconography.

Chapter 11 is intended as a review of the pathogenesis, clinical aspects, and proposed treatment options for the most worrisome long-term complication of the implant treatment: periimplantitis. Acknowledging that a consen-

sus on this topic is far to be reached, an analysis of the proposed management strategies and results is attempted.

I hope that our work will be useful for the colleagues in search of evidence-based answers to their questions and also as a refresh to the most frequent topics in current implantology practice.

Rome, Italy Oreste Iocca, DDS

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Introduction to Evidence-Based Implant Dentistry

1

Oreste Iocca

Abstract

Evidence-based dentistry (EBD) concepts are of extraordinary importance for a good clinical practice. The clinician, the patient, and the scientific evidence are the three main components of EBD, whose integration involves the application of four steps: formulating of a question, getting the evidence, appraising the evidence, and applying the evidence. Evidence-based information comes from electronic databases and hand searches with the use of appropriate bibliographic techniques. Basic knowledge of the methodologies used in observational and experimental studies will allow to perform a critical appraisal of the available evidence. Finally, the application of the evidence-based information to the clinical scenario needs a quality assessment of the studies and is possible only when internal and external validity are high.

1.1 Evidence-Based Dentistry

The definition of evidence-based medicine (EBM) comes from the influential work of Prof. David Sackett who stated that "EBM constitutes a new approach to clinical practice in which clinical decisions derive from the integration of the doctor's experience with the conscientious, explicit and judicious use of the best scientific evidence available, all of this mediated by the preferences of the patient" [1, 2].

Therefore, the three main components of EBM are the clinician, the scientific evidence, and the patient.

Good EBM practice articulates in four steps:

- *Formulating a question* means to translate a clinical doubt into a searchable question format.
- *Getting the evidence* involves the knowledge of all the instruments available to answer the original question.
- *Appraising the evidence* means to possess the instruments to critically analyze the available scientific literature.
- *Applying the evidence* is the process by which the collected evidence is applied to a specific clinical scenario.

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All of these factors apply to all fields of medicine, including dentistry and its subspecialties. Luckily, the term evidence-based dentistry (EBD) is now of common use among dental practitioners who are eager to put in practice the above-mentioned principles [3].

Nevertheless, even the most scrupulous clinician may encounter difficulties in staying updated with the overwhelming amount of evidence available today.

Development of specific sets of knowledge spanning from bibliographic research to statistical test interpretation is fundamental in order to address all the four steps of the good EBD practice.

The definition of best scientific evidence by itself may generate some confusion. It can be defined as the information derived from a properly conducted research or study aimed at proving or countering a scientific hypothesis.

The *evidence pyramid* (Fig. 1.1) has been designed to graphically categorize the quality of various study designs, from the lowest to the highest [4].

Although it is true that the best study design is the RCT, it should be understood that performing a RCT is not always feasible or indicated. In fact, there are situations in which observational studies are preferable. For example, if a rare complication like implant fracture is studied, it would be better to adopt a case–control design that allows to measure the odds of exposure among cases versus a control group. In this way, we select a group of patients that had the implant fracture complication (rare outcome cases) and a control group (implant patients without implant fracture); in other words, we analyze the two groups retrospectively in order to understand why the rare adverse event occurred in the case group in respect to the control group. It is evident that a RCT in order to identify a rare outcome would not be indicated because a rare complication/disease may not occur even with long follow-up periods.

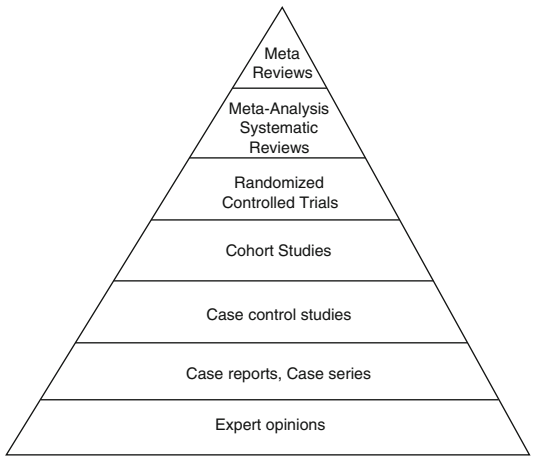

Fig. 1.1 Evidence-based pyramid

In summary, RCTs are at the top of the pyramid because they actually give the best evidence, but this does not mean that observational studies should be considered useless. On the contrary, researchers and readers of the scientific literature must be able to understand the extent to which a particular study design is indicated to answer a specific question.

The *peer-review process* ensures quality control over the evidence-based knowledge. Indeed, a biomedical research is not usually considered worthy of consideration until it is not validate by peer review.

This process is similar in the majority of the medical and dental journals. An author submits a manuscript which is received by the editor of the journal who assesses if the work is suitable for publication. If the manuscript is considered for publication, it needs to be further reviewed. Usually two additional reviewers (normally experts in their given scientific area) receive the manuscript at this point. Usually the reviewers are unaware of the names of the authors in order to ensure integrity of the review process. Once the reviewers accept to review the manuscript, the actual peer-review process begins.

Many journals have their own checklists for assessing quality of the manuscript, but a specific evaluation depends upon the type of study submitted (case report, randomized clinical trial, systematic review, etc.). Evaluation focuses on title and abstract, study design and methodology, soundness of the results, discussion, and conclusions.

The reviewers send their evaluation to the editor, who finally makes the decision of accepting, revising, or refusing the manuscript. In any case, the authors are informed of the final decision; if revision is required (as it usually happens for accepted manuscripts), the process is repeated.

Although subjectivity and biases in the evaluation process may occur, the peer-review mechanism is still considered the best way of performing high-quality dissemination of the scientific knowledge.

1.2 EBD in Practice

1.2.1 Formulating a Question

Unresolved questions, most of the times, arise from specific clinical scenarios. These can refer to etiologic, diagnostic, prognostic, or therapeutic issues.

A good question is the one that, once answered, would provide useful and applicable information for the practicing clinician. In other words, it should be established if the question is important for the clinical practice, if it can be generalized to a whole population, and if it can be incorporated in the everyday practice by the clinicians.

Framing a good question, although it may seem easy, requires skills and expertise in order to not get lost in the quest for evidence. A well-formulated question takes into account the so-called PICO elements, in detail the Population of interest, the Intervention of interest, the Comparison or the reference against which we compare the intervention, and the Outcome of the intervention we are studying.

For example, a question may be related to platform switching, in order to understand if this particular platform configuration gives an advantage in terms of prevention of marginal bone resorption. The question format should be something similar to this: "what is the effectiveness of platform switching in reducing or eliminating the marginal bone resorption over time when compared to nonplatform-switched configurations?"

The PICO elements can help in formulating a structured question:

Population patients undergoing implant treatment
Intervention platform-switched implant insertion
Comparison nonplatform-switched implant insertion
Outcome marginal bone resorption in millimeters measured clinically or radiographically

Once the question is clearly stated and deemed important for the clinical practice, the next step involves the application of defined criteria for the search of relevant evidence from the scientific literature that may help in answering the question.

1.2.2 Getting the Evidence

Today the strategies adopted for searching for the available studies of interest are conducted mostly through the use of electronic databases. Although manual searches are still considered important in order to get studies not retrieved by digital systems due to the date of publishing (old studies may not be present in electronic databases) or because of non-indexed publications.

Medical bibliographic databases have the function of large catalogs that points to information found elsewhere. Undoubtedly, the United States National Library of Medicine (NLM) of the National Institute of Health in Bethesda, Maryland, is the most known and used database for medical research worldwide. A division of the NLM, the National Center for Biotechnology Information (NCBI), was created to allow medical and biotechnology researchers worldwide an automated tool to retrieve scientific information. Most of the researchers are familiar with MEDLINE which is the searchable citation index database of the NLM of which PubMed is its online search engine. PubMed provides links to full-text articles of the scientific publishers indexed in MEDLINE. Moreover, PubMed Central is a digital archive of selected free full-text articles, on various medical and biological topics, accessible by the PubMed users regardless of the sources.

Searches in MEDLINE/PubMed (http://www.ncbi.nlm.nih.gov/) are facilitated if one uses the so-called MeSH terms (Medical Subject Headings). This is a thesaurus of a standard set of terms organized in categorical order; each category contains subcategories arranged hierachically. Each term corresponds to a technical word used for indexing biomedical journal articles (http://www.ncbi.nlm.nih.gov/mesh). The use of MeSH terms guarantees efficient access to medical information indexed in MEDLINE and appropriateness of literature search. For example, "dental implants," "dental implant-abutments design," and "platform switching" are MeSH terms, elencated in hierarchical order, that can be used for a literature search on platform-switched implants.

Other databases are used in literature research; these include Embase®, Cochrane Central Register of Controlled Trials, ClinicalTrials.gov, and others.

Also, evidence summaries that collect and synthesize the current literature on most medical topics are available for clinicians; two examples are Up-To-Date® and Essential Evidence Plus®, among others.

Anyway, no such best-evidence summaries exist specifically for dentistry and its subspecialties.

One of the problems of the above resources is that many of them are not available for free for nonsubscribers. Instead, they require individual or institutional subscription. Understandably, this is not possible for all the practitioners looking for answers and accessibility for most of healthcare professionals is a topic that should be addressed in order to guarantee a wide diffusion of the EBM/EBD culture.

1.2.3 Appraising the Evidence

Critical appraisal of the available evidence is of utmost importance in order to understand the impact and applicability of a study to the clinical practice [5].

The first thing to do is to analyze the type of studies available and the results emerging from them.

In general it is possible to classify two broad sets of clinical studies design: observational and experimental.

1.2.3.1 Observational Studies

Ecologic Studies

These are epidemiological studies that are aimed at evaluating a population rather than individuals. These studies use information coming from National Health Service registries or other similar sources of data. The main shortcoming of these studies is the lack of information about single members of the population and are usually regarded as studies with low level of evidence. Nevertheless, they can be useful to understand a trend over time of a particular condition (e.g., edentulism) in a given population in a specific geographic area. In dentistry and implantology in particular, application of ecologic studies is difficult or not possible due to the difficulties in obtaining meaningful data regarding specific dental problems.

Case Reports and Case Series

Case Reports refer essentially to observations of single cases which are considered to be important for their particular form of presentation or rarity. Case series are consecutive or nonconsecutive reports of specific diseases or conditions usually in a small group of patients. The lack of a comparison group and possible selection bias identifies these studies as low level of evidence, even if they can be important in suggesting an association or a particular line of research which has not been investigated yet. Moreover, the search of case reports in the literature may help the clinician, who is facing a very specific situation, on how to manage it. For example, a search of published case reports regarding the rare situation of dislodgement of an implant in the infratemporal fossa can give some clue to the practitioner on how to manage this rare situation.

Cross-Sectional Studies

Cross-sectional studies consist in the individuation of a sample from the population of interest and the collection of information about possible

etiologic risk factors or association of particular conditions with a given disease. One characteristic of this design is the evaluation of exposure and outcome at a point in time, with no follow-up period. In other words, being conducted at a specific time point, the evaluation is on the prevalence of a particular disease and not on the incidence (which supposes an evaluation of a healthy population over time).

The chosen population is identified on the basis of the hypothesis that inspires the study, often on diseases and conditions that have a high prevalence in the population.

For example, a typical cross-sectional study can be aimed at assessing the discomfort or pain associated with pocket probing in patients with peri-implant and periodontal pockets. In the study by Ringeling and coll [25]. Pain referred by the patient with a VAS score was measured in each group in order to determine any difference in intensity of pain between peri-implant probing and periodontal probing. Studies of this kind allow to take a snapshot of the association of increased/decreased pain.

The main advantage of this design is the lack of follow-up period which allow to perform the study rapidly and with less expenses. On the other hand, missing the temporality, it becomes difficult to establish a causality between the exposure and the condition of interest.

Regarding the previous example, once it was established that pain scores were higher in case of peri-implant probing, it remained difficult to ascertain if this was due to the mere presence of the implant or to confounding factors (age, concurrent diseases, psychological factors, etc.), but on the other hand, results were suggestive of the association at that point in time.

Case–Control Studies

These studies are characterized by the particular modality of selection of the patients chosen for examination. In fact, a group of patients will be selected for the presence of a disease/condition (case group) and another group will be selected for the absence of the same disease/condition (control group).

Typically the recruited subjects are those afferent to a hospital or a department but anyway considered representative of an entire population. The control subjects are selected randomly by the same population with the sole exclusion criteria of having the same disease as the case group; the presence of other diseases or conditions does not constitute reason for exclusion in order to avoid the phenomenon of "hyperselection."

After selection of case and control groups, data is analyzed retrospectively in order to identify any association between an exposure and the outcome of interest.

For example, the association between IL-1 gene polymorphisms and early implant failure can be analyzed selecting from the same clinic a group of patients experiencing early implant loss (cases) and a control group of patients with implants still in place [22]. All patients matched for age, gender, and smoking habits. Then an allele and genotype analysis from a blood sample allowed the study of the association between specific IL-1 polymorphisms and early implant failure.

This is a typical example of retrospective analysis in which a biologic sample (blood) is used as an indicator of previous risk (the presence of specific gene polymorphisms) for a given outcome (implant loss).

Advantages of this design consist in rapid completion of the study because no follow-up time is required. Also, in contrast to random selection from the population, the selection of specific cases of interest allows to study even rare cases that in a cohort population would not occur frequently.

Shortcomings include the difficulty in selecting a matching control group and the retrospective design which is prone to biases.

Less commonly, a case–control study can be performed with a prospective design, even if in this case there is the necessity to wait until enough cases have been accumulated.

A nested case–control study instead is performed during a cohort or RCT study. In this case a group of cases part of the original study are compared to a control group from the same study that did not have the outcome of interest.

Cohort Studies

These studies are also termed follow-up studies, signifying that one or more groups of patients (the cohort) are followed longitudinally over a period of time. The cohort is free of disease at recruitment because the aim of this kind of study is to evaluate the development of an outcome and identify possible risk factors. Usually this is accomplished comparing two cohorts, one exposed and one not exposed to the risk factor.

For example, a study [23] evaluated unsplinted implant-supported restorations replacing the posterior dentition, reporting the results after 4 years of follow-up. Survival rates and marginal bone loss were reported as outcomes of interest and correlated them with the restoration material and implant length. This an example of prospective cohort study, in which a cohort of patients is followed over time and then the outcome of interest (survival or marginal bone level) is tested for correlation with a given exposure (materials of restoration or implant length).

Cohort studies can be retrospective – in this case, the exposure is identified in normal subjects without the disease – and evaluate if the outcome of interest occurs after a period of time has elapsed.

Advantages of cohort studies are primarily due to the possibility of following up the patient over time, and in this way, they help to establish an association between the exposure and a given outcome. On the other hand, lack of randomization and bias from dropouts (i.e., a lack of control over the study) limit the strength of the evidence; indeed, the main reason why RCTs are considered of higher quality is that in RCT the exposure is controlled by the researcher, while in the cohort studies it is out of control.

Much of clinical research is presented in the form of observational research. It has been estimated that around nine out of ten studies published in peer-reviewed medical and dental journals come in the form of observational research. This is particularly true for implant dentistry studies, of which a minority are RCTs and the vast majority are observational studies.

To improve the reporting of observational studies (cohort, case–control, and cross-sectional), a group of experts developed a checklist of items called STROBE (strengthening the report of observational studies in epidemiology) [7]. Items relate to title, abstract, introduction, methods, results, and discussion (Table 1.1).

It is expected that this checklist would be fully applied by researchers in order to improve the reporting of outcomes coming from the various observational research efforts and also render more homogenous the results.

1.2.3.2 Experimental Study Design

Randomized Controlled Trials

Randomized controlled trials (RCTs) are considered to be the studies providing the highest level of evidence; this is because with this particular design, the researcher has control over the entire study. This control allows to eliminate or at least reduce the risk of bias implicit in clinical research [6].

Biases are distortions of the true effects of a treatment/exposure on the healthy or diseased population. A bias may be due to specific population characteristics, to a lack of accounting for exposure to a risk factor and to all the other so-called confounders. These biases are possibly overcome with careful design of RCT. In particular, with careful selection of the patients to include in the study, with the control of the exposure/intervention by the researcher, and when potential confounders are known, the trialist may adjust for them in order to reduce their impact [8].

For example, a RCT was aimed at evaluating outcomes of short implant 6 mm long versus 11 mm implants and sinus lift in the posterior atrophic maxilla [26].

Reduction of possible biases was performed establishing inclusion and exclusion criteria regarding patient characteristics (e.g., bone height, presence of antagonist teeth, etc.) and exposure/intervention control (all patients underwent the same antibiotic prophylaxis, same surgical technique according to the assigned group, the same materials, etc.), and finally adjustment of the possible confounding factors was performed (excluding heavy smokers, those with uncontrolled systemic pathologies, etc.). It is clear that this control cannot be performed with the other study designs.

Table 1.1 The STROBE statement—checklist of items that should be addressed in reports of observational studies

	Item number	Recommendation
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rational	2	Explain the scientific background and rationale for the investigation being reported
Objectives	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design	4	Present key elements of study design early in the paper
Selling	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6	(a) *Cohort study*—give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up
		Case–control study—give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls
		Cross-sectional study—give the eligibility criteria, and the sources and methods of selection of participants
		(b) *Cohort study*—for matched studies, give matching criteria and number of exposed and unexposed
		Case–control study—for matched studies, give matching criteria and the number of controls per case
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8[a]	For each variable of interest, give sources of data and details of methods of assessment (measurement).
		Describe comparability of assessment methods if there is more than one group
Bias	9	Describe any efforts to address potential sources of bias
Study size	10	Explain how the study size was arrived at
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding
		(b) Describe any methods used to examine subgroups and interactions
		(c) Explain how missing data were addressed
		(d) *Cohort study*—if applicable, explain how loss to follow-up was addressed
		Case–control study—if applicable, explain how matching of cases and controls was addressed
		Cross-sectional study—if applicable, describe analytical methods taking account of sampling strategy
		(e) Describe any sensitivity analyses

(continued)

Table 1.1 (continued)

	Item number	Recommendation
Results		
Participants	13[a]	(a) Report the numbers of individuals at each stage of the study—e.g., numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analyzed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive	14[a]	(a) Give characteristics of study participants (e.g., demographic, clinical, social) and information on exposures and potential data confounders
		(b) Indicate the number of participants with missing data for each variable of interest
		(c) *Cohort study*—summarize follow-up time (e.g., average and total amount)
Outcome data	15[a]	*Cohort study*—report numbers of outcome events or summary measures over time
		Case–control study—report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—report numbers of outcome events or summary measures
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95 % confidence interval). Make clear which confounders were adjusted for and why they were included
		(b) Report category boundaries when continuous variables were categorized
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results	18	Summarize key results with reference to study objectives
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalizability	21	Discuss the generalizability (external validity) of the study results
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

[a]Give such information separately for cases and controls in case–control studies, and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies. Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of *PLoS Medicine* at http://www.plosmedicine.org/, *Annals of Internal Medicine* at http://www.annals.org/, and *Epidemiology* at http://www.epidem.com/). Separate versions of the checklist for cohort, case–control, and cross-sectional studies are available on the STROBE Web site at http://www.strobe-statement.org/

Most importantly, RCTs allow to face the issue of unknown confounders through the process of randomization. This is important because random distribution of study subjects allows to have matched variables equally distributed in the control and treatment group. In simple terms, if unknown confounders cannot be controlled, they are at least equally distributed in the two groups (or *arms*); this should result in the greatest probability that the intervention is causally related to the outcome.

Three types of randomization are usually performed (simple, blocked, and stratified):

- *Simple randomization* is the casual allocation of studied subjects in the control or treated group; in this way, the allocation ratio can be unequal, especially for small samples a simple random allocation can result in substantial imbalance (e.g., 3:1, 4:1, etc.).
- *Block randomization* refers to the casual allocation of patients in small groups including equal number of subjects, which is particularly useful in multicenter studies in order to maintain an equal ratio between the treatment and control groups (1:1).
- *Stratified randomization* allows to randomize according to specific strata like age, gender, etc., in case a difference is known between groups (e.g., older patients may have worst outcomes for a given surgical procedures).

The term *allocation concealment* refers to the fact that those recruiting the patients are not informed about to which arm the next patient will be allocated. This is usually performed adopting an "external" randomization center which does not know anything about the patients but just assigns them to a random group according to the randomization type.

Another important concept applicable to RCTs is the blinding [8]:

- *Single blinding* means that one of the categories participating in the study does not know what kind of intervention is receiving (treatment or placebo, treatment A or treatment B, etc.); usually this refers to the patient.
- *Double blinding* can be a confusing term because it usually refers to three categories unaware of the treatment administered: the patient, the investigator, and the assessor.
- *Triple blinding* is the same of double blinding but with the adjunct that a blind data analysis is performed.

Blinding is considered to reduce the biases that may come from knowing the assigned treatment. It is clear that awareness of the treatment assigned on the part of the dentist, the patient, or the investigator may influence their behavior and impair the validity of the results.

Sometimes it is not possible to blind one of the categories in the study. For example, in a RCT involving the evaluation of short versus long implants, the clinician performing the surgery will know which implant is placing, and in this way, blinding is impossible for him, although in this case it is probably not important for the validity of the study.

Regarding the analysis of the results of RCT, three approaches are usually employed (Fig. 1.2):

- *Intention-to-treat analysis (ITT)* refers to counting the patient in its assigned group regardless of dropouts or death during the study. In other words, once randomized to a given group (so there is the *intention* to administer the treatment), whether or not he will ever receive the assigned treatment, he will be analyzed as having received it. One may asks why counting a patient that actually never received a treatment or dropped out from the study. The answer is that this approach preserves randomization. Indeed if more patients drop out from a given arm because of more adverse events compared to the other arm, and analysis is performed only on patients finishing the trial, an imbalance is created between the two groups and validity of the results is compromised. In summary, the aim of ITT analysis is to maintain the two groups as equal as possible avoiding biases and preventing the loss of randomization process.
- *As-treated analysis* considers only the patient that actually received a given treatment. This

analysis may be important when patients need to be switched from one arm to another as it is the case for patients assigned to a medical treatment arm, but for some reason, they need a surgery, and so they are reassigned to the surgical group. This is a loss of randomization and may impair the validity of the analysis. Also, the blinding is usually compromised in this case.

- *Per-protocol analysis* evaluates only patients that complete the trial and are fully compliant with the assigned treatment. Again, this leads to a loss of randomization, and the loss of information regarding the noncompliant patients does not allow an evaluation of confounders.

Finally, selection of the outcome to evaluate in the trial should be taken into consideration. Although it may seem an easy task in some situations, it can become difficult in others. For example, implant survival, which is a true end point, can be considered easy to evaluate in a RCT aimed at establishing a difference in outcomes between a particular implant surface and another. On the other hand, the so-called surrogate end points are sometimes used in order to gain conclusions regarding the primary (or true) end point. This is the case, for example, of some peri-implantitis treatment studies in which surrogate end points such as pocket probing depth, clinical attachment level, and bleeding on probing are used instead of the true outcome (implant loss). Sometimes this is necessary because evaluation of the true end point would require excessive follow-up or larger samples. The problem in this case is that validation of surrogate end points is not always clear and is an argument of debate if a study using only surrogate end points gives reliable results.

In order to improve the quality of performed RCT, a group of experts comprising editors, trialists, and methodologists gathered in Ottawa, Canada, in 1993, in order to discuss various topics about RCTs. In subsequent meetings, a document collecting a set of recommendations was

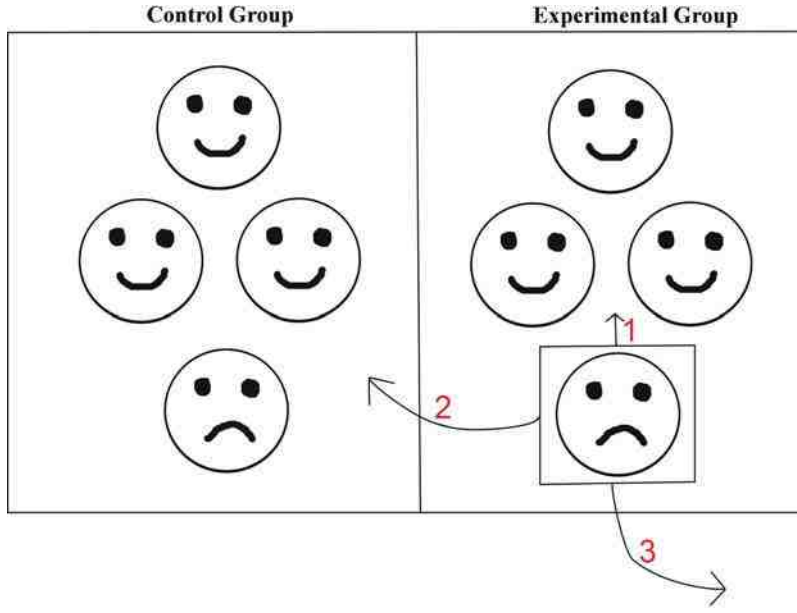

Fig. 1.2 Schematization of the analytic approaches to randomized clinical trials. *1*, *Intention-to-treat* analysis *(ITT)* in which the patient assigned to a given group will be counted in his assigned group regardless of dropout or death. *2*, *As-treated* analysis considers only patients that received a given treatment; in this case, the patient was reassigned to the control group because he did not receive the experimental treatment. *3*, *Per-protocol* analysis evaluates only the patients that complete the trial; in this case, the patient dropped out or died and he will not be counted

produced which finally led to the publication of the CONSORT (CONsolidated Standard of Reporting Trials) statement [9]. This is a checklist of items deemed essential for optimal reporting of a clinical trial; its objective is to help authors in improving the reporting of their trials.

The checklist includes recommendation for the title and abstract, the introduction, the methods, the results, discussion, and additional information (Table 1.2).

1.2.3.3 Systematic Reviews and Meta-analysis

Systematic reviews and meta-analysis are at the top of the evidence pyramid because they collect all the available evidence with scientific rigor and give the possibility of synthesizing a huge amount of data in a single study.

Systematic reviews are aimed at identifying all the relevant published studies on a given topic, assessing the quality of each, and interpreting the findings in an impartial way [10].

The need of systematically collecting the available evidence comes from the fact that huge amount of information is published every year, and keeping up with the primary research evidence may become impossible.

Development of a systematic review, usually performed by two reviewers, requires the formulation of a clear question, and this can be accomplished with the PICO elements. Then the published evidence is searched carefully using all the database available and with handsearching. Reviewers can choose to include only RCTs or studies of lower quality as well. After collection of all the possible studies, an assessment is done regarding the eligibility of the studies according to predetermined exclusion and inclusion criteria; this selection is usually performed on the basis of the abstracts. In this way, all the relevant studies considered for the inclusion pass to the full-text phase in which the authors of the review perform a methodological quality assessment in which ulterior studies of poor quality are excluded. Finally, the data of all the studies is extracted and usually graphically represented in a summary table.

In the same fashion as for RCTs, a group of experts developed a checklist which should aid the reviewers to improve the reporting of systematic reviews and is called the PRISMA statement (Table 1.3) [11].

Systematic review data can be aggregated and put in context in order to draw a general conclusion on a given topic or, if data is homogenous enough, further analyzed and manipulated in the form of meta-analysis.

Meta-analysis is a statistical technique that allows to combine the evidence coming from multiple studies and can help in giving a precise estimate of the effects of given intervention [12].

A good meta-analysis starts with good-quality systematic review. The findings of the systematic review and its relative data are combined using appropriate statistical methods.

Meta-analyses are important because it allows to answer questions that single studies are unable to do. This is due to the fact that combining data coming from multiple studies theoretically is like enlarging the sample population, and in this way, it is possible to obtain statistically significant results. Anyway, it is clear that such analysis is limited by the quality of the underlying primary studies. When primary studies of good quality are lacking, this may lead to unclear or biased results or, in some cases, impossibility of performing the analysis at all [13–16].

1.2.3.4 Systematic Review of Systematic Reviews and Meta-analyses

The last step in the search of evidence for healthcare interventions is the systematic review of systematic reviews and meta-analyses (meta-reviews) [17].

One of the problems faced by clinicians appraising the literature is to encounter multiple reviews and meta-analysis on the same topic that come to different results. Performing a meta-review may allow to the creation of a summary of all the available reviews in a single document. This can be helpful in drawing general conclusions and arrive at more informed evidence-based decisions. Meta-reviews are performed in a

Table 1.2 CONSORT 2010 checklist of information to include when reporting a randomized trial

Section/topic	Item no	Checklist item	Reported on page no
Title and abstract			
	1a	Identification as a randomized trial in the title	
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts[45 65])	
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	
	2b	Specific objectives or hypotheses	
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	
Participants	4a	Eligibility criteria for participants	
	4b	Settings and locations where the data were collected	
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	
Outcomes	6a	Completely defined prespecified primary and secondary outcome measures, including how and when they were assessed	
	6b	Any changes to trial outcomes after the trial commenced, with reasons	
Sample size	7a	How sample size was determined	
	7b	When applicable, explanation of any interim analyses and stopping guidelines	
Randomization:			
Sequence generation	8a	Method used to generate the random allocation sequence	
	8b	Type of randomization; details of any restriction (such as blocking and block size)	
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	
Blinding	11a	If done, who was blinded after assignment to interventions (e.g., participants, care providers, those assessing outcomes) and how	
	11b	If relevant, description of the similarity of interventions	
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	

Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analyzed for the primary outcome	
	13b	For each group, losses and exclusions after randomization, together with reasons	
Recruitment	14a	Dates defining the periods of recruitment and follow-up	
	14b	Why the trial ended or was stopped	
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95 % confidence interval)	
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing prespecified from exploratory	
Harms	19	All important harms or unintended effects in each group	
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	
Generalizability	21	Generalizability (external validity, applicability) of the trial findings	
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	
Other information			
Registration	23	Registration number and name of trial registry	
Protocol	24	Where the full trial protocol can be accessed, if available	
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	

Table 1.3 Checklist of items to include when reporting a systematic review (with or without meta-analysis)

Section/topic	#	Checklist item	Reported on Page #
Title			
Title	1	Identify the report as a systematic review, meta-analysis, or both	
Abstract			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number	
Introduction			
Rationale objectives	3	Describe the rationale for the review in the context of what is already known	
	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS)	
Methods			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number	
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale	
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched	
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated	
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis)	
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently in duplicate) and any processes for obtaining and confirming data from investigators	
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made	
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was clone at the study or outcome level), and how this information is to be used in any data synthesis	
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means)	
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis	
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies)	

Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were prespecified	
Results			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram	
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations	
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome-level assessment (see Item 12)	
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study:	
		(a) Simple summary data for each intervention group	
		(b) Effect estimates and confidence intervals, ideally with a forest plot	
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency	
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15)	
Additional analysis discussion	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression)	
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers)	
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias) and at review level (e.g., incomplete retrieval of identified research, reporting bias)	
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research	
Funding			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data) and role of funders for the systematic review	

similar manner compared to traditional systematic reviews, i.e., careful search of the literature on a given topic but limiting the research to systematic reviews and meta-analyses and then synthesizing the data in order to draw a general conclusion.

Meta-reviews have many advantages; they allow the appraisal of the general quality of the available reviews on a given topic. They allow understanding the heterogeneity between the studies. In fact, if consistent discrepancies exist between the available reviews, this means that primary studies are poorly performed or insufficient in order to draw definitive conclusions on a given intervention; these can lead to encourage further research on that specific topic. Moreover, meta-reviews allow to identify multiple biases as suggested by the different reviews analyzed; this gives a sort of larger picture on the selected topic. Lastly, analysis of different reviews and meta-analysis allow to understand which statistical tool is the most used and which one best describes the chosen outcome.

In conclusion, meta-reviews are an excellent tool to give a "snapshot" of the available evidence and identify which areas of a topic are clear and applicable to clinical practice and which one instead requires further research efforts [18].

1.2.4 Applying the Evidence

1.2.4.1 Quality of Reporting of Clinical Studies in Implant Dentistry

Assessment of the quality of reporting of studies in implant literature is important mainly because only evidence coming from good-quality research ensures that results of a study can be implemented in routine clinical practice.

Pjetursson and coll. [19] evaluated the quality of reporting of longitudinal data in implant dentistry. They found that the majority of the studies reported for implant-supported restorations are mainly based on prospective and retrospective observational studies, with a clear lack of RCTs. For this reason, the evidence on this topic is observational rather than experimental. Ulteriorly, recommendations regarding the reporting of these kinds of studies according to the STROBE statement are unattended by most authors. Common reported problems in the analysis of the literature included poor reporting of study design, such that many times it was considered difficult for the reader to figure out whether a study was classified as cohort, case–control, or prospective/retrospective. Also, eligibility criteria, methodology of research, and analysis of confounding factors were often lacking. Moreover, the majority of the studies on implants and implant restorations usually limit the analysis on implant survival without addressing the issue of restoration survival and complications. Finally, it is common that dental implant studies do not specify how they came to a specific study size with a specific power calculation.

This is a rather disappointing picture and one may ask how it is possible to arrive at an applicability of study results. One possibility is to rely on well-performed systematic reviews and meta-analysis, which can provide cumulative results of various outcomes. As previously stated, it is anyway clear that properly performed RCTs and cohort studies can provide a better evidence and a quality substrate to improve the quality of systematic reviews and meta-analyses as well.

Kloukos and coll. [6] analyzed the quality of RCTs published in prosthodontics and implantology journals; in particular, the adherence to the CONSORT statement was evaluated.

Results showed that the majority of the trials (64.7 %) lacked a reporting of sample size calculation, allocation concealment was not addressed in 62 % of the studies, and blinding was not reported in around 37 % of them.

The authors concluded that even if numerous journals have adopted the CONSORT statement, very few have implanted an active compliance. In conclusion, it was considered important for researchers to improve the quality of reporting and for editors to implement more stringent criteria for publication of RCTs.

Another important factor that may be considered influential in clinical research results is the sponsorship of implant companies. Industry funding and pro-industry results have been considered a

problem in medical and dental literature, conferring to the studies of the so-called sponsorship bias.

Popelut and coll. [20] analyzed this topic collecting data from implant studies and tried to correlate the presence of a financial sponsorship with annual failure rates.

Indeed, results showed that funding sources may have a significant effect on the annual failure rates of dental implants. Failure rate was significantly lower in industry-associated trials when compared with non-industry. It also emerged that trials where funding source was not specified had an even lower failure rate; this was explained by the fact that maybe authors that deliberately do not report a funding source did not have the same quality control of sponsorship studies and so results were more biased.

This analysis clearly pointed out that transparency of sponsorship is of utmost importance. Moreover, when a sponsorship is declared, it is the duty of the reader to assess carefully if results are biased in some way. Also, experimental instead of observational design and application of the CONSORT guidelines can aid in avoiding the phenomenon of sponsorship bias.

1.2.4.2 Internal Validity and External Validity

Application of research results to clinical practice depends upon the internal validity and external validity of the studies [21, 22].

Internal validity refers essentially to the quality of the studies, in simple terms how well a study measures what it is supposed to measure. This is evaluated hierarchically, with study designs at the top of the evidence pyramid considered to have a higher internal validity compared to designs at the bottom. Moreover, adherence to the abovementioned checklists for the various designs should confer high internal validity.

External validity refers to the applicability of the evidence in practice. Although internal validity is the prerequisite for external validity, this does not mean that a good-quality study finds an application to the real-world situation. In fact, external validity means that the cost of the intervention, the ease of implementation, and the importance of the disease allow an adoption of the studied intervention on the part of the clinician.

If we go back to the definition of EBD, patient's preferences and doctor's expertise are a fundamental component of good practice. Aseptic application of evidence is avoided. Instead, the dental specialist must develop his/her skills starting from dental school and then in postgraduate programs, continuing education courses, conferences, etc. Integration between the technical aspects of a given procedure and the evidence-based decisions about the same procedure will constitute the foundation for an evidence-based practice rather than a personal-based one. Finally, the patient's preferences and desires should be met whenever possible, of course trying to reach the common aim of providing the highest level of care.

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Basics of Biostatistics

2

Oreste Iocca

Abstract

Statistical knowledge is at the basis of understanding and reporting the results of scientific research. Basic concepts of probability are the first building blocks for most of the statistical concepts. Conditional probability, at the basis of Bayesian statistics, is becoming popular among researchers and usually opposed to the most commonly used frequentist approach.

This last one is based on the concepts of distribution of variables, hypothesis testing, *p*-value, and confidence intervals.

Systematic reviews and meta-analyses are becoming important tools for synthesis of the available evidence. A new, still unexplored, method of analyses of primary studies is the network meta-analysis for multiple treatment comparisons. This may become an important way of assessing the efficacy of numerous treatments when direct comparison of primary studies is impossible.

At the basis of reporting and understanding of the medical and dental literature, there is a need of using rigorous methods aimed at collection, analysis, and interpretation of data. This can be accomplished with the knowledge of basic statistical tools [1]. Usually, dental research is performed on a sample of persons which should be representative enough of a given population. The conclusions drawn from the sample are generalized to the whole population in a process known as inferential statistics.

This is in contrast with descriptive statistics in which the analysis of the data is performed on the sample available, and data is not assumed to come from a larger population.

2.1 Probability

Concepts of probability are at the foundation of statistical concepts. Probability refers to a random process that gives rise to an outcome. It is always described as a proportion and always takes values between 0 and 1.

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For example, the probability of tossing a coin can randomly produce the outcome of the head or tail.

In this example, the probability of tossing head will be written as $P(H)$ and probability of tossing tail as $P(T)$.

$P(H)$ and $P(T)$ are a classical example of *disjoint or mutually exclusive* outcomes. In fact, only one outcome can occur at any toss.

In this case, the probability that one of this events will occur is given by the addition rule:

$$P(H \text{ or } T) = P(H) + P(T) = 1/2 + 1/2 = 1$$

It is intuitive that all the possible outcomes are included in this case; indeed, a probability of tossing head or tail includes the totality of the possible outcomes.

When the two events are *not disjoint*, for example, when there is the possibility that *A* and *B* events can occur by themselves but exists also the possibility that they can occur together:

$$P(A \text{ or } B) = P(A) + P(B) - P(A \text{ and } B)$$

Independency refers to the fact that knowing the result of one outcome does not have an influence on the second one.

For example, knowing the outcome of a coin toss does not have an influence on the outcome of rolling a six-faced colored die (which means that 1/6 of the die is white, 1/6 is red, etc.).

The *multiplication rule* for *independent processes* defines the probability that both independent events occur and are calculated in this way:

$$P(A \text{ and } B) = P(A) * P(B)$$

In the case of the coin and die outcomes, the probability of tossing head $P(H)$ and rolling a red on a six-faced die $P(R)$ will be:

$$P(H \text{ and } R) = P(H) * P(R)$$
$$= 1/2 * 1/6 = 1/12 = 0.083$$

This means that there is a probability of 8.3 % of tossing a head and rolling a red face.

2.1.1 Conditional Probability and Bayes' Theorem

This is defined as the probability of an outcome (*A*) given that a second outcome (*B*) has been observed; this can be written as follows:

$$P(A \mid B) = \frac{P(A \text{ and } B)}{P(B)}$$

From this we can derive the general multiplication rule.

$$P(A \text{ and } B) = P(A \mid B) * P(B)$$

Finally the sum of conditional probabilities will be

$$P(A_1 \mid B) + P(A_2 \mid B) + \ldots + (PA_n \mid B)$$

where n represents all the possible outcomes for a variable.

These rules are at the basis of the *Bayes' theorem*, which allows to answer some specific questions given a conditional probability.

$$P(B \mid A) = \frac{P(A \mid B) * P(B)}{P(A)}$$

Using this formula in context will help in understanding the utility of Bayes' theorem in clinical research. From published data it is estimated that prevalence of peri-implantitis (B^+) in the implant patient population is around 22 %, from which we derive that peri-implant healthy patients (B^-) are around 78 %.

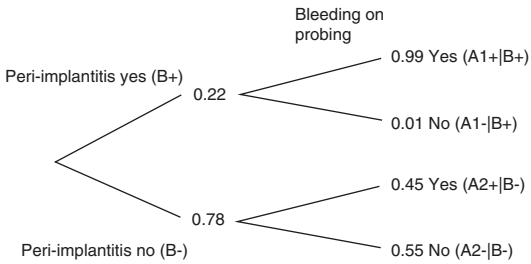
Also, it was established in observational studies that positive predictive value of bleeding on probing (*A*) is around 99 % $P(A^+|B^+) = 0.99$; in other terms, a patient with peri-implantitis almost certainly will present with bleeding on probing.

On the other hand, negative predictive value is estimated to be around 55 % or $P(A^-|B^-) = 0.55$; this means that a patient not having peri-implantitis will not present bleeding on probing in around 55 % of the cases.

Now if we want to reverse the question and we want to know which is the probability that the

patient has peri-implantitis (B^+) if we found bleeding on probing (A^+), we can apply the Bayes' theorem and use a graphical tool to clarify how we obtain the results.

We can represent the situation with a tree diagram in which the probability of having peri-implantitis is denoted as $P(B^+)$, probability of having bleeding on probing given is (A^+), in particular probability of having bleeding on probing given that one has peri-implantitis is denoted as $P(A1^+|B)$, and probability of having bleeding on probing given that one do not have peri-implantitis is denoted as $P(A2^+|B^-)$



From the tree diagram, we understand that $P(A1^+|B^+)$ or simply probability of having *bleeding on probing* given that one has *peri-implantitis* is almost 100 %, but in clinical situation we check for bleeding on probing in order to perform a diagnosis of peri-implantitis. In other words, we reverse the scenario and check for the probability of having *peri-implantitis* given that the patient has *bleeding on probing* or $P(B^+|A^+)$. In this case, the Bayes' theorem helps us in resolving this question.

With the application of the theorem, we found out that

$$P\left(B^+ \mid A^+\right) = \frac{P\left(B^+ \text{ and } A^+\right)}{P\left(A^+\right)}$$

$$= \frac{P\left(A^+ \mid B^+\right) * P\left(B^+\right)}{P\left(A1^+ \mid B^+\right) * P\left(B^+\right) + P\left(A2^+ \mid B^+\right) * P\left(B^+\right)}$$

$$= \frac{0.99 * 0.22}{\left(0.99 * 0.22\right) + \left(0.45 * 0.78\right)} = \frac{0.218}{0.569} = 0.384$$

In conclusion, we found that a patient with bleeding on probing has a probability of having a diagnosis of peri-implantitis of 38.4 %. This would suggest that, although evaluation of bleeding on probing is important in the process of diagnosis of peri-implantitis, it is better to integrate it with other diagnostic tools like probing depth and x-ray evaluation.

This may seem counterintuitive because we stated at the beginning that a patient with peri-implantitis has a 99 % probability of having bleeding on probing. It is important to remember that we *reversed* the question and tried to figure out what would be the probability of having peri-implantitis once we found bleeding on probing.

To make another example, it is reported that around 99 % of players playing in the NBA (the professional basketball association in the United States with only around 360 players part of it) are taller than 180 cm (6.0″); this can be expressed as $P(180+|\text{NBA}+) = 0.99$; therefore, if you play in the NBA, it is almost certain that you are taller than 180 cm. If we reverse the question and we want to know which is the probability of playing in the NBA if we are taller than 180 cm or $P(\text{NBA}+|180+)$, we don't need the Bayes' theorem to understand that, even being taller than 180 cm, the probability of playing in the NBA is minimal!

Bayesian approach is a way of calculating conditional probabilities. We combine the data of our prior knowledge (anterior probability) in order to calculate a revised probability (posterior probability). It is clear that the anterior probability can differ according to the sources from which we extract the data; going back to the previous example, various authors report different rates of prevalence for peri-implantitis; therefore, our results would have changed accordingly if we chose another value for the probability of having peri-implantitis in implant patient population. This may seem to add some subjectivity to the analysis, but at the same time makes it possible to recalculate the results in light of new data (new prior probability) in a process of updating beliefs that is the strength of Bayesian statistics.

Frequentist approach, essentially based on *p*-value, confidence intervals, null hypothesis, and power (discussed later), is the most commonly used in the scientific literature and usually

opposed to the Bayesian one. But in the last few years, Bayesian statistics is gaining popularity among researchers due to the possibility of adding knowledge with the update of a prior probability [2].

In this regard, some authors [3] arrived at the conclusion that clinicians are natural Bayesians, in the sense that they apply Bayesian rule in clinical practice even without knowing Bayesian statistics.

Their claim is based on the fact interpreting a test result, a clinical sign, or a symptom acts in the same way as updating a prior probability. They conclude that clinical decision-making is Bayesian at its core.

In the future, it is expected that the Bayesian approach will be further incorporated in the medical research.

2.2 Distribution of Variables

A random variable is a process or outcome that can assume a numerical outcome. For example, a random variable can be the number of edentulous people in a geographic area.

A probability distribution is the one that includes all the possible numerical values for a given variable.

The *normal distribution* is taken as the reference distribution because it is the most common and taken as a reference to solve many problems in statistics.

Normal distribution is described as symmetric, unimodal, and bell shaped and by definition has mean $\mu = 0$ and standard deviation $\sigma = 1$; mean and standard deviation describe exactly the normal distribution and are called distribution parameters.

A standardization of the normal curve is called the *Z*-score, which is defined as the number of standard deviations a value falls above or below the mean. If we know the mean of a given distribution for a given population and also the standard deviation, we can calculate the *Z*-score for a given *X* value as:

$$z = \frac{x - \mu}{\sigma}$$

For example, if in a patient population, the mean periodontal probing depth is 6.0 mm and the standard deviation is 1.5 mm, we may calculate the *Z*-score for a patient who has a periodontal probing depth of 7.5.

$$z = \frac{x - \mu}{\sigma} = \frac{7.5 - 6.0}{1.5} = 1.0$$

In this case, the patient is 1 standard deviation above the mean, and a normal probability table (also called *Z* table, which is a precalculated table associated with the percentiles for a particular standard deviation) will tell us that the patient lies in the 84th percentile, which means that his periodontal probing depth is higher than 84 % of the other patients from the same population. All the probing values below the 84th percentile are delimited by the gray area (Fig. 2.1).

The importance of the *Z*-score and the area under the normal curve is that if we sample at least 30 independent observations and data are not strongly skewed, the distribution of the mean will be approximated by a normal model. In (Fig. 2.2), we have 12 random samples each composed of at least 30 observations, which fits the normal model (Fig. 2.2).

2.2.1 Confidence Intervals

A plausible range of values for the population parameter is called *confidence interval*; in order to obtain this value, we take into account the standard deviation associated with an estimate called the standard error (SE). *SE* describes the error associated with the estimate; in simple terms, it reflects the variability of the statistics when we don't have values of the entire population but instead just values of a sample from the population we want to study; *SE* is calculated as

$$SE_{\bar{x}} = \frac{S}{\sqrt{n}}$$

where s is the standard deviation of the sample and n the sample size.

It is known from the *Z*-score table that 95 % of observations that lie under the normal curve is comprised between −1.96 and +1.96 standard deviations from the mean (Fig. 2.3).

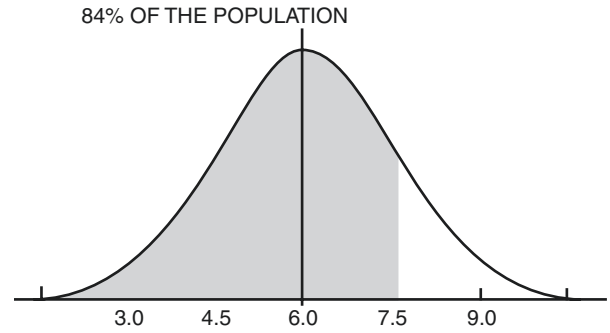


Fig. 2.1 Normal distribution of patients periodontal probing depth. All the scores below the 84th percentile are delimited by the gray area

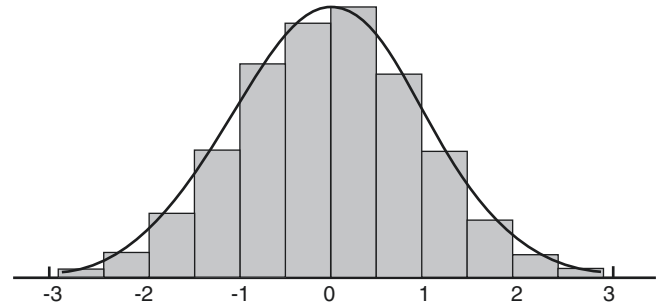


Fig. 2.2 Random samples each composed of at least 30 observations which fit the normal model

Given that the standard error represents the standard deviation associated with the estimate, the formula for a 95 % confidence interval for a point estimate that comes from a normal distribution will be

$$\left(\begin{array}{l}\text{point estimate} - 1.96 * SE,\ \text{point estimate} \\ \quad + 1.96 * SE\end{array}\right)$$

Confidence intervals display the range of plausible values between or among groups, and they always contain the effect estimate in a predefined level; a 95 % CI means that if 100 samples are drawn from a population, 95 of them would contain the true population value. In statistical terms, it is said that we can be 95 % confident that the population parameter is in the calculated range.

For example, if we take a random sample of 50 patients treated with implants in our clinic and we measure the pocket depths around the implants, with a mean of 3.5 mm and standard deviation of 1.3 mm, a 95 % CI for this sample will be calculated in this way:

$$SE = 1.3 / \sqrt{50} = 0.18$$
$$95\%\ \text{CI}\left(3.5 - 1.96 * 0.18,\ 3.5 + 1.96 * 0.18\right)$$
$$= \left(3.14, 3.85\right)$$

We are 95 % confident that if we take 100 samples of 50 patients from the implant population in our clinic, 95 % of this samples will have values of pocket depths comprised between 3.14 and 3.85 mm.

2.2.2 Hypothesis Testing

Frequentist approach is based on the formulation of a hypothesis, which represents the skeptical perspective to be tested and called null hypothesis or H_0; it is opposed to the alternative hypothesis which goes against the null hypothesis.

Statistical testing usually evaluates if the null hypothesis can be rejected or not. In statistical terms, a test may lead to reject the null hypothesis in favor of the alternative hypothesis, or it fails to

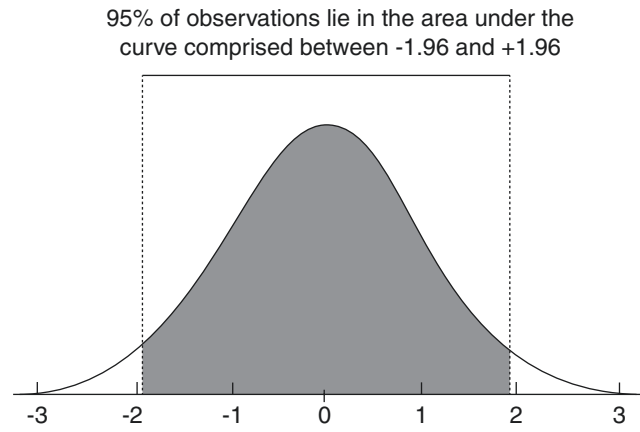


Fig. 2.3 Normal curve where the gray area corresponds to 95 % of observations

reject the null hypothesis in the sense that it is not implausible that H0 is true.

In hypothesis testing, two types or errors are possible:

Type I error consists in rejecting H0 when it is actually true.
Type II error consists in failing to reject H0 when HA is actually true.

A significance level $\alpha = 0.05$ means that we do not want to commit a type I error more than 5 % of the times.

Type II error is symbolized by β and is determined by the sample size. Statistical power, a very important concept for the validity of a study, is defined as the probability of rejecting the null hypothesis or $1-\beta$. Calculation of the power goes beyond the scopes of this introduction. Here is enough to say that increasing the sample size, increases the power. Usually it is accepted that a minimum power of 80 % is needed; this means that β should not be higher than 0.20, so that $1-0.20=0.80$. This would mean that the probability of rejecting the null hypothesis given that it is not true is 80 %.

With the *p*-value we quantify the strength of evidence against the null hypothesis and in favor of the alternative. The *p*-value is defined as the probability of observing the data at least as favorable to the alternative hypothesis.

If we conduct a *one-sided hypothesis test*, for example, we can formulate the test in this way:

We set a normal probing depth around implants to be around 4 mm; now we have a sample of implant patients treated with a smooth collar, and we assume that this may contribute to reduced probing depth after 1 year; in this case, we set a *negative one-sided hypothesis test* in this way (it is negative because we want to check for a value less than the hypothesis; if we would check for a value greater than the hypothesis, we would say that it is a positive test).

$$\text{H0}: \text{ probing depth mean with smooth collar} = 4.0\,\text{mm}$$

$$\text{HA}: \text{ probing depth mean with smooth collar} < 4.0\,\text{mm}$$

Instead if we would like to check if probing depth is different than 4.0 mm, we perform a *two-sided hypothesis test*.

$$\text{H0}: \text{ probing depth mean with smooth collar} = 4.0\,\text{mm}$$

$$\text{HA}: \text{ probing depth mean with smooth collar} \neq 4.0\,\text{mm}$$

If we take a sample of 100 patients treated with smooth collar with a significance level of $\alpha = 0.05$, null hypothesis will be rejected with a *p*-value <0.05. This means that if the null hypothesis is true, our sample mean (that we suppose comes from a normal distribution) will lie into 1.96 standard

deviations from the mean *for a double-sided test* or below the fifth percentile *for a one-sided negative test* or more than 95th percentile for a one-sided positive test.

If we get a mean probing depth of 3.1 mm with a standard deviation of 1.1 mm, can we state that the sample of patients with this probing depth mean actually come from a different population? In statistical terms, are our results statistically significant?

We can perform a *Z* test to test our hypothesis, which is Z = mean of the sample – null value/SE = 3.1–4.0/0.11 = – 8.18.

If we check this z value on the normal distribution table, the area under the curve or p-value associated with $z = 0.11$ is less than 0.0002. This lower tail area provides sufficient strong evidence for rejecting the null hypothesis.

If we designed our test as two sided, so just checking for HA ≠ H0, we would perform a *Z* test in the same fashion as before, but this time we should multiply the *Z*-score * 2 because in this case we are checking for the area under the curve comprised between the lower and the upper tail.

In this case, $z = -8.18$ which corresponds to the area under the left tail, because the normal model is symmetric −8.18*2 = 16.36 which corresponds to a p-value of <0.0001 and again allows to reject the null hypothesis. Alternatively stated, if the null hypothesis is true, there is a probability of less than 0.0001 of observing such a large mean for a sample of 100 patients.

2.2.3 The *t* Distribution

The *t* distribution has the same shape as the normal distribution but with a single parameter, the degrees of freedom (df), which corresponds to the number of observations −1 (or $n-1$) and describes the shape of the t distribution. In simple terms, the larger the sample, the more the t distribution will resemble the normal distribution. Also, instead of the *Z*-score table, for the t distribution, we use the t table in which the area under the curve is calculated according to the degrees of freedom. The t distribution is used when we need to estimate the mean and standard error from a small sample and in this case is more accurate than the normal distribution. If the sample size is at least 30, the *t* distribution becomes nearly normal.

2.2.4 ANOVA and F Test

Analysis of variance (ANOVA) and the associated statistical test *F* are used to check with a single hypothesis test whether the mean across groups is equal.

For example, we have four groups of patients treated with four different implants (*A*, *B*, *C*, *D*) with different surfaces, and we check for marginal bone level changes (MBL) at 1 year. We found that the mean MBL is $A = 1.1$, $B = 1.3$, $C = 0.9$, and $D = 1.5$.

We can perform a hypothesis test in this way:

$$\text{H0} : \mu_1 = \mu_2 = \mu_3 = \mu_4$$
$$\text{HA} : \text{at least one mean is different}$$

ANOVA is used in this case to test if a difference exists between two or more groups, and the test statistics used in this case is called *F* which follows an *F* distribution with two types of degree of freedom, df1 = $k-1$ where k are the groups and df2 = $n-k$ where n are the number of subjects from all the groups.

The *F* tests give us the ratio between the variability between groups (calculated as mean square between groups or MSG) and the variability within groups (mean square error or MSE). A simplified way to understand the *F* test is to consider it in this way.

$$F = \frac{\text{Variance between treatments}}{\text{Variance within treatments}}$$

The corresponding *F* results, once checked, will be used to compute the p-value in the same way as with the other tests. If p-value is less than our predetermined significance level of 0.05, we reject the null hypothesis in favor of the alternative. Regarding the previous example, this would mean that the mean bone level change at 1 year varies between the four groups.

In order to know which of the groups have statistically different means, we compare the means of each group. This is done performing a pair *t*-test for all the groups; in this case, A vs. B, A vs. C, A vs. D, B vs. C, and B vs. D (this is usually done by a software). The results of the single *t*-tests will tell us which groups have a statistically significant difference.

In conclusion, ANOVA examines the big picture considering all the groups simultaneously. If there is evidence that some evidence exists, we can try to check which groups have a statistically significant difference between each other.

2.2.5 Chi-Square Test

When comparing two or more proportions or percentages, the chi-square (χ^2) is a common test performed to find the *p*-value. Of course, it exists a χ^2 distribution with $(r-1)\,(c-1)$ degrees of freedom, where r are the rows and c the columns of the table from which we analyze the data.

Prosthetic complications	External connection	Internal connection	Total
Yes	27	38	65
No	150	190	340
Total	177	228	405

$$\chi^2 = \sum_{i=1}^{k} \frac{\left(O_i - E_i\right)^2}{E_i}$$

In this example we have the observed data (O) and we want to compare them with the expected data (E).

The rate of complication or total of complications over total of patients = 65/405 = 0.16 and the rate of no complications over the total of patients = 340/405 = 0.84.

In this way the expected rate of complication for external connection patients would be 177 * 0.16 = 28.3, and the expected rate of no complications for the external connection would be 177 * 0.84 = 148.7. In the same way, the expected rate of complications for the internal connection patients would be 228 * 0.16 = 6.08 and the rate of no complications 228 * 0.84 = 159.6.

The table for the expected values can be therefore drawn in this way.

Prosthetic complications	External connection	Internal connection	Total
Yes	28.4	36.6	65
No	148.5	191.5	340
Total	177	228	405

Now applying the chi-square formula

$$\chi^2 = \sum_{i=1}^{k} \frac{\left(O_i - E_i\right)^2}{E_i} = \frac{(27-28.4)^2}{28.4} + \frac{(150-148)^2}{148.5} + \frac{(38-36.6)^2}{36.6} + \frac{(190-191.5)^2}{191.5} = 1.01$$

In this case, for the 2×2 table of the example, we have $(2-1)\,(2-1) = 1$ df; a value of 1.01 with 1 df on the χ^2 distribution table will correspond to the area under the tail >0.05, so we reject the null hypothesis, and for the data available, there is no difference in the rate of prosthetic complications between internal and external connection.

2.3 Regression Analyses

Regression analyses allow to consider the relation existing between one or more explanatory or independent variables (x_1, x_2, x_3, etc.) and a dependent variable (y).

2.3.1 Linear Regression

Linear regression is the simplest form of regression analysis and takes into account an explanatory variable (x) and a dependent variable (y) represented in a scatterplot.

Scope of the analysis is to establish if a linear correlation exists between the two variables. The equation used for the linear regression analysis is $y = b0 + b1*x$, where $b0$ is the intercept of the line and $b1$ is coefficient calculated according to the variable values (calculation of their values goes beyond the scopes of this introduction).

The correlation describing the strength of the linear relationship, between the two variables, denoted as r, always takes the value between −1 and +1.

A value of r closer to 1 means that there is a strong linear relationship between the variable x and y, if one increases the other increases as well. A value of r closer to −1 means that a linear relationship exists between the two variables, but in this case when one increases, the other decreases. A value close to 0 means that there is no association between the variables.

Another value, r^2, tells us the amount of variability in the y variable explained by the x variable.

For example, a study [4] evaluated the relationship between the CT values in Hounsfield units of the peri-implant bone and primary implant stability; in the figure 2.4 are reported the scatter diagrams and the correlation lines. The reported r values for straight implants were 0.813 in (*A*), 0.858 in (*B*), and 0.714 in (*C*). This means that a high positive correlation was shown for all the variables analyzed and in particular a strong correlation between the HU values and the insertion torque values, the implant stability quotient, and the removal torque value (Fig. 2.4).

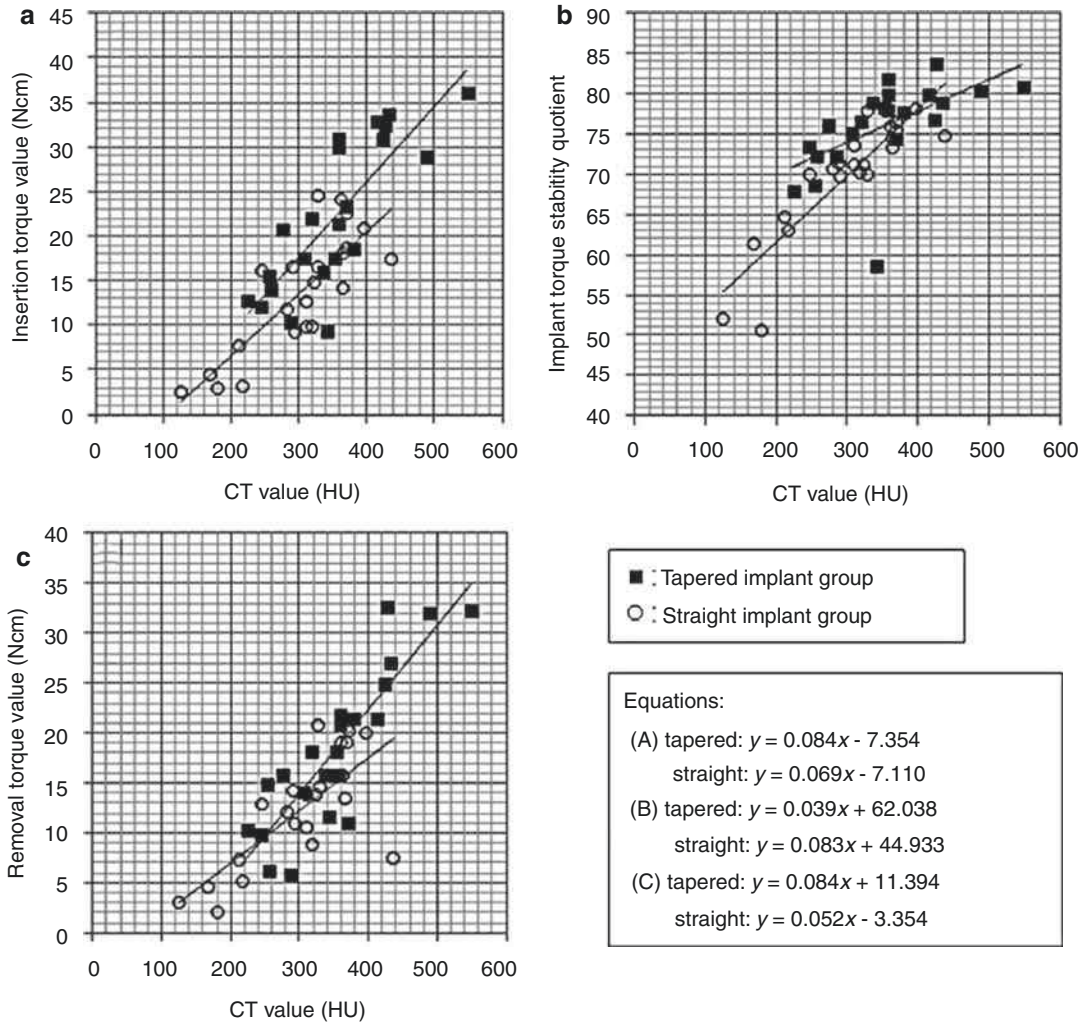


Fig. 2.4 Scatter diagrams and correlations lines with the corresponding r values (Reproduced with permission from Howashi and coll)

2.3.2 Multiple Regression

Multiple regression extends the two variable regressions to a case in which we have more than one independent variable (e.g., x_1, x_2, x_3).

2.3.3 Logistic Regression

Logistic regression is used when a dependent variable y exists in binary form (0 or 1). It can be adopted to know which x variable increases or decreases a clinical outcome ($y = 0$ or 1).

2.4 Time-to-Event Analysis

Time-to-event curves are used to describe the outcome of an intervention over time. Clinical trials commonly employ this kind of analysis. In fact, in clinical trials during the length of the study, we have subjects that entry at the beginning or during the study and other that complete, die, or drop out from the study. These data are commonly represented with the Kaplan-Meyer curve which is characterized by plots of the overall survival on the y axis and time from diagnosis on the x axis.

Hazard rate is the probability of an event to occur in the next time interval, and the hazard ratio (HR) is the estimate of the ratio of the hazard rate in the treated versus the control group.

Cox proportional model is a regression method for survival data that provides an estimate of the hazard ratio and its confidence interval.

It fits a model of the form:

$$\log_e \left[\mathrm{h}(t) / \mathrm{h}_0(t) \right] = b_1 x_1 + b_2 x_2 + \ldots + b_p x_p$$

where

h(t) is the probability of the outcome at time t
h_0 is the probability of the outcome at the baseline
ht/h_0 is the hazard ratio
x_i are the predictor variables
b_i are the regression coefficients for the variables x_i

Without going into calculation of the data, we can take as an example the study by Becker and col. [5] which evaluated the survival of Straumann dental implants with TPS surfaces over a period of 12–23 years.

In this study, according to the ITI implantation types (types I, II, III, and IV), it came out that the exponent for the regression coefficient, which is the HR, was 3.1643 with a 95% CI of 1.459–6.863 (Table 2.1, Fig. 2.5).

What is important to understand when a study of this kind reports the HR and its CI is that the HR represents the odds that an individual in the group will manifest the outcome at the next evaluation period. Regarding the previous example, an HR of 3.1643 means that an individual in type II group has a probability of losing an implant at the following evaluation period 3.1643 times higher than type I, type III 3.1643 times higher compared to type II, and type IV 3.1643 times higher compared to type III.

2.5 Meta-analysis

Meta-analysis is a statistical method that allows to compare and combine the results of multiple selected studies on a given topic. The basic data of meta-analysis are the *effect sizes* which are quantitative indices that measure the strength of the effect in individual studies. Common effect sizes extracted from the studies can be proportions, odds ratio, relative risk, raw mean difference, standardized mean difference, correlation (r), etc.

Effect sizes are assumed to be normally distributed with known variance.

A meta-analysis allows to statistically manipulate the extracted effect sizes in order to assess the consistency of effects across the studies and compute a summary effect.

One of the strengths of a meta-analysis is that we are able to assign a weight to each study included. This is done calculating the inverse of the variance for each study. If we consider that the variance represents the entity of dispersion from the mean, if we calculate its reciprocal value, we understand that the higher is the variance, the smaller will be the weight. Conversely,

Table 2.1 Values of the regression study by Becker and coll

	Regression coefficient	Exp (regression coefficient)	Lower 95 % confidence limit	Upper 95 % confidence limit	*p*-value
ITI implantation type	1.277	3.1643	1.459	6.863	.00354

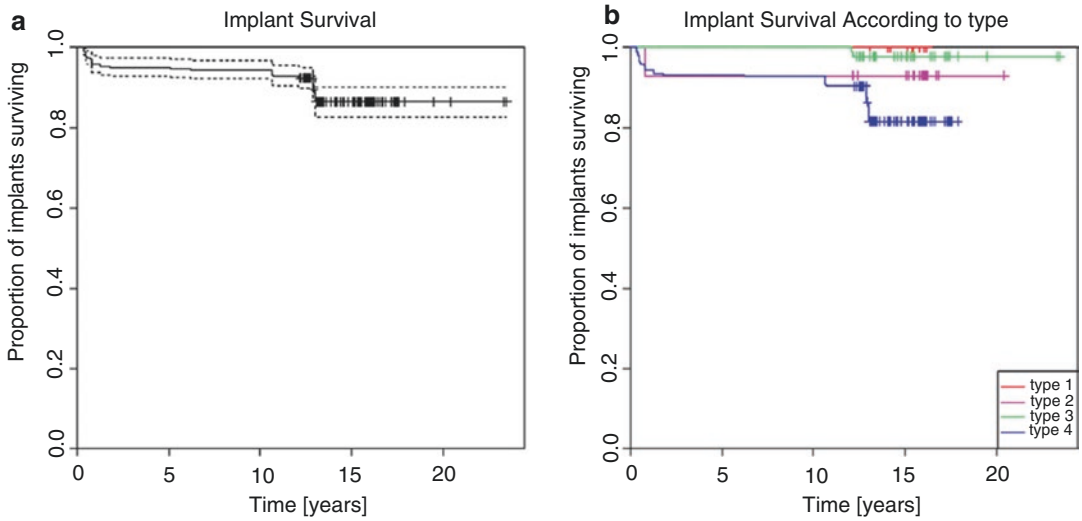


Fig. 2.5 Kaplan-Meier analysis of all the studied implants (**a**), further distinguished by ITI implantation type (**b**) (Reproduced with permission by Becker and coll)

the smaller the variance, the larger the weight of the study.

$$w = \frac{1}{\text{variance}}$$

In a meta-analysis, a *p*-value is also calculated with the usual statistical tests; normally if the value falls under 0.05, the result of the meta-analysis is considered statistically significant.

Meta-analyses are based on two statistical models, fixed effect and random effect.

If the analysis is performed under the fixed effect model, we suppose that all the studies included have one and just one true effect. This occurs rarely in medical and dental field.

Random effects instead implies more realistically that there is no reason to assume that the true effect size is the same for the whole population under study, but the effect size is comprised in a range due to various factors. For example, the true effect size in a population can vary accordingly if we consider age, systemic disease, socioeconomic status, etc.

In summary, with the fixed effect model, we consider all the observed effects in the included studies, and we try to give an estimation of the only one true effect size for the whole population.

We calculate the weight of each study first.

$$w_i = \frac{1}{VY_i}$$

Then, the weighted mean of the effect size is computed as

$$M = \frac{\sum_{i=1}^{k} w_i Y_i}{\sum_{i=1}^{k} w_i}$$

The variance of the summary effect is calculated as

$$V_M = \frac{1}{\sum_{i=1}^{k} w_i}$$

with standard error $SE_M = \sqrt{V_M}$.

Now it is easy to calculate the 95 % confidence interval in the usual way.

$$\left(M - 1.96 * SE_M, M + 1.96 * SE_M\right)$$

In case of the random effects model, the basic assumption are the same, but in this case, we take into account the between-study variance τ^2 (whose calculation goes beyond the scopes of this introduction).

And then we calculate the 95 % CI in the same way as for the fixed effect model.

Another important aspect regarding a meta-analysis is the evaluation of heterogeneity between studies. This is calculated with the I^2 index, since the amount of sampling error depends on the size of the sample, I^2 will get larger when the sample sizes in the primary studies is smaller. In general, we can consider an I^2 2 of 25 %, 50 %, and 75 % as low, moderate, and high heterogeneity, respectively.

In the following example reported is a meta-analysis evaluating marginal bone level change (in mm) of delayed versus immediately loaded dental implants after at least 1 year of follow-up (Fig. 2.6). In the seven studies included for the

study name	year	delayed N	delayed mean	delayed SD	immediate N	immediate mean	immediate SD	MD	lower	upper
shibly	2012	29	0.750	0.170	26	0.990	0.220	-0.240	-0.345	-0.135
jokstad	2014	144	1.100	0.700	104	1.300	0.700	-0.200	-0.377	-0.023
barewal	2012	14	0.225	0.280	7	0.330	0.380	-0.105	-0.422	0.212
den hartog	2011	31	0.900	0.570	30	0.910	0.610	-0.010	-0.306	0.286
meloni	2012	20	0.860	0.160	20	0.830	0.160	0.030	-0.069	0.129
schincaglia	2008	15	1.200	0.550	15	0.770	0.380	0.430	0.092	0.768

Continuous Random-Effects Model

Metric: Mean Difference

Model Results

Estimate	Lower bound	Upper bound	Std. error	p-Value
–0.047	–0.209	0.115	0.083	0.569

Heterogeneity

tau^2	Q (df=5)	Het. p-Value	I^2
0.029	24.351	< 0.001	79.467

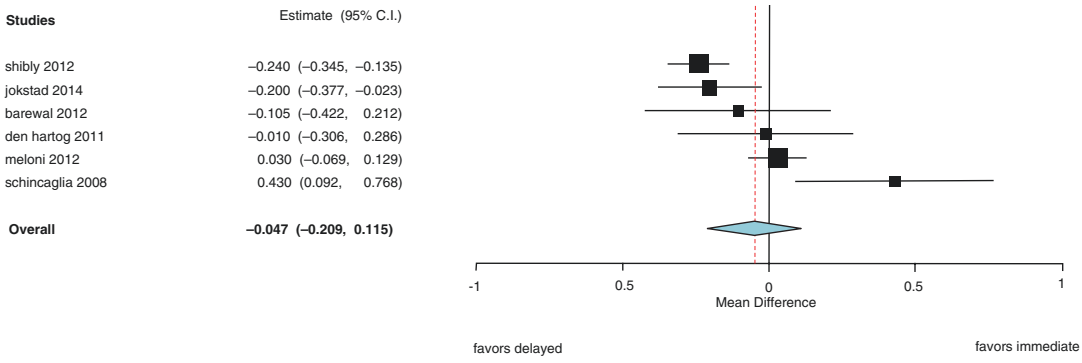


Fig. 2.6 Example of a meta-analysis evaluating marginal bone level changes of delayed versus immediately loaded dental implants after at least 1 year of follow-up (see text for details)

analysis, mean difference has been chosen for effect size comparison.

Is it possible to understand that a random effect model gives not statistically significant results (p-value (0.569)) Moreover, high heterogeneity is evident from the I^2 result of 79.5 %.

In conclusion, results of this meta-analysis show that there does not seem to exist a difference in marginal bone level change after at least 1 year of follow-up. Also, high heterogeneity between studies is evident.

2.5.1 Network Meta-analysis

A network meta-analysis is a method of conducting multiple treatment comparisons. For example, we can have a set of studies comparing treatment A versus treatment B and another set of studies comparing treatment A versus treatment C but no studies directly comparing treatment B versus treatment C.

For the purposes of indirectly comparing treatment B vs. C, we create a graphical network, hence the name of the analysis.

The majority of network meta-analyses are conducted using a Bayesian approach. In this way, they estimate treatment effects of each intervention and combining the prior probabilities give the corresponding posterior probability distribution. Bayesian network meta-analyses allow to obtain an estimation of the probability that each treatment can produce better outcomes than competing interventions.

For example, a Bayesian network meta-analysis was conducted [12] with the aim of assessing the efficacy of various peri-implantitis treatments. A network of the studies has been drawn (Fig. 2.7); thereafter a Bayesian analysis has been conducted showing the results in a bar graph (Fig. 2.8).

From the graph, it is possible to check which treatment has the highest probabilities of being ranked first, second, etc.

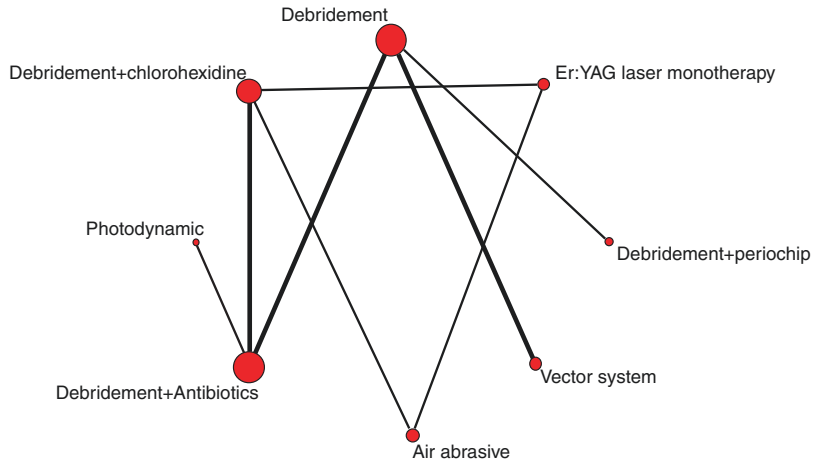


Fig. 2.7 Network of studies as included in the study of Faggion and coll [12] (Reproduced with permission)

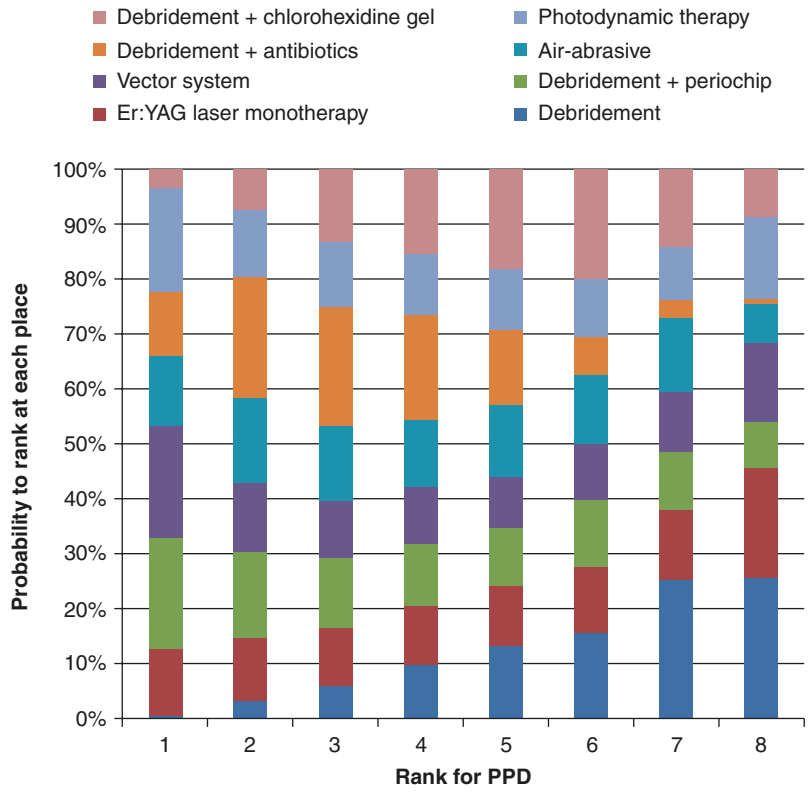


Fig. 2.8 Ranking of treatments after Bayesian analysis as conducted by Faggion and coll [12] (Reproduced with permission)

Of course, results of analysis of this kind should be interpreted with caution, because the underlying primary studies are not always of high quality.

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Teeth or Implants?

3

Oreste Iocca, Giuseppe Bianco,
and Simón Pardiñas López

Abstract

One of the main challenges for the modern implantologist is to resolve the clinical dilemma about whether to extract or retain a tooth. At this regard, evidence-based decisions are based on the concepts of survival, success, and failure. These concepts are often not clearly reported in the literature, which may complicate information retrieval from the literature. Comparison of implant solutions with endodontic treatment needs a separate analysis between primary endodontic procedures, re-interventions, and endodontic surgical options.

Comparison with fixed prosthesis on natural abutments is best made analyzing separately the success and failure of single crowns and multiple-unit restorations.

The traumatized tooth may also pose some diagnostic and therapeutic doubts, especially because trauma often involves young patients.

Finally, the periodontal compromised patient must have a specific evaluation before implant placement, mainly for the prognostic implications associated with a history of periodontal disease.

Development of treatment-decision algorithms in all these situations may aid the clinician in developing a treatment plan.

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3.1 Teeth or Implants

Patients with missing teeth or damaged dentition can undergo different restorative procedures or tooth extraction followed by implant placement. In order to provide the highest level of care, the clinician must take into account the individual needs and preferences of the patient but also the pros and cons of a given approach.

Tooth loss is the result of compromised health of hard tissues, pulp, or periodontium. It finds its causes in many factors such as behavioral patterns, socioeconomic status, genetic predisposition, and environmental influences.

It is not easy for the clinician to decide whether to retain a compromised tooth or replace it with an implant restoration. In fact, the different treatment options weigh peculiar risks and benefits, which must be taken into account in order to formulate an appropriate treatment planning.

Helping patients to keep their natural dentition should be the aim of any dental professional. The challenge is to decide when a particular dental disease can be treated conservatively or should lead to extraction and implant placement.

3.1.1 Survival and Success

Definitions of survival and success are important in order to make comparisons between endodontic, prosthetic, and implant treatment modalities.

When implant treatment is considered, it is important to distinguish between *survival*, which is the simple evaluation of the implant loss or persistence of the implant in the mouth, and *success*, whose criteria have been defined originally by Albrektsson in this way [1]:

- Absence of mobility
- Absence of signs and symptoms referred by the patient
- Loss of bone around the implant <1.5 mm in the first year after loading and 0.2 mm thereafter
- No evidence of peri-implant radiolucency

Additional criteria were added by Smith and Zarb [2]:

- Implants do not preclude placement of crown or prosthesis.
- A minimum success rate of 85 % after 5 years and 80 % after 10 years should be maintained.

One problem arises when the implant literature is analyzed: *survival* is usually the only parameter considered, and the evaluation of the abovementioned criteria is usually not performed. For this reason, it becomes difficult to actually evaluate the *success* rates of oral implants.

Same issues exist for the definition of *endodontic success criteria* which are often based on clinical, radiographic, and patient-referred symptomatology. The majority of the studies measure *nonsurgical endodontic success* as:

- Retention of the treated tooth
- The healing of the previous periapical pathology evaluated radiographically
- The prevention of the occurrence of the new disease and the absence of subjective symptoms

The *periapical index (PAI)* [3] is a visual system of categorization based on periapical x-ray evaluation in which a predefined set of x-rays and illustrations have been categorized in a scale from 1 (normal periapical structures) to 5 (large periapical lesion). Even if proved reproducible and reliable between operators, it is not often used in clinical studies. An updated PAI (Table 3.1 and Fig. 3.1) based on Cone-Beam

Table 3.1 PAI index

n	Quantitative bone alterations in mineral structures
0	Intact periapical bone structures
1	Diameter of periapical radiolucency > 0.5–1 mm
2	Diameter of periapical radiolucency > 1–2 mm
3	Diameter of periapical radiolucency > 2–4 mm
4	Diameter of periapical radiolucency > 4–8 mm
5	Diameter of periapical radiolucency > 8 mm
Score (*n*) + *E**	Expansion of periapical cortical bone
Score (*n*) + *D**	Destruction of periapical cortical bone

Reproduced with permission from Estrela and coll. [4]

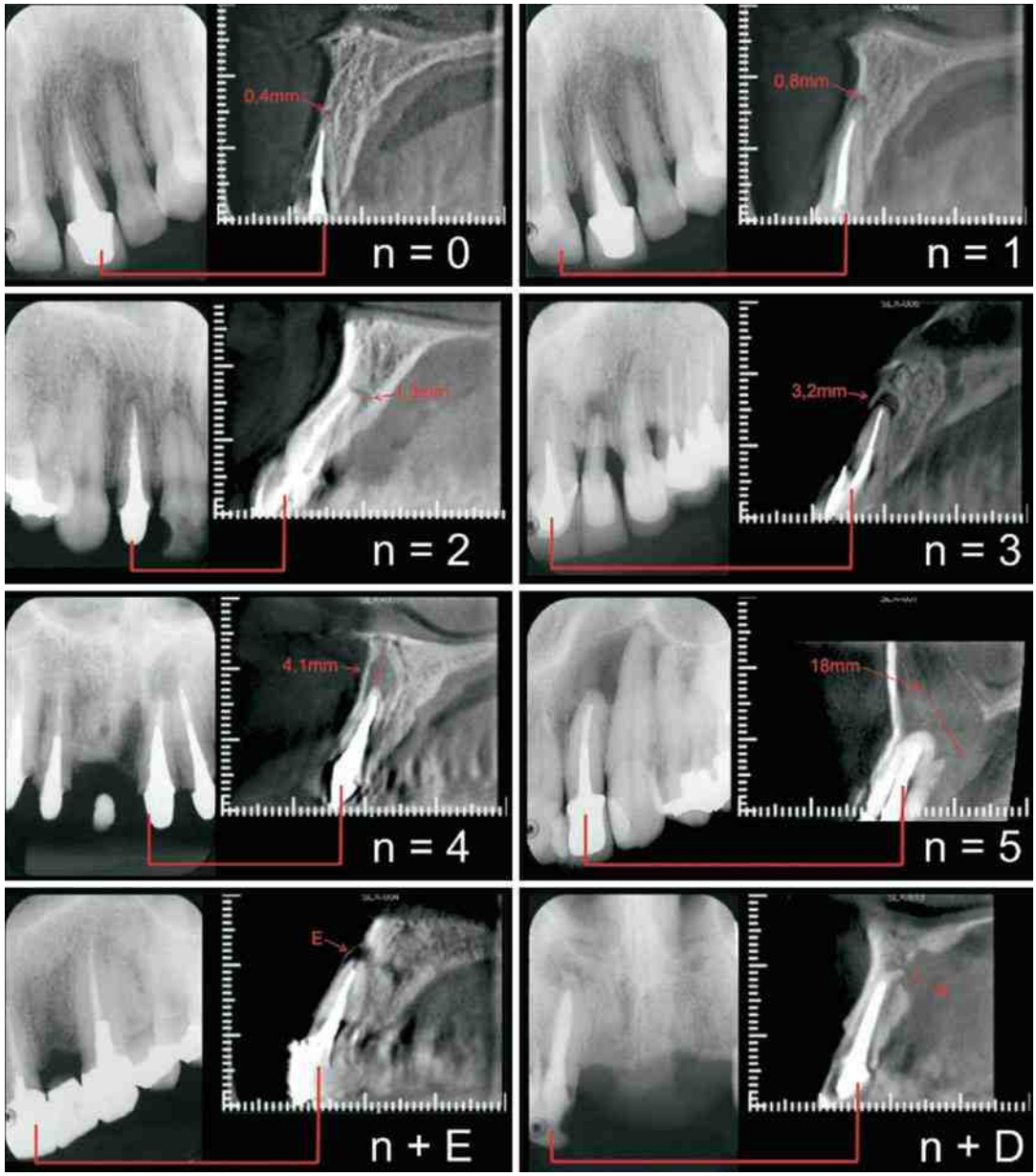


Fig. 3.1 PAI index on CBCT (Reproduced from Estrela and coll)

evaluation may be useful for the standardized reporting of endodontic lesions [4].

In practice, endodontic studies mostly evaluate the absence of clinical symptoms and radiographic measure of periapical healing regardless of the above criteria.

The *fixed dental prosthesis* success criteria are not uniformly defined; clinical retention of the restoration and loss of the natural abutments have been considered in the majority of the studies, but a consensus classification system does not exist.

3.2 The Endodontically Treated Tooth

Endodontic treatment is necessary when the dental pulp is compromised for any reason. Endodontics as a whole includes primary treatment, secondary treatment (re-intervention), and endodontic surgery; all of them have specific indications and different survival outcomes.

When endodontic literature is analyzed, it is very important to take in mind that some innovations, in the last two decades, favorably changed the prognosis of the endodontically treated tooth: the introduction of rotary instruments, the better understanding of the concepts of proper irrigation, shaping and three-dimensional obturation of the canal system, and the use of operatory microscope and ultrasonic instrumentation (Fig. 3.2).

All of these are innovations that likely improved the survival/success rate of previously unfavorable clinical conditions. In other words, the better comparison between endodontic and implant literature is made with studies of the same era [5].

3.2.1 Primary Endodontic Treatment

Nonsurgical primary endodontic treatment yields a high success rate even considering studies made before the advent of modern techniques. A complete systematic review [6] which analyzed the outcome of root-canal treatment in studies of the last four decades reported an *89 % (88–91 95 % CI)* weighted *success* rate with a minimum of 6 years of follow-up and an *84 % (81–87 95 % CI)* weighted *success* rate with studies of 6+ years of follow-up.

Instead, the *survival* rates were found to be *94 % (92–96 95%CI)* for studies with a minimum of 6 years of follow-up and 97 %(97–97 95 % CI) with 6+ years of follow-up.

Comparison of endodontically treated teeth and dental implants may be confounded by a

Fig. 3.2 Innovations that changed the endodontic surgical practice: the microscope, angulated ultrasonic tips, and microscopic armamentarium (Reproduced from Kim and coll)

number of variables, primarily the abovementioned unclear definitions of success and failure. Also, the type of restoration (filling, post and core, etc.) is considered a major determinant of survival, but it is not always specified.

Finally, even the most recent systematic reviews include studies of different eras in which treatment outcomes can vary substantially due to improvements of techniques and materials.

Direct comparison of endodontic versus implant treatment is best made on single-tooth restorations because of similarities between the two options [7], but the majority of studies do not focus or do not specify the kind of restoration used. Also, randomized clinical trials are not available, mainly because they would be considered unethical in most instances.

It is anyway possible to identify studies that try to compare indirectly endodontic versus implant treatment.

Systematic reviews analyzing survival rates of implant versus nonsurgical root-canal treatment put on evidence that there is no difference in outcomes between the two groups. This gives a clear indication that extracting a tooth which can be saved by endodontic therapy is questionable.

In conclusion, having defined all the abovementioned limitations, it is possible to state that nonsurgical root-canal therapy performed on a tooth with a healthy periodontium and no presence of other complicating factors is a predictable treatment modality which shows no difference in survival rate when compared with implant treatment (Table 3.2) (Fig. 3.3) [8].

Table 3.2 Systematic reviews comparing nonsurgical root-canal treatment versus implants

	Minimal follow-up	Proportion estimate: survival rate (CI 95 %)
Iqbal and Kim [9]	72 months	Endodontics 97.2 % (94.8–99.6) Implants 94.2 (92–96.4)
Torabinejad [6]	120 months	Endodontics 92 % (84–97) Implants 97 % (95–99)

3.2.2 Secondary Endodontic Treatment

The presence of persistent periapical pathology requires evaluation by the clinician in order to assess the need and the feasibility of endodontic re-intervention. Common causes of failure are due to insufficient/improper instrumentation and irrigation of the canal system, persistence of intracanalar microbiota, or complex canal anatomy. Secondary endodontics includes two options: *orthograde retreatment* and *endodontic surgery*.

Orthograde retreatment is preferred if the tooth has persistent apical pathosis and a canalar anatomy that allows instrumentation up to the apex.

Endodontic surgery instead is indicated when orthograde access is difficult or impossible due to complex canalar anatomy and iatrogenic causes (fractured instruments, insoluble cements, irremovable post, etc.) or when a fixed dental prosthesis is in place and its removal is not advised for economical or technical reasons [10].

Traditional endodontic surgery involves the use of surgical burs and amalgam as a root-end filling.

In the last few years, endodontic surgical procedure shifted toward a *microsurgical approach* (Fig. 3.4) involving the use of a microscope, angled ultrasonic instruments which facilitate accurate root-end preparation, and new better performing materials such as the MTA or superEBA.

This had important repercussion on clinical results and success rates as showed in the following studies:

A Cochrane review of randomized clinical trials comparing *nonsurgical retreatment* with *traditional endodontic surgery* has been performed [11], and the results showed that there is no apparent advantage in one treatment choice over the other in terms of long-term outcomes. This means that when a doubt exists whether a tooth should be re-treated via orthograde access or with a non-microscopic surgical technique, no difference is expected in survival outcomes. Indeed, this being considered, a *traditional surgical approach* should be avoided due to the

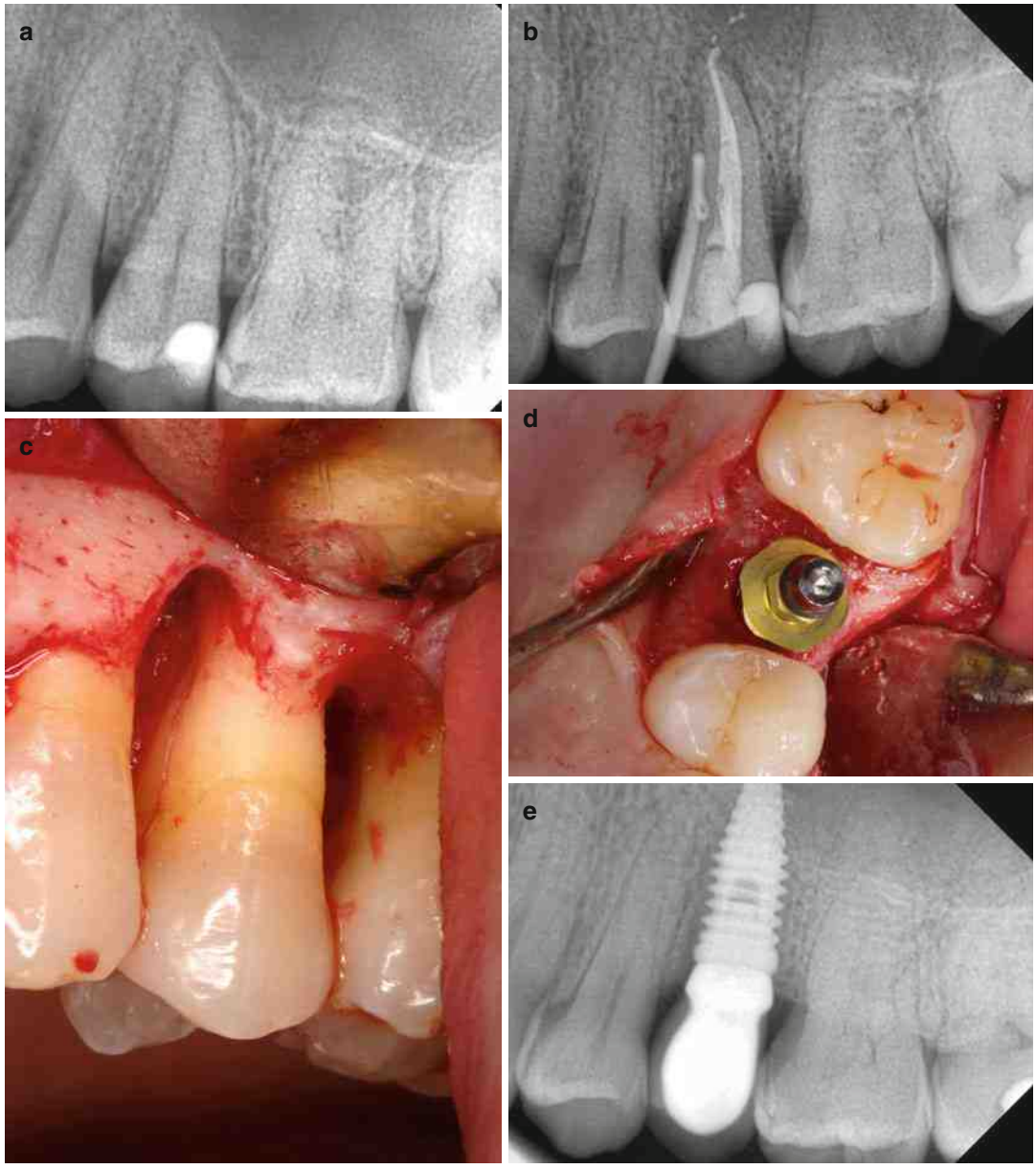


Fig. 3.3 In this case, an endodontic approach was attempted in order to treat the necrotic tooth #15 (**a**), after 3 months suppuration ensued (**b**), exploratory surgery revealed a vertical fracture (**c**) which rendered necessary extraction and implant placement (**d–e**)

fact that surgery inherently predisposes to greater risk of complications (post-op pain, scarring, amalgam discoloration, etc.)

On the other hand, a microscopic approach seems to give an advantage compared to orthograde retreatment. This was shown in a meta-analysis performed comparing *nonsurgical retreatment* with *endodontic microsurgery* [12] which showed a pooled success rate of 92 % (0.88–0.96 CI 95 %) for the *microsurgery group* and 80 % (0.74–0.86 CI 95 %) for the *nonsurgical group*; the difference was statistically significant.

Consequently, it is safe to assume that *endodontic microsurgery* is a reliable treatment option and the only effective alternative when *orthograde retreatment* is deemed difficult or impossible.

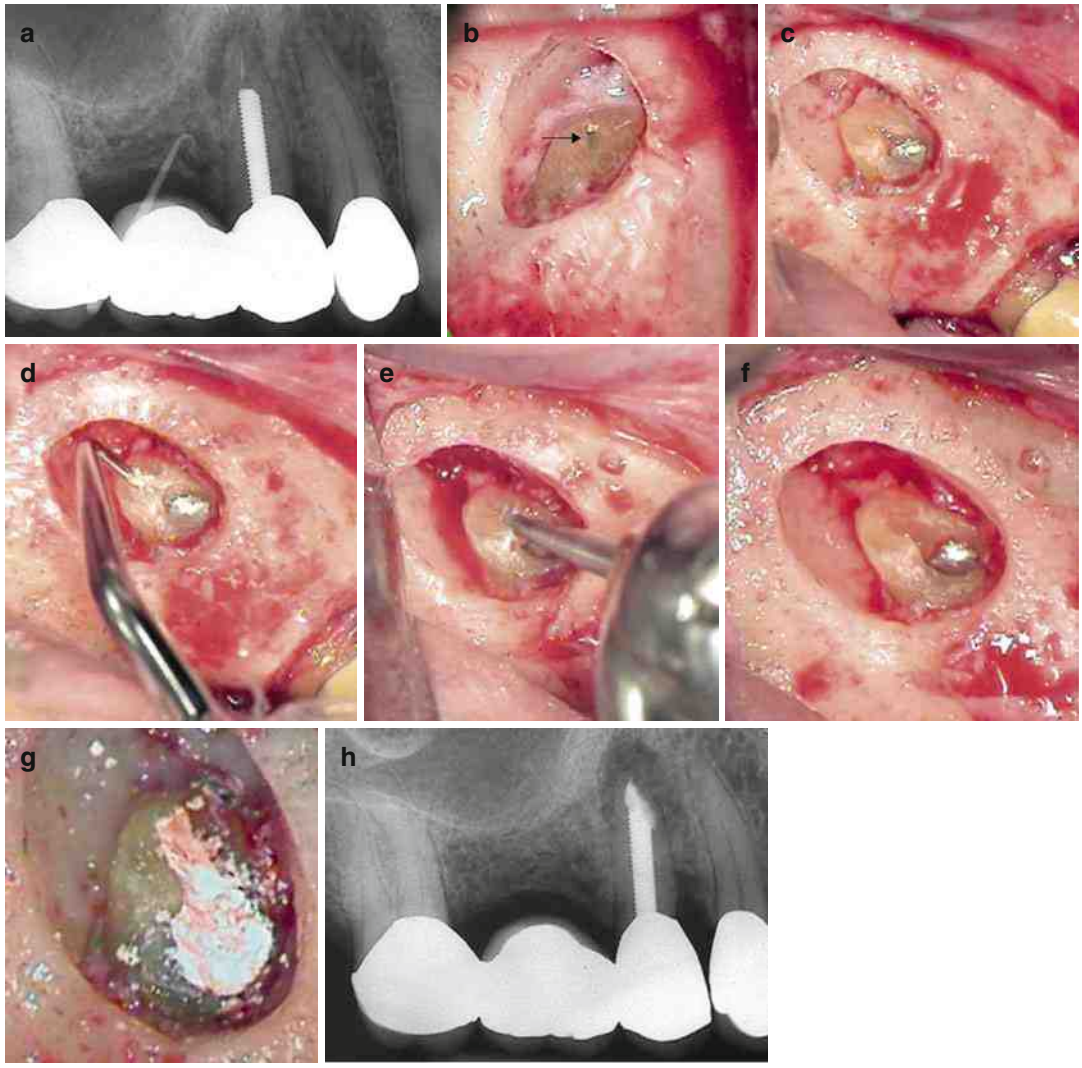
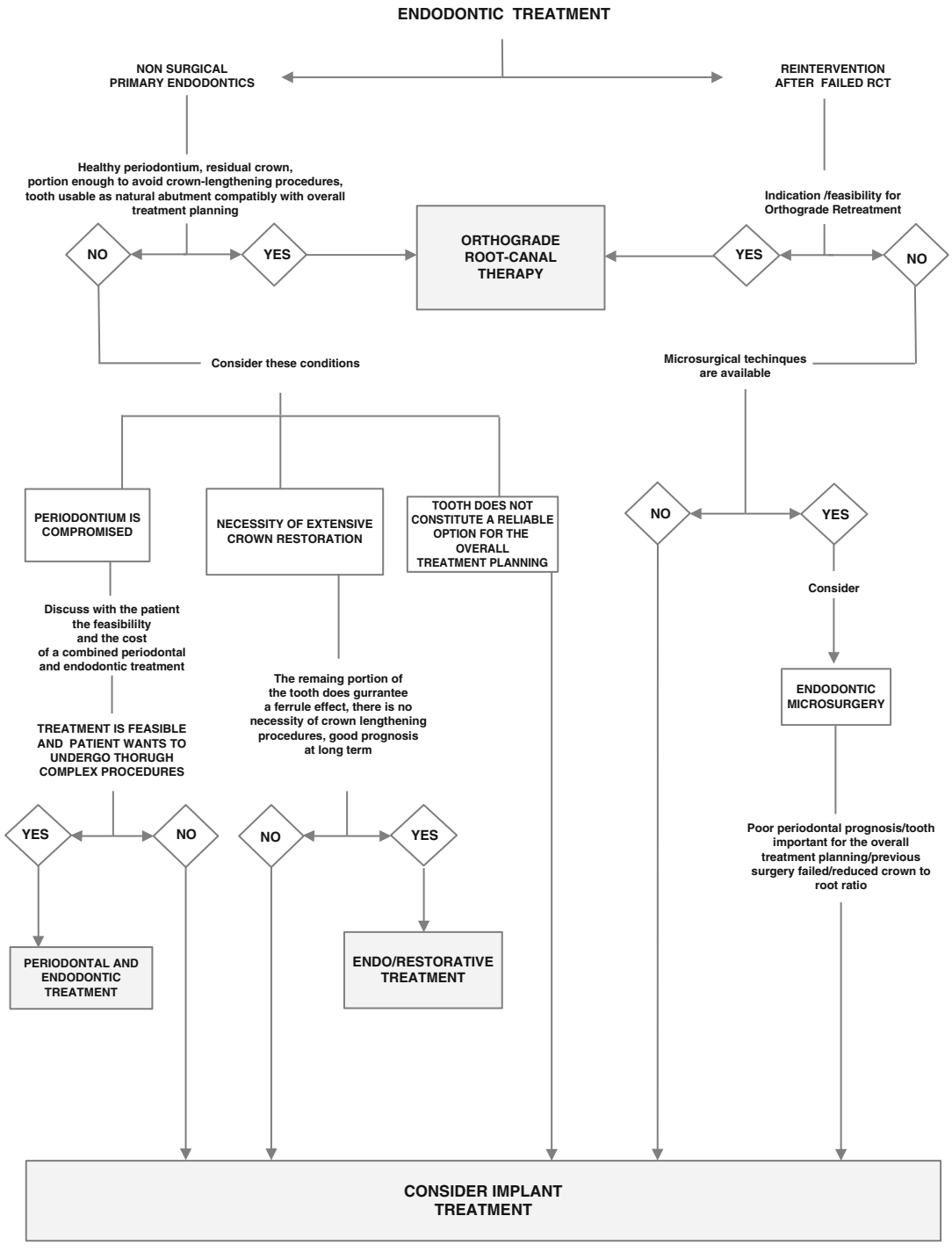


Fig. 3.4 Example of microscopic surgery performed with angulated ultrasonic instruments (**a**–**e**), microscope, and MTA apical obturation (**e**–**h**) (Reproduced with permission from Kim and coll. Problem solving in endodontics: prevention, identification and management, page 33, 5e, Mosby 2010)

In light of this, it is appropriate to compare *implant treatment* with *endodontic microsurgery*. Direct comparison studies are not available, but a systematic review by Torabinejad and coll. [13] reports survival rates for *single implant restorations* that vary from 96 % (0.93–0.98 CI 95 %) at 2–4 years follow-up to 98 % (0.95–0.99 CI 95 %) at 6+ years of follow-up. *Endodontic microsurgery* group showed survival rates of 94 % (0.91–0.97 CI 95 %) at 2–4 years and 88 % (0.84–0.92 CI 95 %) with 4–6 years of follow-up.

In the end, the single implants had higher survival rates than teeth treated with microsurgical endodontics [14].

Of course, clinical decision making cannot be based on these data alone, first of all because studies directly comparing endodontic microsurgical procedures with dental implants are lacking. Finally, multiple factors needs to be evaluated: the preferences of the patient after thorough discussion of the economical and biological costs of one treatment over the other, the overall oral health status, and the treatment planning as a whole (Flow Chart 3.1).



Flow Chart 3.1 Endodontic treatment

3.3 Fixed Dental Prosthesis on Natural Abutments

Fixed dental prosthesis is defined in the glossary of prosthodontic terms as "any dental prosthesis that is luted, screwed, or mechanically attached or otherwise securely retained to natural teeth [57]. This treatment option has been historically the standard of care for replacing single or multiple missing teeth. Anyway, in order to obtain optimal functional and esthetic results, a significant reduction of tooth structure is necessary. Moreover, various complications are associated with this kind of restorations so that the question is raised if natural teeth abutments are still an option in case of single or multiple edentulism.

3.3.1 Complications and Survival of FDP on Natural Abutments

Different systematic reviews and meta-analyses attempted to describe the complications and the survival/success rates of different types of FDP. The results for each review are reported in Tables 3.3, 3.4, 3.5, 3.6, and 3.7.

It is possible to understand that complication rates differ according to the type of restoration analyzed and the materials used. Also, it is logical that the longer is the follow-up time, the longer will be the risk of developing complications and failures.

Metal-ceramic crowns and prosthesis have been the gold standard in fixed prosthodontics for many decades, but in the last decade, all-ceramic restorations have assumed an important role in clinical practice, primarily for the superior esthetic outcomes.

When complication rates of fixed dental prostheses are analyzed, it is observed that common complications of metal-ceramic restorations

Table 3.4 Complication rates on FDP metal-ceramic restorations on natural abutments (5-year estimate according to Tan and coll.)

	Conventional FDP metal-ceramic
Tan and coll. [19] 5-year estimate	Need for endodontic treatment 10 %
	Caries 9.5 %
	Loss of retention 6.4 %
	Porcelain fracture 3.2 %
	Fracture of the abutment teeth 2.1 % Periodontal disease 0.5 %

Table 3.5 Complication rates of single crowns on natural abutments (5-year estimate according to Pjetursson and coll.)

	Single crown metal-ceramic	FPD, single crown all ceramic
Pjetursson and coll. [20] 5-year estimate	Ceramic chipping 5.7 % Loss of retention 2.8 % Need for endodontic treatment 2.1 % Caries 1.8 %	Marginal discoloration 5.3 % Ceramic chipping 3.7 % Loss of retention 2.8 % Need for endodontic treatment 2.1 % Caries 1.8 %

Table 3.3 Complication rates on various types of restorations on natural abutments

	Single crown, metal-ceramic	FDP, metal-ceramic	All-ceramic crown	Resin-bonded prosthesis	Post and core
Goodacre and coll. [18]	Need for endodontic treatment 3 % Porcelain fracture 3 % Loss of retention 2 % Periodontal disease 0.6 % Caries 0.4 %	Caries 18 % Need for endodontic treatment 11 % Loss of retention 7 % Esthetics 6 % Periodontal disease 4 % Tooth fracture 3 % Prosthesis fracture 2 % Porcelain veneer fracture 2 %	Fracture 7 % Loss of retention 2 % Pulpal health 1 % Caries 0.8 % Periodontal disease 0.0 %	Debonding 21 % Tooth discoloration 18 % Caries 7 % Porcelain fracture 3 % Periodontal disease 0.0 %	Post loosening 5 % Root fracture 3 % Caries 2 % Periodontal disease 2 %

Table 3.6 Complication rates of various types of restorations on natural abutments (10-year estimate according to Sailer and coll.)

	Single crown metal-ceramic	Single crown all-ceramic feldspathic/silica	Single crown all-ceramic leucit or lithium disilicate	Single crown all-ceramic glass infiltrated	Single crown all-ceramic alumina	Single crown all-ceramic zirconia
Sailer and coll. [21] 5-year estimate	Ceramic chipping 2.6 % Marginal discoloration 1.8 % Need for endodontic treatment 1.7 % Caries 1 % Loss of retention 0.6 % Framework fracture 0.3 % Esthetic failure 0.5 %	Framework fracture 6.7 % Marginal discoloration 4.3 % Need for endodontic treatment 3.7 % Ceramic chipping 1.2 % Caries 0.6 % Loss of retention 0.6 % Esthetic failure 0.5 %	Framework fracture 2.3 % Marginal discoloration 2.3 % Ceramic chipping 1.5 % Loss of retention 1 % Need for endodontic treatment 0.7 % Caries 0.5 % Esthetic failure 0 %	Marginal discoloration 8.3 % Framework fracture 2.1 % Caries 2.1 % Ceramic chipping 1.8 % Need for endodontic treatment 0.7 % Esthetic failure 0.5 % Need for endodontic treatment 0 %	Esthetic failure 3.6 % Ceramic chipping 3.5 % Framework fracture 2.4 % Loss of retention 2.2 % Caries 1.4 % Marginal discoloration 0 %	Loss of retention 4.7 % Ceramic chipping 3.1 % Caries 0.5 % Marginal discoloration 0.4 % Esthetic failure 0 %

Table 3.7 Complication rates on FDP restorations on natural abutments (5-year estimate according to Pjetursson and coll.)

	FDP metal-ceramic	FDP all-ceramic reinforced glass	FDP all-ceramic alumina	FDP all-ceramic zirconia
Pjetursson and coll. [22] 5-year estimate	Marginal discoloration 21.4 % Ceramic chipping 8.6 % Ceramic fracture 5 % Loss of retention 2.1 % Caries 1.2 % Framework fracture 0.6 % Need for endodontic treatment n.a.	Framework fracture 8 % Ceramic fracture 6.5 % Ceramic chipping 5.2 % Marginal discoloration 3.5 % Loss of retention 2.9 % Caries 0.5 % Need for endodontic treatment n.a.	Ceramic chipping 31.4 % Marginal discoloration 17.2 % Framework fracture 12.9 % Ceramic fracture 6.6 % Loss of retention 2.6 % Caries 2 % Need for endodontic treatment n.a.	Ceramic chipping 19.5 % Marginal discoloration 28.5 % Framework fracture 1.9 % Ceramic fracture 14.5 % Loss of retention 6.2 % Caries 3.2 % Need for endodontic treatment 2.2 %

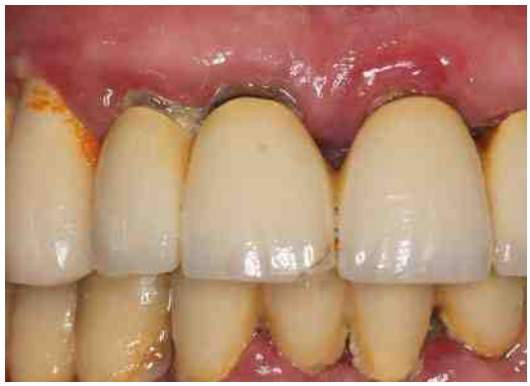


Fig. 3.5 Three-unit restoration on natural abutments presenting with chipping, root exposure and caries, gingival inflammation, and recession

include loss of vitality, decementation, root caries, chipping, and esthetic problems [19] (Figs. 3.5 and 3.6). Regarding all-ceramic crowns, complications vary according to the materials adopted, but in general, common adverse events are crown fracture, marginal discoloration, loss of vitality, and caries.

Survival rates results are showed in Table 3.8. There is a difference in survival between metal-ceramic and all-ceramic kind of restorations which is not statistically significant.

3.3.2 Survival and Complications of Implant-Supported FDP and Single Crowns

Common complications reported in the literature are indicated in Table 3.9. Complication rates vary accordingly if we consider single crowns or FDP supported by an implant. Regarding single-implant restorations, more or less common complications include loosening of abutment screw, loss of retention, fracture, chipping, abutment fracture [27].

Regarding the implant-supported FDP [28], common reported complications include prosthetic fracture, abutment or screw loosening, abutment or screw fracture, metal framework fracture (Fig. 3.7). Implant fracture is a rare but possible complication (Fig. 3.8) (Tables 3.10 and 3.11).

Implant-supported FDP and single crowns survival rates are also documented in different systematic reviews (Table 3.12), ranges of 89–95 % and 80–95 % of survival are found for single crowns and fixed dental prostheses respectively. Be careful that *Prostheses Survival* are reported in this case. When just *implant survival* is specifically analyzed, higher rates are reported.

An interesting aspect that must be analyzed is the difference in complications and survival rates when studies are subdivided by year of publication. In fact, it seems reasonable that newer technologies and materials that have changed during time influenced the outcomes of treatment. A systematic review by Pjetursson and coll. investigated the studies published before and in the year 2000 and those published after the year 2000 [33]. The findings confirmed an improvement in overall prostheses *survival* in the most recent implant publications. These was true for both *implant-supported FDP* and *single crowns* regardless if they were cemented or screw retained.

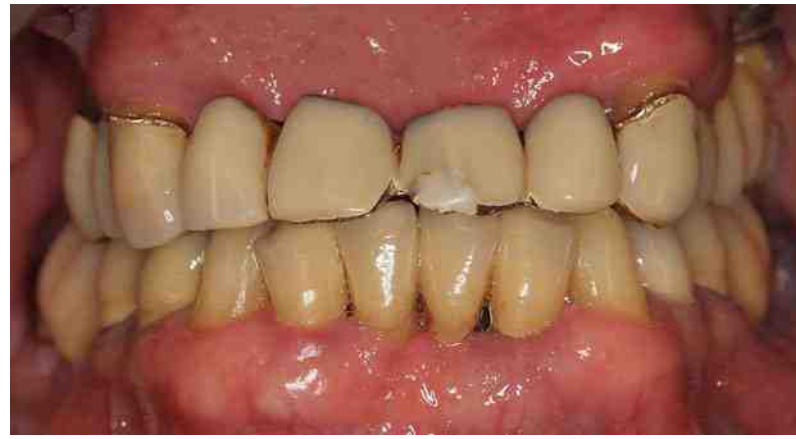


Fig. 3.6 FDP presenting with esthetic complications such as gingival recession, metal-border exposure, and chipping

Table 3.8 Survival analysis of natural abutments restorations according to various meta-analyses

Creugers and coll. [23]	Conventional metal-ceramic FDP	74 % (0.69–0.80 CI 95 %) after 15 years
Scurria and coll. [24]	Conventional metal-ceramic FDP	75 % (0.70–0.79 CI 95 %) after 15 years
Tan and coll. [19]	Conventional metal-ceramic FDP	89.1 % (0.81–0.94 CI 95 %) after 10 years
Salinas and Eckert [25]	Conventional FDP	67.3 % (0.50–0.84 CI 95 %) after 15 years
Pjetursson and coll. [22]	Conventional metal-ceramic FDP Conventional FDP all-ceramic (zirconia)	94.4 % (0.91–0.97 CI 95 %) after 5 years 90.4 % (0.85–0.94 CI 95 %) after 5 years
Sailer and coll. [21]	Single crown metal-ceramic Single crown all ceramic (zirconia)	94.7 % (0.94–0.97 CI 95 %) after 5 years 96.6 % (0.95–0.97 CI 95 %) after 5 years
Pjetursson and coll. [20]	Single crown metal-ceramic Single crown all ceramic	95.6 % (0.92–0.97 CI 95 %) after 5 years 93.3 % (0.91–0.95 CI 95 %) after 5 years
Sailer and coll. [26]	Single crown metal-ceramic Single crown all ceramic	94.7 % (0.94–0.97 CI 95 %) after 5 years 92.1 % (0.83–0.95 CI 95 %) after 5 years

Table 3.9 Complication rates of implant restorations according to Goodacre and coll.

	Implant surgical complications	Prosthetic complications	Peri-implant soft tissue complications
Goodacre and coll. [27]	Hemorrhage-related complications 24 % Neurosensory disturbances 7 % Mandibular fracture 0.3 %	Prosthetic fracture 14 % Opposing prosthesis fracture 12 % Prosthesis screw loosening 7 % Abutment screw loosening 6 % Prosthesis screw fracture 4 % Metal framework fracture 3 % Abutment screw fracture 2 % Implant fractures 1 %	Fenestration/dehiscence 7 % Gingival inflammation 6 % Fistulas 1 %

If just *implant-supported single crowns* are analyzed, reduced prosthetic complication rate are found in newer studies. In particular, esthetic outcomes and biological complications for restorations are found to be significantly lower than older studies [29, 31].

If just *implant-supported FDPs* are analyzed, the rate of prosthetic complications remains similar between older and newer studies, with a 5-year rate ranging from 16 to 53 % [27, 28, 30, 32]. This is an aspect that merits consideration because even if the survival rates are high, the patient and the clinician

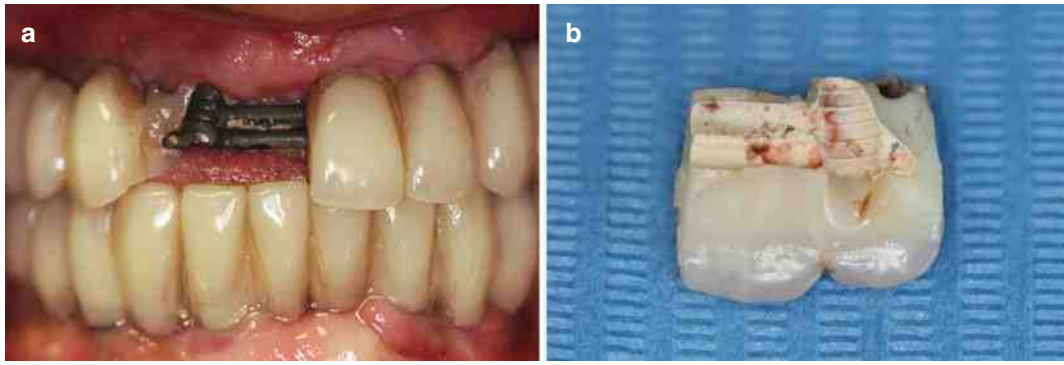


Fig. 3.7 (**a**, **b**) Prostheses fracture is a relatively common complication of implant-supported restorations

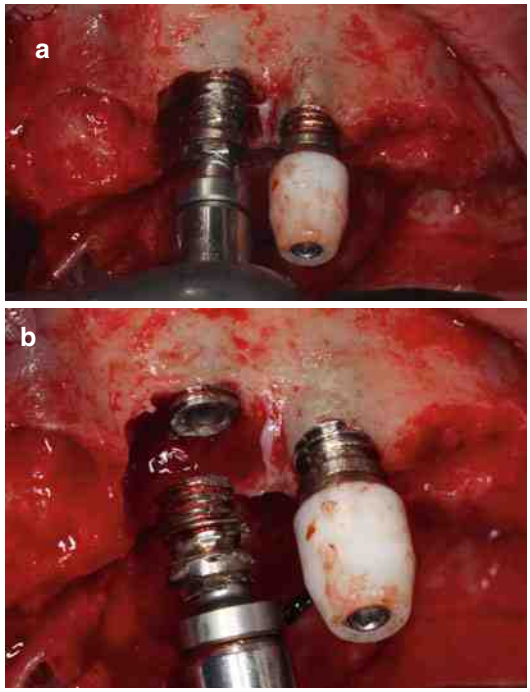


Fig. 3.8 (**a**, **b**) Implant fracture is a rare, yet possible, complication

must take into account that during the follow-up a certain amount of time will be spent fixing the abovementioned complications.

Finally, whether the lower complications and higher survival rates are due to true technological improvements or simply to a positive learning curve obtained by the clinicians after many years of oral implants studies, this remains an open question. It is anyway possible that both factors have a role.

3.3.3 Comparison of Natural Abutments Versus Implant-Supported Restorations

Direct comparison of FDP on natural abutments with implant restoration is not straightforward due to the lack of direct comparative studies. Also, even if implants and natural abutment serve the same scope (i.e., substain a prosthetic device), to some extent, comparison of the complications is difficult for the inherent differences between the two treatment options.

That being said, a descriptive comparison of survival is feasible on the basis of the published studies.

Survival of implant restorations shows higher rates of short-term failures, mostly due to lack of osseointegration instead of prosthetic problems, but performs better at long term compared to natural teeth prostheses [25].

Consistent with the previous discussion, it is possible to assume that implant-supported restorations have a better prognosis on the long term when compared to prostheses on natural abutments. Also, tooth preparation of teeth adjacent to edentulous spaces requires sacrifice of healthy tooth substance and is associated with a high risk of biological complications such as caries and fractures of the prepared abutments.

On the other hand, implant placement requires surgical expertise and can create some difficulties in recreating natural hard and soft tissue contours in esthetic areas.

Table 3.10 Complication rate of implant restorations (5-year estimates according to Pjetursson and coll.)

	Biological complications	Prosthetic complications
Pjetursson and coll. [28] 5-year estimate	Overall without specifying the details 8.6 %	Prosthetic fracture 13.2 % Abutment or screw loosening 5.8 % Abutment or screw fracture 1.5 % Metal framework fracture 0.8 % Implant fracture 0.4 %

Table 3.11 Complication rate of single crown implant restorations (5-year estimate)

	Biological complications, single crowns	Prosthetic complications, single crowns
Jung and coll. [29] 5-year estimate	Soft tissue complications (inflammation, bleeding, suppuration) 7.1 % Esthetic complications 7.1 % Bone loss >2 mm 5.2 %	Loosening of abutment or screw 8.8 %% Loss of retention 3.5 % Framework fracture 1.3 % Abutment or screw fractures 0.4 % Implant fracture 0.18 %
Pjetursson and coll. [30] 5-year estimate	*Marginal bone loss 8.5 %*	Prosthetic fracture 7.8 % Chipping 7.8 % Loss of screw access hole 5.4 % Abutment or screw loosening 5.3 % Loss of retention 4.7 % Abutment or screw fracture 1.3 % Metal framework fracture 0.5 % Implant fracture 0.5 %
Zembic and coll. [31] 5-year estimates	*Overall without specifying 6.4 %*	Abutment or screw loosening 4.6 % Crown loosening 4.3 % Chipping 2.7 % Esthetic complications 0.9 % Abutment fracture 0.2 %

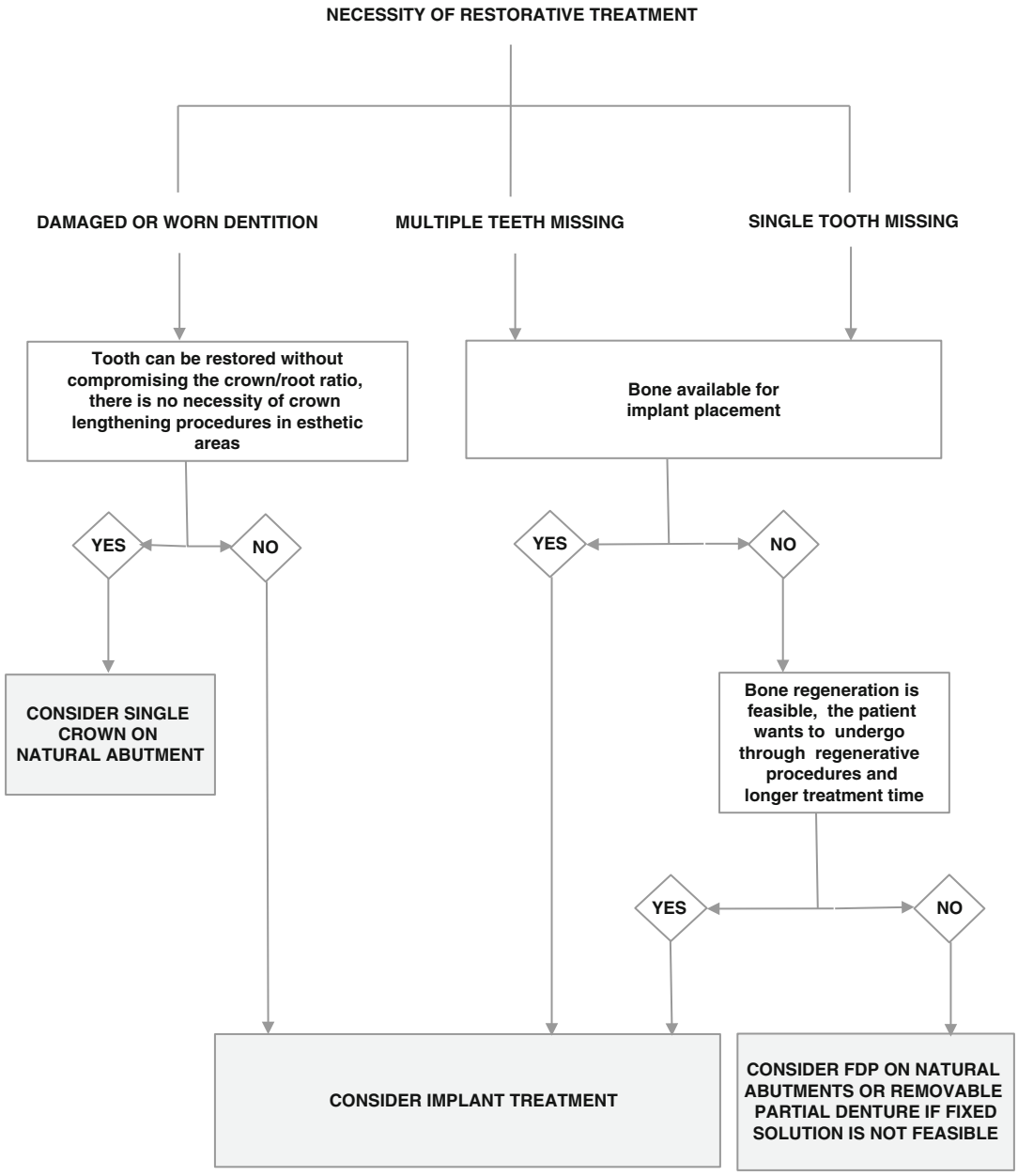
Table 3.12 Survival rate of FDP and single crowns according to various systematic reviews

Lindh and coll. [32]	FDP implant supported	93.6 % (0.91–0.95 CI 95 %) after 8 years
Pjetursson and coll. [28]	FDP implant supported	86.7 % (0.83–0.89 CI 95 %) after 10 years
Torabinejad and coll. [6]	FDP implant supported	95 % (0.93–0.96 CI 95 %) after 6+ years
Pjetursson and coll. [30]	FDP implant supported	80.1 % (66.8–89.4 CI 95 %) after 10 years
Jung and coll. (2012) [29]	Single crown implant supported	89.4 % (0.83–0.94 CI 95 %) after 10 years
Zembic and coll. (2014) [31]	Single crown implant supported	95.6 % (0.94–0.97 CI 95 %) after 5 years

In conclusion, after careful evaluation of the needs and the will of the patient, when a single tooth needs to be replaced, implant treatment is the best option. Also, implants used as a support to FDP for multiple teeth replacement reduce mechanical and biological complications and enhance prostheses longevity when compared with FDP on natural abutments (see Flow Chart 3.2).

3.4 The Traumatized Tooth

Dental trauma is a common occurrence in the young population. The majority of traumatic dental injuries occur in children and adolescents. It is estimated that 71–92 % of all dental traumas occur before the age of 19 [34]. Most common site of injury is the anterior maxilla.



Flow Chart 3.2 Necessity of restorative treatment

Different topologies of dental trauma are identified: infraction, enamel fracture, enamel-dentin fracture, enamel-dentin-pulp fracture, crown fracture without pulp exposure, crown fracture with pulp exposure, root fracture, alveolar fracture, concussion, subluxation, extrusive luxation, lateral luxation, intrusive luxation, and avulsion.

Treatment decisions after evaluation of a traumatized tooth are based on clinical and

radiographic findings. When possible, every effort should be made to preserve pulp vitality in order to ensure a positive long-term prognosis [35].

Current guidelines, proposed by the *International Association of Dental Traumatology* [36], indicate that conservative/endodontic treatment is the first choice for fractures of enamel-dentin with or without pulp exposure (Table 3.13). Other types of trauma require instead a multidisciplinary evaluation, and implant treatment is one of the most reliable options for unrestorable traumatized dentition. It is important to remember that implant insertion can be performed only on the adult population with no further bone growth expected. Contrarily in younger patients, the main goal of treatment is to preserve the bony architecture and soft tissue contours in a way to prepare for implant placement when growth has ceased [37].

The choice to a traumatized tooth requires careful evaluation of both the restorability and the prognosis of the tooth (Fig. 3.9). Especially in young patients, a compromise treatment can be

Table 3.13 Guidelines for management of dental injuries

	IADT guidelines for management of traumatic dental injuries
Crown-root fracture 	In this case if the fracture line is above the gingiva level, the fractured coronal portion is removed and restorative treatment is performed. In the case in which the fracture line is below the gingiva level, feasibility of a restorative approach depends upon the apical extension of the fracture line, if this is too deep extraction with immediate or delayed implant placement is performed
Root fracture 	Repositioning of the coronal segment may be a possibility if the displacement is minimal; this will be followed by splinting and monitoring for at least 4 weeks, and endodontic treatment is performed if pulp necrosis develops, if radiographic signs of inflammation or impaired healing develops extraction, and if implant placement is indicated

Table 3.13 (continued)

	IADT guidelines for management of traumatic dental injuries
luxation 	With all the types of luxation (subluxation, intrusive, extrusive, lateral), tooth repositioning surgically or orthodontically allows to obtain optimal long-term results. Extraction and implant treatment is not usually indicated
Avulsion 	It occurs in up to 3 % of all dental traumas of permanent teeth. It is one of the true dental emergencies and requires prompt evaluation and treatment decisions. Replantation is still considered the gold standard and it should be ideally performed immediately after the accident. If this is not possible, the tooth is maintained in appropriate storage media (balanced Hank's solution, saliva, milk, saline) and transported to the dental facility. If the time delay is <60 min, the prognosis of the replanted tooth is good; if the replantation is performed after 60 min, the chance of developing ankylosis and/or root resorption is high. In this situation, it is appropriate to evaluate with the patient if it is better to consider implant restorations

chosen, keeping in mind that these patients have high survival expectancy; therefore, delayment of extraction even for teeth with bad prognosis is a possibility [38–40]. Discussion with the patient is of utmost importance in order to obtain satisfactorily results at long term (Flow Chart 3.3).

3.5 Periodontal Compromised Patient

In the past, periodontics had the primary aim of maintaining the teeth in the mouth as long as possible in order to postpone as much as possible the replacement of natural teeth with a removable denture or to allow a fixed restoration on the periodontally compromised teeth. This was accomplished with bone resective surgery or with root amputation procedures.

With the advent of implantology, there was a paradigm shift from tooth preservation to bone preservation. Osseous resective surgery performed with the aim of eliminating the periodontal pocket has been shown to be successful in the compliant patient. On the other hand, preserving bone for a future implant insertion may be more important than the short-term pocket reduction around a compromised tooth.

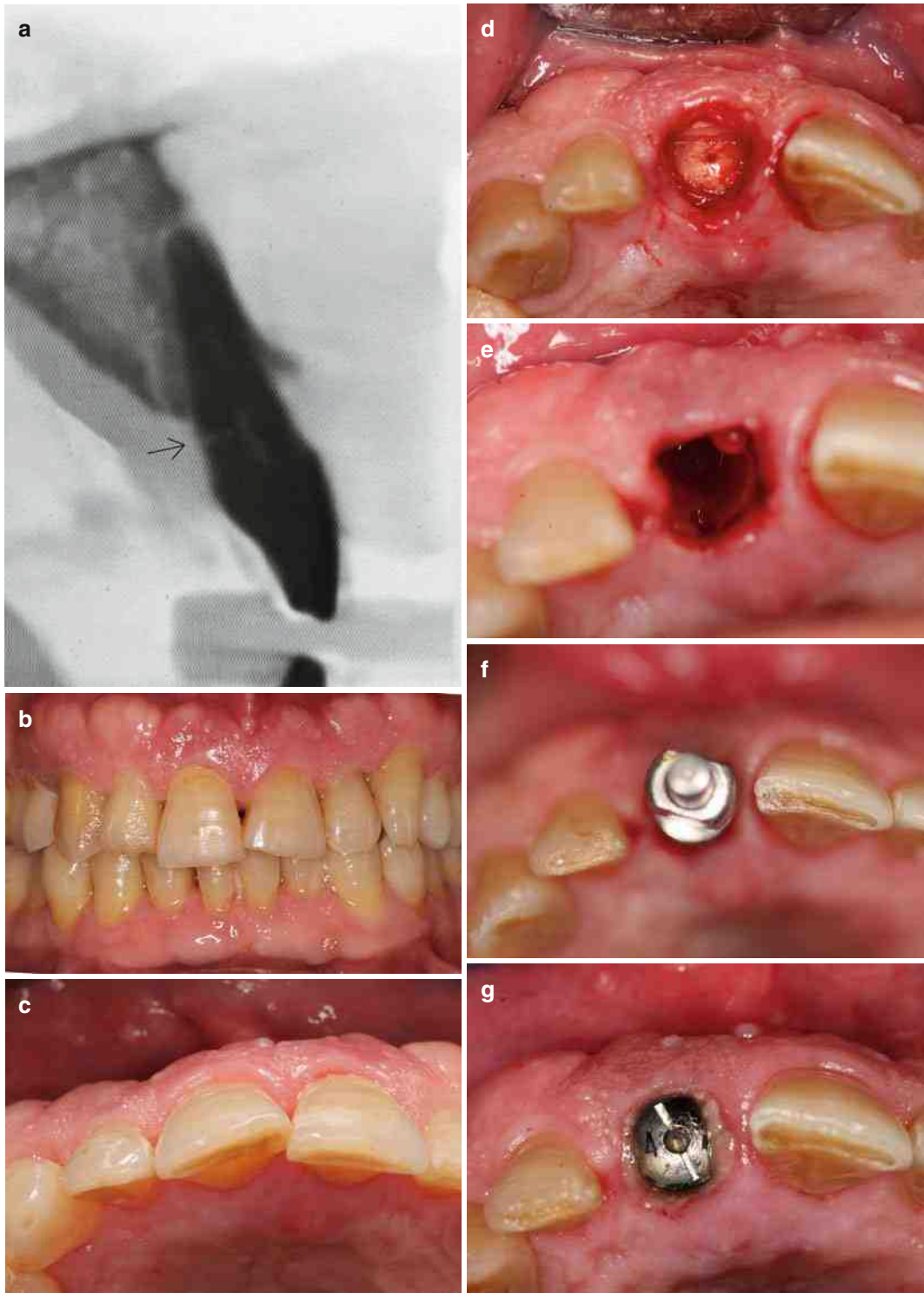


Fig. 3.9 (**a–h**) Ct evaluation shows a root fracture (**a**), clinically a slight crown displacement is evident (**b**, **c**), removal of the fractured crown reveals a fracture line well below the gingival plane (**d**), restoration is considered inappropriate due to the necessity of crown-lengthening procedures and poor esthetic prognosis, an extraction is performed and immediate implant is placed (**e–h**)

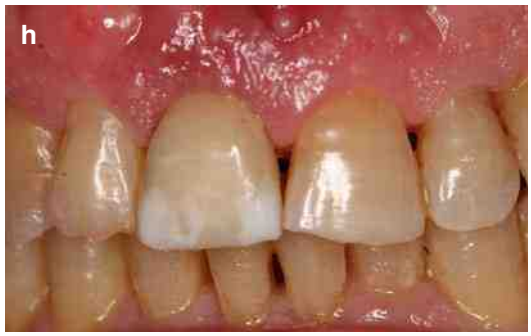


Fig. 3.9 (continued)

Periodontal regenerative procedures are another treatment option; however, complete regeneration of the periodontium has been shown difficult to achieve and not predictable in some cases [41]. Moreover, regeneration is possible only with some types of periodontal defects, while in patients with generalized periodontitis, the only possibility is to try to slow the progression of the disease.

With these premises, it is important to resolve when to proceed with the extraction or when a conservative approach can be adopted [42].

In general, four factors are taken into account in the evaluation of the dentition affected by periodontal disease:

- *Endodontic/restorative status*: If the tooth necessitates complex endo/restorative procedures (post and core, endodontic surgery, crown lengthening, etc.), the prognosis is poor. Moreover, the costs for the patient can be much higher if the failing tooth would need to be replaced with an implant after a short period of time.
- *Status of the adjacent dentition*: If the periodontally compromised tooth/teeth are considered strategic abutments, one should consider which would be the consequences once the treatment fails. If the risk of compromising an extensive prosthetic work is high, extraction should be considered.
- *Periodontal status*: Pocket depth, furcation involvement, crown-root ratio, and oral hygiene are all factors to consider before proceeding with complex periodontal treatment. Poor patient compliance and poor tooth prognosis should lead toward less complex treatment options.
- *Esthetics*: Anterior teeth involved by periodontal disease merits careful evaluation. Bone resective procedures are excluded in this case. Periodontal regeneration is a possibility if the periodontal defect has a favorable prognosis (three to four wall pockets). Otherwise, extraction and implant placement may aid in achieving good esthetic results.

3.5.1 Implant Treatment in the Patient with a History of Periodontal Disease

Implant treatment in periodontitis susceptible patients has been evaluated in numerous studies with the aim to assess the risk of implant loss and success rates in this specific population.

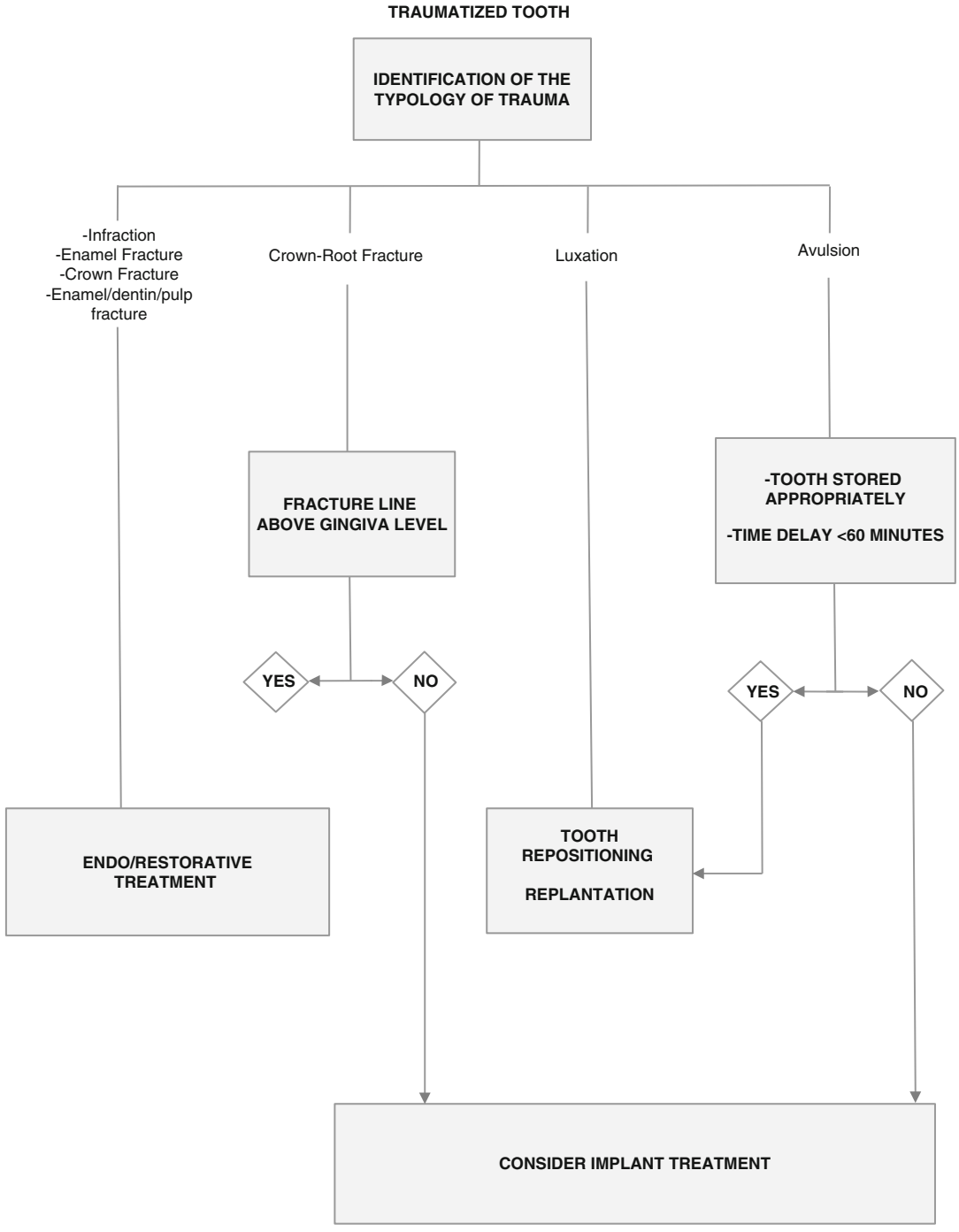
It is assumed that patients affected by periodontal disease are at increased risk of developing inflammatory complications which may increase the rate of implant failures; this is a logical assumption given the similar pathobiology and microbiological aspects between periodontitis and peri-implantitis [43].

Meta-analyses are best suited for making a comparison between healthy and periodontally compromised patients undergoing implant treatment because they allow collection and update of results from contradictory studies.

The results of all meta-analyses published so far are concordant with the fact that patients with a history of periodontitis have an increased risk of implant loss compared with patients with a negative history of periodontal disease (Tables 3.14, 3.15, and 3.16).

Potential shortcomings arise from confounding factors, such as smoking and diabetes mellitus, which are not always clearly accounted for or not considered at all. Also, no RCT have been published on the argument so far.

Anyway, it must be pointed out that potential weakness in the analyses is overcome by the fact that the results are exceptionally homogeneous across all the studies [44–49]. This strengthens the



Flow Chart 3.3 Traumatized tooth

Table 3.14 Published meta-analyses on periodontal healthy versus periodontitis patient undergoing implant treatment

	Effect size	*Periodontal healthy vs. periodontal compromised* Results (95 % CI)	Statistically significant	Clinical meaning
Wen and coll. [44]	RR	1.04 (1.02–1.04)	+	In favor of periodontal healthy patients
Chrcanovic and coll. [45]	RR	1.78 (1.50–2.11)	+	In favor of periodontal healthy patients
Sgolastra and coll. [46]	RR	1.89 (1.35–2.66)	+	In favor of periodontal healthy patients
Safii and coll. [47]	OR	3.02 (1.12–1.85)	+	In favor of periodontal healthy patients

Table 3.15 Published meta-analyses evaluating aggressive versus chronic nonaggressive forms of periodontal disease

	Effect size	Chronic periodontitis vs. aggressive periodontitis patients results (95 % CI)	Statistically significant	Clinical meaning
Wen and coll. [44]	RR	1.03 (1.01–1.05)	+	In favor of nonaggressive
Sgolastra and coll. [46]	RR	1.59 (1.10–2.32)	+	In favor of nonaggressive
Monje and coll. [48]	RR	3.97 (1.68–9.37)	+	In favor of nonaggressive

Table 3.16 Published meta-analyses evaluating the risk of development of peri-implantitis

	Effect size	*Periodontal healthy vs. periodontal compromised* Results (95 % CI)	Statistically significant	Clinical meaning
Wen and coll. [44]	RR	1.03 (1.01–1.05)	+	In favor of periodontal healthy patients
Sgolastra and coll. [46]	RR	2.21 (1.42–3.43)	+	In favor of periodontal healthy patients
Monje and coll. [48]	RR	3.97 (1.68–9.37)	+	In favor of periodontal healthy patients

results and, most importantly, gives a clear clinical indication: patients with a history of periodontal disease are candidate to implant treatment (Fig. 3.10) but should be informed of the fact that there is an increased risk of implant loss compared to periodontal healthy individuals. Moreover, aggressive periodontitis ulteriorly increases this risk compared to chronic periodontitis [48].

In conclusion, when implant treatment is proposed to this particular population of patients, it must be taken into account that strict follow-up and maintenance procedures should be adopted and early detection of peri-implant disease must be searched for in order to prevent or slow-down the progression of the disease [50–55] (Flow Chart 3.4).

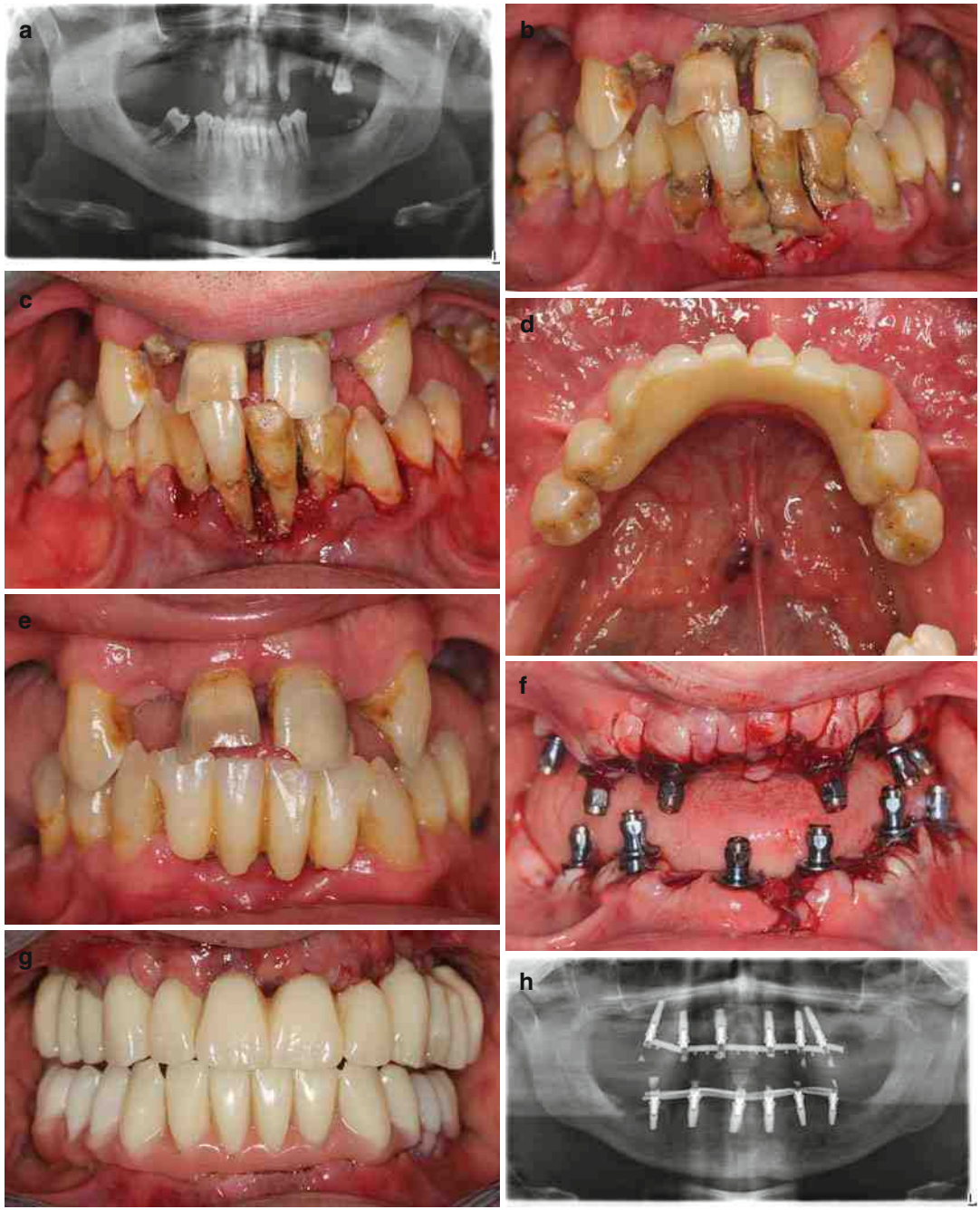
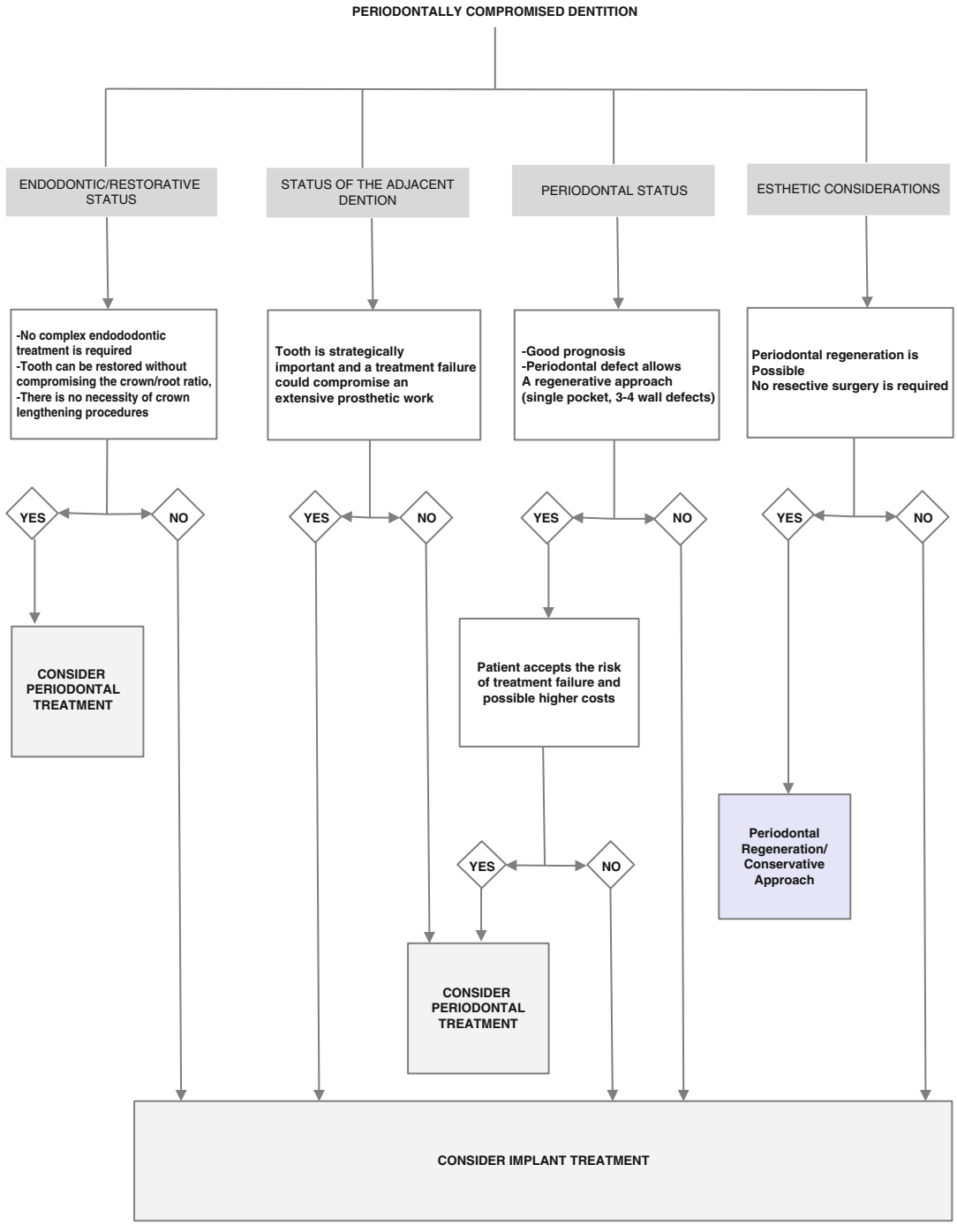


Fig. 3.10 (**a–h**) Patient affected by chronic periodontitis and poor hygiene control (**a–b**) after tartar ablation teeth are considered of having poor prognosis, (**c**) and extraction is performed; initially just anterior teeth are extracted in order to give to the patient provisional restorations while he acquires proper oral hygiene measures, and healing is completed (**d–e**). After 3 months of follow-up, the patient undergoes implant treatment (**f–h**)



Flow Chart 3.4 Periodontally compromised dentition

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Bone Response to Implants

4

Oreste Iocca

Abstract

A successful implant treatment presupposes an effective osseointegration, which is the direct apposition of bone to the implant surface. The implant surface plays a huge role in the bone response leading to osseointegration. For this reason, evaluation of chemical and physical characteristics is considered important in order to choose the best implant and obtain optimal clinical results. Although it is not clear which specific surface confers a true advantage, there is a general consensus that a roughened surface gives better results compared to machined one.

Bone remodeling after extraction may have an influence on the implant treatment planning and clinical results. Finally, optimal osseointegration mechanisms, good primary stability, and high bone-to-implant contact (BIC) should guarantee the best results at long term.

A relatively recent technology, the piezoelectric surgery, which has the best cutting efficiency on mineralized tissue without overheating the bone, may contribute to reduce the bone trauma before implant placement. Also, it can aid in inserting the implants in difficult clinical situations like the contiguity to delicate structures such as the inferior alveolar nerve or the maxillary sinus.

4.1 Bone Response to Implants

Osseointegration is defined histologically by the direct apposition of bone to the implant surface and clinically by the ankylosis of the implant in the bone structure. It is clear that osseointegration is dependent by the interactions of the implant surface with the bone tissue.

Materials and surface topography are crucial in determining the bone response to the insertion of the implant, and many studies are performed in order to improve the interaction of bone to the implant and consequently enhance the success of implant treatment.

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4.1.1 Implant Surface Characteristics

Implant surface plays a fundamental role in the processes of bone response and osseointegration; for this reason, it is important to define the key surface parameters so to understand how surface modifications impact healing time for osseointegration and ultimately success rates of oral implants [1, 2].

The surface characteristics of dental implants can be categorized as *chemical* and *physical*.

4.1.1.1 Chemical Characteristics

Chemical characteristics refer to the core implant material and the surface additions introduced in different ways. Titanium (Ti) is the most widely used material for implant fabrication, but in the last few years, zirconia has emerged as an alternative to titanium implants.

Both pure Ti and alloys are used in manufacturing of dental implants. Commercially pure Ti is available in four grades, their composition varying in the concentration of oxygen and iron. Grade 4 is the most widely employed form of pure Ti for dental implants due to the high elastic modulus and tensile strength. Alloying elements are added in order to increase the mechanical strength. Grade 5 is Ti alloyed with vanadium and aluminum (Ti-6Al-4 V)

Zirconia implants are made of ittrya-partially stabilized zirconia (Y-PSZ) or ittrya-stabilized tetragonal zirconia (Y-TZP); this last one is the most widely used for superior corrosion and wear resistance compared to other dental ceramics.

- The *surface* of the implant can be defined as the 100 nm superficial layer of the implant [3].
- *Impregnation* of the surface means that a chemical adjuvant is integrated with the core material. Degree of impregnation refers to the percentage of the impregnated element on the core material; the so-called high impregnation (i.e., >5 % of added element) can be observed when there is a true chemical modification of the core material and the TiO2 layer such as it happens with the anodized implants (see later). *Coating* instead refers to a superficial apposition on the core material.
- *Coating* with apposition of various materials on the surface of the implant has been adopted by some manufacturers, whereas others are still being investigated as potentially improving the performances of bone-implant interactions. Hydroxyapatite coatings have been the most widely used and studied extensively, but the long-term prognosis is controversial considered that microbial adhesion, osseous breakdown, and coating failure are regarded as common occurrences.

Other materials such as bioactive glasses and TiN coatings are currently investigated and gave good clinical results in vitro and in small in vivo studies. Due to the lacking of large accurate clinical studies, a thorough comparison of the performances of different implant coatings is not considered possible.

4.1.1.2 Physical Characteristics

Solid surfaces, independent of the method of formation, have irregularities and deformations that gave them unique textures.

Micro- and nanoscale features are considered to have a huge impact on the bone-implant interaction. Surface topography refers to the degree of roughness and surface irregularities. In order to describe the surface topography, 2D and 3D parameters must be described separately [4].

The most common *microscopic* parameters used by investigators in performing a quantitative description of the bidimensional evaluation (profile Fig. 4.1 are:

Rz sum of the maximum values of profile peak height and valley depth in a sampling length Fig. 4.2

Ra arithmetical mean of the absolute values of peak heights and valley depths in a sampling length Fig. 4.3

Rsm average interpeak distance along the profile in a sampling length

The most common reported three-dimensional parameters are:

Sa is the 3D equivalent of Ra, expressing the average of absolute values of peak heights and valley depths on a three-dimensional display Fig. 4.4.

Sds density of summits or number of peaks in a given area Fig. 4.5.

Sdr, developed surface area ratio, expresses a measurement of the surface enlargement if a given surface is flattened out. A totally flat surface has Sdr value of 0 %; an Sdr of 100 % means that the roughness of the surface doubles its surface if flattened out.

According to Wennerberg and coll. [5], three-dimensional evaluation is the best way to describe implant surface characteristics because it is more consistent and reliable compared to bidimensional evaluation alone. In particular, Sdr value is a hybrid parameter that must take into account both Sds and Sa values and in this way gives information about the number and height of peaks over a given surface [6].

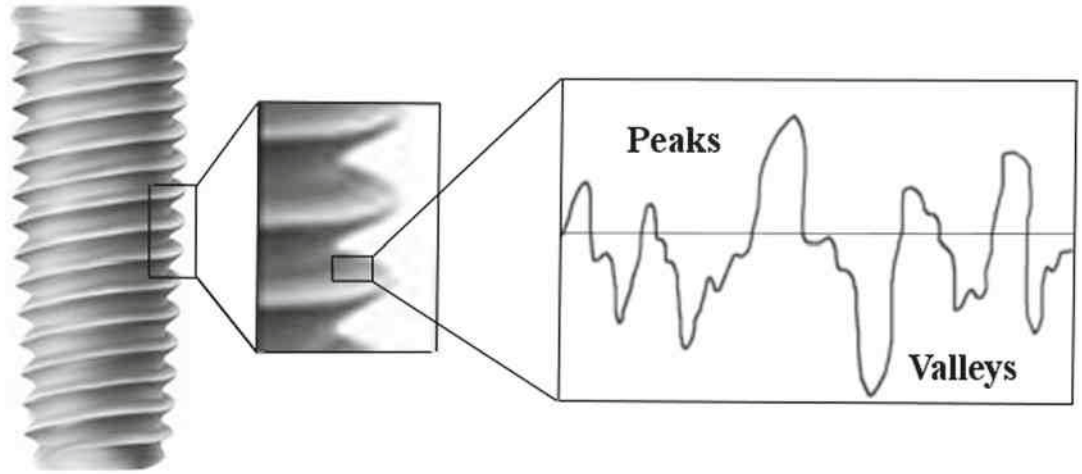

Fig. 4.1 Implant surface

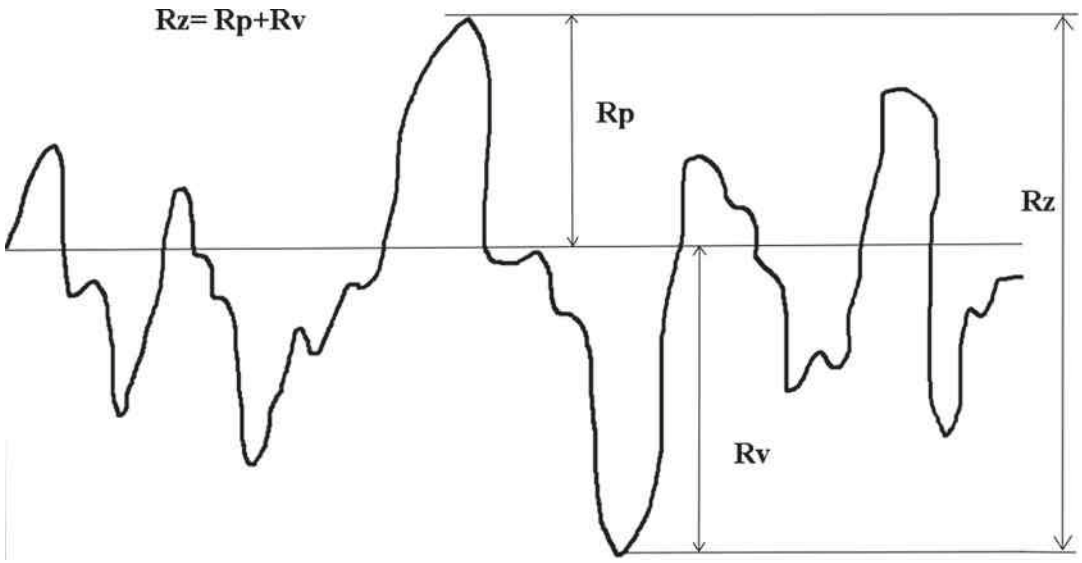

Fig. 4.2 2D schematization of the implant surface and Rz representation

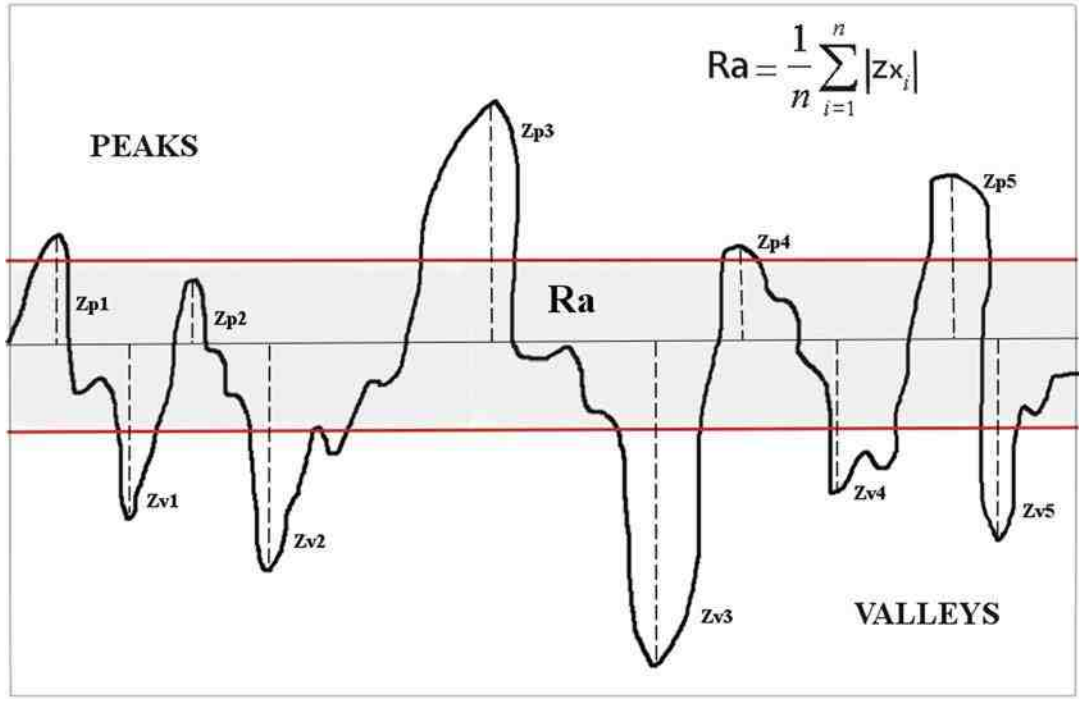

Fig. 4.3 2D schematization of the implant surface and Ra representation

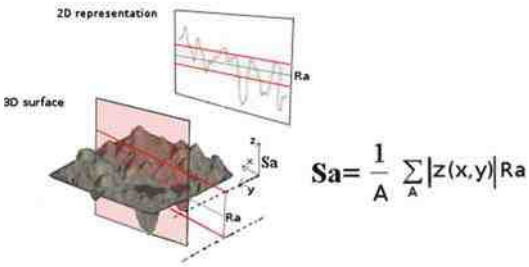

Fig. 4.4 3D schematization of the implant surface and Sa representation

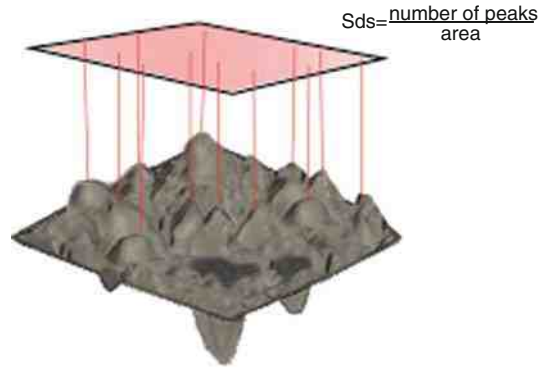

Fig. 4.5 3D representation of the implant surface and Sds representation

At a *nanoscale level*, surface energy is a measure of the extent of unsatisfied bonds at the surface. In other words if the surface is hydrophobic or hydrophilic, two properties that influence the surface wettability. Theoretically, a high surface energy (i.e., high hydrophilia) increases the wettability to blood and in consequence cell attachment, differentiation, and proliferation [7]. One aspect to consider in this regard is that all surfaces show some sort of nanotopography but not all show significant nanostructures (objects of the size between 1 and 100 nm). If nanostructures are not clearly visible or not homogeneous and repetitive, the surface can be considered as nanosmooth [8]. Nanoscale topographies are considered an important aspect and an exciting field of research in the processes of osseointegrations, mainly due to observations coming from in vitro studies. In vivo applicability of the results coming from basic research studies still needs to be cleared [9].

4.1.2 Implant Surface Topography Modifications

For decades, the gold standard implant surface has been the Branemark implant which is often described in the dental literature as synonymous with "machined" implant, without actually specifying the turning process applied in manufacturing. Indeed, no machining method, however precise, can produce a totally flat surface. It follows that a machined surface, according to the different machining methods adopted, can have very different topographies. Therefore, in many studies comparing machined surfaces with various rough surfaces, it is unclear which kind of surface is actually analyzed. With that premised, it is possible to distinguish the various surfaces in this way [5] (Fig. 4.6):

- *Machined surfaces*, Sa values <0.5 μm
- *Minimally rough surfaces*, Sa 0.5–1 μm
- *Rough surfaces*, Sa of >2 μm

It seems clear that the process of osseointegration occurs independently of certain surface characteristics, considering that osseointegration occurs with a great number of different surfaces. Surface modifications, in particular roughening methods, have found to be important in improving the bone-implant response with the aim of reducing healing time for loading and also to allow a stronger anchorage of the implant to the bone in those situations where bone quality is considered poor (type IV bone type).

- *Roughening of implants by acid-etching*

Acid-etching with strong acids such as HCl, HF, etc. is able to produce microscopic pits on the implant surface with sizes in the range of 0.5–2 μm in diameter [36]. Acid-etching has been found to improve notably osseointegration in experimental animal studies when compared to machined surfaces, but no major clinical differences in terms of survival rates are reported when comparing etched surfaces with machined implants in vivo.

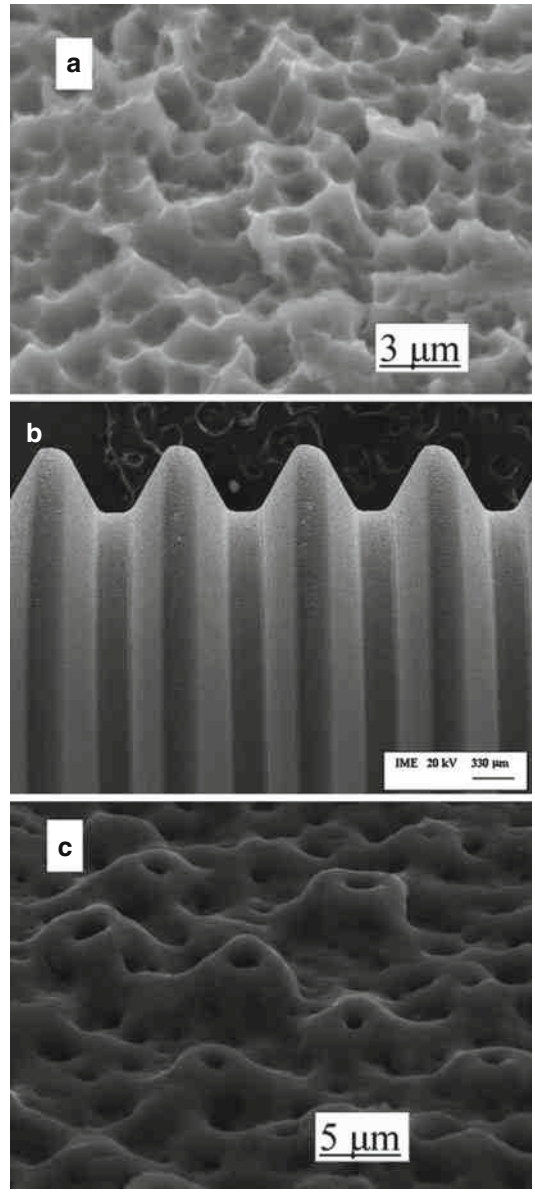

Fig. 4.6 (**a–c**) SEM picture of machined (**a**), minimally rough (**b**), rough surface (**c**) (Reproduced with permission from Elias and col.)

- *Roughening of implants by titanium plasma spray*

TPS involves the injection of titanium powder into a plasma torch at very high temperature, the Ti particles sprayed over the implant surface form a film about 30 μm thick.

With this method, it is possible to achieve very rough surfaces with an average Ra of 7 μm. Analysis of the literature shows that this kind of roughness is clinical disadvantageous in terms of survival rates when compared with smooth and minimally rough surfaces.

- *Roughening of implants by grit blasting*

Grit blasting consists in roughening of the surface via blasting with hard ceramic particles nozzled at high velocity by a means of compressed air. Different ceramic materials are adopted for this scope. Alumina is frequently used but also titanium oxide and calcium phosphate can be employed.

Optimal surface roughness can be achieved with this method, and a recent review [5] reported average Ra values ranging from 0.6 to 2.1 μm.

Blasted implants show a better osseointegration when compared with machined surfaces, but this does not reflect as a clinical advantage in terms of success/failure rates.

- *Roughening of implants by anodization*

Porous surfaces are obtained in galvanostatic chambers placing titanium implants in strong acids at high potential (100 V). This electrochemical processing produces a thickening of the oxide layer on the implant surface to more than 1000 nm, this oxide layer is then dissolved by the strong acid in the solution along the current convection lines, and this creates microscopic pores on the surface.

Anodized surfaces have been found to increase the bone response, most likely through increased mechanical interlocking and also creation of biochemical bonding. From review of the literature, anodized surfaces have been found to give a clinical advantage compared to machined ones when implants need to be placed and loaded immediately.

- *Roughening of implants by blasting + etching*

This is a combination of blasting and etching techniques. In this way it is possible to obtain an optimal roughness with the blasting procedures and, at the same time, a smoothening of the irregular peaks with the additional etching. A stronger osseointegration is found when compared to machined implants, but no clinical studies are available to clearly show a superiority of this surface to others.

- *Ceramic surfaces*

Implants coated with hydroxyapatite (HA) were introduced on the market around three decades ago. The first generation of this kind of implants showed initial success, but later they showed high failure rates essentially because the initial osseointegration was then followed by delamination of the whole surface from the underlying titanium. For this reason their use was abandoned.

Modern coatings of HA instead are 1 μm or less in thickness due to the fact that HA particles are plasma sprayed on the surface of the implant. The risk of developing the complications of the first-generation HA-coated implants should be lower, but more clinical studies with long-term follow-up are needed in order to definitely recommend them for clinical use.

In summary, it has been shown that bone response to implant insertion is influenced by the surface topography. Many studies lack a characterization of the topography, and even machined surfaces can vary considerably in their topographical characteristics according to the turning techniques adopted by the manufacturer. In light of this, it is difficult to compare studies in an attempt to define which is the ideal surface. On the other hand, there is a general evidence on the basis of animal and clinical studies that roughening of the implant surface leads to a stronger bone response [10]. Moderately rough surfaces with *Sa values* between 1 μm and 2 μm and *Sdr* of 50 % are considered to be optimal even if the biological reasons of this are still unclear. The advantage of rough surfaces when compared to machined ones is to be found especially in those situations in which stronger bone response is needed, for example, in case of poor bone quality or to

speed up the healing time when immediate or early loading protocols are adopted.

4.1.3 State of the Available Evidence About the Current Most Common Implant Surfaces

Considering that implant success rates reported in the majority of the available studies exceed 90%, it is important to evaluate which surface modification gives better results in terms of more rapid osseointegration and reliability in more challenging cases such as low bone quality or elderly patients with expected poor healing, metabolic impairment, osteoporosis, etc.

It is evident that currently available methods of processing dental implant surfaces have the potential to improve some of the abovementioned conditions, given the good results in animal and some clinical studies. On the other hand, attempts made to provide a statistical synthesis of the available evidence on the topic were not considered feasible after a systematic review of the literature, mainly because surface characterization in most of the available studies is improperly performed or not reported at all.

There is a lack of studies investigating the influence of implant surface characteristics on the incidence of peri-implantitis. Animal studies and observational studies on humans [11] found no differences from a clinical and histological point of view between rough and machined surfaces at various follow-up periods (few weeks up to 5 years). It is assumed that rough surfaces are more difficult to clean than a machined one; this can contribute to the self-propagation of an established peri-implant disease, but some experimental studies on dogs have shown that, after cleaning, rough surfaces displayed a higher rate of re-osseointegration compared to machined surfaces [12].

What needs to be addressed is that still additional clinical studies with proper specification of the implant surfaces adopted are needed in order to provide strong indications over the use of a surface over another in a given clinical situation. Moreover, comparative clinical studies with different implant surfaces are rarely performed, and it makes even more difficult to arrive at an objective conclusion (Table 4.1).

4.1.4 Zirconia Dental Implants

Titanium dental implants with either smooth or rough surfaces show high success and survival rates and have been used with confidence for the past few decades. Restorations supported by titanium implants might be compromised by the dark color that can become exposed, especially in the thin gingival biotype. For this reasons, due to the increased demand for esthetics, zirconia dental implants have emerged as an alternative to titanium [13]. Ittrya-stabilized tetragonal zirconia (Y-TZP) possesses some properties that render it suitable for implant manufacturing, especially its high flexural strength and fracture toughness. In vitro and animal studies show promising results in term of osseointegration, soft tissue response, and bacterial colonization. In the same way as titanium, surface roughening seems to improve the bone response in terms of enhanced of osseointegration.

Regarding long-term stability, a phenomenon known as *aging* of the material has emerged as a problem for zirconia implants used in orthopedics. This process refers to a progressive transformation of the metastable tetragonal phase into the monoclinic phase, which is detrimental for the mechanical resistance of the material. Further long-term studies should be performed in order to test if aging might become an issue for dental implant use as well [14] (Fig. 4.7).

Currently, no scientific clinical data allows to recommend the use of this type of implants, and it is a reason of concern that, albeit potentially successful both biologically and mechanically, zirconia implants are available on the market without long-term clinical investigations supporting their safety and predictability on patients [15].

In conclusion, the use of zirconia implants is not recommended based on the available infor-

Table 4.1 Most diffuse implant surfaces with reported values of Sa and Sdr as measured by Wennerberg and Albrektsson [5]

	Biomet 3i *Prevail*	Biomet 3i *NanoTite*	Biomet 3i *Osseotite*	Branemark	Astra Tech *TiOblast*	Nobel Biocare *TiUnite*	Astra Tech *OsseoSpeed*	Straumann *SLActive*	Straumann *SLA*
Surface characteristics and processing methods	Turned collar, acid-etched body. Grade 5 titanium, which is harder and smoother	CaP modifications created discrete crystalline deposition	Turned collar, acid-etched implant body	Turned	Blasted with titanium dioxide particles	Anodized	Blasted with titanium dioxide particles followed by chemical modifications by hydrofluoric acid	Acid-etched and grit blasted then rinsed under nitrogen protection and stored in NaCl solution. Hydrophilic	Acid-etched and grit blasted. Hydrophobic
Sa	0.3 µm	0.5 µm	0.68 µm	0.9	1.1 µm	1.1 µm	1.4 µm	1.75 µm	1.78 µm
Sdr	24.00 %	40.00 %	27.00 %	34.00 %	31.00 %	37.00 %	37.00 %	143.00 %	97.00 %

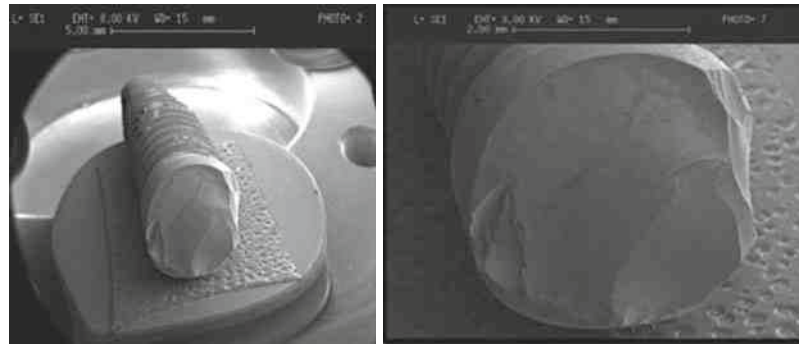

Fig. 4.7 (**a, b**) Fractured zirconia implant at electron microscopic evaluation, cracks are evident (**b**) (Reproduced with permission from Osman and col.)

mation, and much more research efforts are needed before considering them as a viable alternative to titanium implants.

4.2 Bone Remodeling After Dental Extraction and Tissue Healing Around Dental Implants

Socket healing after tooth extraction gained considerable consideration in the dental research community due to the fact that the changes that occur after tooth extraction have important repercussions on implant insertion, success rates, and esthetic results.

The alveolar process is defined as the bone surrounding the tooth. The inner portion of the alveolar socket is composed by *bundle bone* (*alveolar bone proper*) where there is the insertion of the Sharpey's fibers of the periodontal ligament. This portion of the socket is a tooth-dependent tissue distinguished from the alveolar bone which, contrarily to what happens for the *bundle bone*, persists even after tooth extraction.

Dimensional changes occur after tooth extraction and they have been studied both in animal and human studies. It is now clear that there is always some sort of alveolar ridge reduction following tooth loss, both in vertical and horizontal dimensions [16, 70] (Fig. 4.8). Two recent reviews analyzed bone dimensional changes of post-extraction sockets in humans [17, 18] (Table 4.2). Both are concordant on the fact that, on average, the bone loss in width is greater than the loss in height and that there is a more substantial buccal bone resorption compared to the lingual aspect. This is consistent with the fact that the majority of the buccal plate is composed by bundle bone and in consequence rapidly resorbed following tooth extraction. Most of the dimensional change occurs primarily in the first 3 months. In quantitative terms it can be expected that around 50 % reduction of the ridge will occur following extraction, the molar regions suffering the greatest rate of resorption. Absolute values reported in the reviews based on clinical studies fall in the range of 3.0–4.0 mm on the horizontal dimension and 1.0–1.5 mm on the vertical dimension. There is a general concordance in this value regardless of the measurement methods adopted (surgical reentry or radiographical evaluation).

Caneva and col. [19] experimentally placed immediate implants in fresh extraction sockets of six dogs; the conclusion was that implants should be positioned at least 1 mm below the alveolar crest and lingually positioned in relation to the center of the crest (Fig. 4.9). Tomasi and col. evaluated in a human study the position of the implant and its relation to buccal crest resorption. The results showed that the buccolingual position of the implant has an influence on the amount of buccal crest resorption.

One meta-analysis specifically addressed the issue of bone modeling after immediate implant insertion in a clinical setting; in this study, the usual pattern of more pronounced resorption on the horizontal aspect opposed to the vertical one was confirmed but considered to be more modest when compared to post-extraction sites without implant placement [20].

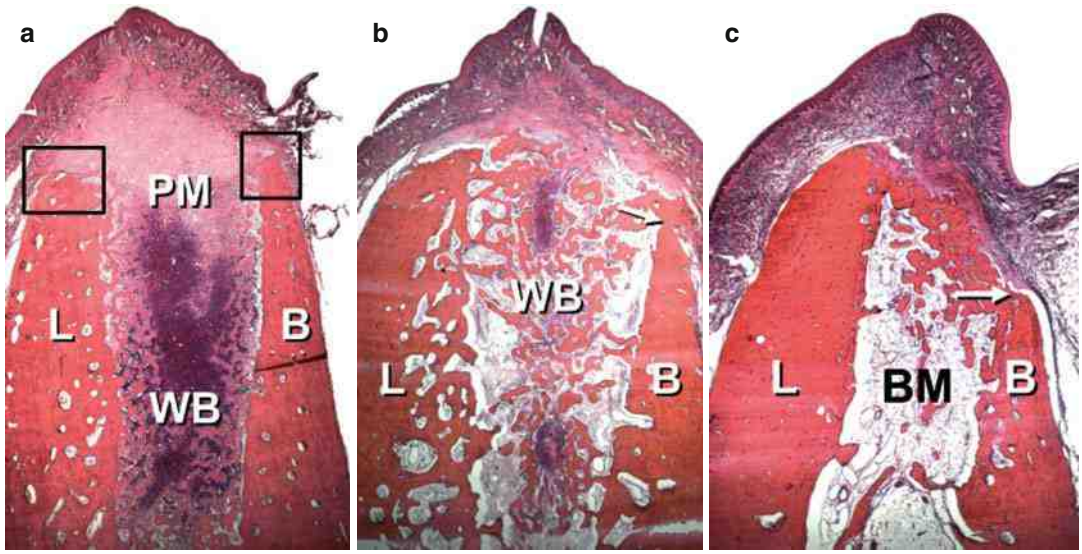

Fig. 4.8 (**a–c**) Alveolar ridge alterations after extraction, histologic examination (HE 16× magnification) in beagle dogs at 1 week (**a**), 2 weeks (**b**), and 8 weeks after extraction (**c**). *L* lingual, *B* buccal, *C* blood clot, *PM* provisional matrix, *WB* woven bone, *BM* bone marrow (Reproduced with permission from Araujo and col.)

Table 4.2 Systematic reviews evaluating the bone dimensional changes of post-extraction sockets in humans

	Studies included in the review	Alveolar width change in mm (95 % CI)	Alveolar height change in mm (95 % CI)
Van der Weijden and col.	RCT, clinical trials, case series	3.87 (3.7–4.06)	1.67 (1.4–1.9)
Tan and col.	RCT, clinical trials, cohort studies	3.79 (2.46–4.56)	1.24 (0.8–1.5)

Knowledge of bone resorption patterns is important for the implantologist because of their repercussions on clinical decision-making. For example, placement of an implant immediately after extraction has to take into account the bone resorption that will inevitably occur. A space of at least 2 mm should be left between the implant and the buccal bone surface; otherwise the resorption that will occur in the following months would be the cause of exposure of some of the implant surface [21].

Moreover, bone resorption in the esthetic areas may lead to loss of the physiologic bone contour which may render necessary a soft and hard tissue graft at the moment of implant placement or at the moment of implant uncovering.

Finally, the current evidence does not seem to show that immediate implant placement by itself is able to preserve the bone resorption after extraction. Weak evidence exists that immediate placement may slightly reduce the amount of resorption, but more studies are needed to confirm these results [22].

4.2.1 Alveolar Ridge Preservation Prior to Implant Placement

Alveolar ridge preservation techniques involve the insertion of a grafting material into the extraction socket in order to minimize as much as possible the alveolar process reduction in width and height. Different biomaterials have been used to obtain this scope with different degrees of success [23]. Materials available include:

Autografts – bone harvested from the same patient

Allograft – bone grafted from the same species (cadaver bone)

Xenografts – bone harvested from other species, for example, bovine bone
Alloplast – synthetic material

A problem in analyzing the effect of alveolar ridge preservation techniques is that the majority of the studies on this topic are case reports, case series, or inadequately performed clinical trials.

As a consequence of this methodological and clinical heterogeneity, many systematic reviews performed are not able to provide relevant outcomes such as linear or volumetric changes. The available meta-analyses on RCTs and non randomized trials provided quantitative results which are described in Tables 4.3, 4.4, and 4.5 [24–26].

Both works found that alveolar ridge preservation techniques limit the physiologic ridge reduction when compared to unassisted healing and also point out that the effects of ARP are very variable, most likely for the influence of local and systemic factors.

Anyway, one aspect on which all the systematic reviews are concordant is that ridge preservation procedures limit, although cannot stop completely, the buccolingual width and buccal wall height reduction when compared to unassisted socket healing. It is still unclear what bio-

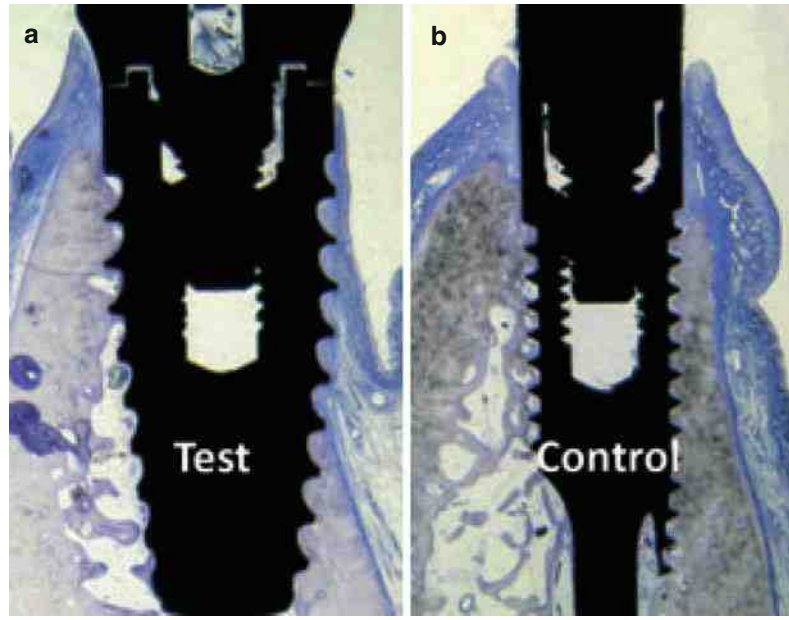

Fig. 4.9 (**a, b**) Experimental study on dogs using implants of different diameter; it is evident that using a larger-diameter (**a**) implant does not prevent the buccal bone resorption but instead leads to implant exposure. The smaller diameter implant instead is in contact with bone both lingually and buccally. Toluidine blue (16× magnification) (Reproduced with permission from Caneva and col.)

Table 4.3 Meta-analysis by Vittorini Orgeas and col.

	Effect Size	Bone *width* changes in mm after grafting (95 % CI)	Bone *width* changes in mm after use of a barrier alone (95 % CI)	Bone *width* changes in mm after use of a barrier and grafting (95 % CI)	Bone *height* changes in mm after use of a grafting (95 % CI)	Bone *height* changes in mm after use of a barrier alone (95 % CI)	Bone *height* changes in mm after use of a barrier and grafting (95 % CI)	Clinical meaning
Vittorini Orgeas and col. [24]	Weighted mean difference	1.3 (0.01–2.66)	2.99 (2.3–3.5)	1.99 (0.086–2.4)	0.78 (−0.95–2.5)	0.9 (0.4–1.3)	0.9 (−1.1–3.1)	In favor of socket grafting

Evaluating width and height changes in socket grafting versus unassisted healing after 6 months

Table 4.4 Meta-analysis of Avila-Ortiz and col.

	Effect Size	Buccolingual measurement (95 % CI)	Midbuccal measurement	Midlingual measurement	Medial measurement	Distal measurement	Clinical meaning
Avila-Ortiz and col. [25]	Mean difference in mm	1.89 (1.41–2.36) *p-Value <0.001*	2.07 (1.03–3.12) *p-Value <0.001*	1.18 (0.17–2.19) *p-Value 0.22*	0.48 (0.18–0.79) *p-Value 0.002*	0.24 (–0.05–0.53) *p-Value 0.102*	In favor of socket grafting

Evaluating width and height changes *in socket grafting* versus *unassisted healing after 6 months*

Table 4.5 Meta-analysis by Willenbacher and col.

	Effect size	Buccolingual measurement (95 % CI)	Apico-coronal measurement (95 % CI)	Clinical meaning
Willenbacher and col. [26]	Mean difference in mm	1.54 (0.44–2.64) *p-Value not reported*	1.12 (0.62–1.63) *p-Value not reported*	In favor of socket grafting

Evaluating width and height changes *in socket grafting* versus *unassisted healing after 6 months*

material gives a clear advantage over another. Also, it is not well defined which one of the available techniques allow to obtain the best results. Regarding the results on flap vs. flapless extraction of teeth, conflicting results emerge from the reviews; some studies strongly recommend to avoid flap surgery, but others suggest that the surgical technique does not have an influence on the alveolar resorption outcomes [27].

The use of barrier membranes seems to show no clear advantage compared to use of no barrier at all.

A Cochrane review on the argument [23] confirms this assumption and adds that there is no evidence to conclude that the socket preservation techniques have any impact to the look or lasting qualities of implant restorations.

As mentioned before, the main reason for these unclear results reside in the fact that the majority of the studies included in the systematic reviews are at high risk of bias like unclear randomization process, blinding of patient/examiner, and unclear selection of representative population group. Also, the high heterogeneity between the studies is another factor to consider [28].

In summary, the rationale behind alveolar ridge preservation techniques is that extraction of a tooth will inevitably lead to a reduction in alveolar process height and width. Therefore, trying to minimize this process is desirable both from surgical and prosthetic reasons, especially in esthetic areas. Decision of grafting a post-extraction socket should be evaluated carefully because, even if it is a simple technique with low risk of complications, it adds a cost to the patient [29–31].

There is evidence that shrinking of the alveolar process can be minimized by some extent but, mainly due to the high variability in results between comparable clinical studies, net conclusions on materials and techniques to adopt are still unclear and further research is needed in order to draw stronger conclusions on the argument.

4.3 Bone Integration of Dental Implants

Osseointegration is defined as the direct bone-to-implant contact without apposition of fibrous tissue. Temporal sequence of events that lead to osseointegration include coagulum formation, granulation tissue, formation of a provisional matrix, woven bone development, and finally lamellar bone organization (Fig. 4.10). Abrahamsson and col. described a dog model in which two types of screw-type implants with different surfaces, one sand blasted/acid-etched and the other machined, were studied histologically at different time points. The results of the study constitute an excellent model of osseointegration [33]. These were the histological observations for the rough implant surface:

- In the first few hours following implant installation, blood clot is in contact with the implant surfaces, so that erythrocytes, neutrophils, and macrophages are trapped in a network of fibrin. In 3–4 days, the clot is replaced by granulation tissue composed by mesenchymal cells; disorganized connective tissue matrix and the first vessel sprouts are evident.
- In 1 week most of the inflammatory cells are resorbed and immature *woven* bone can be evidenced together with newly formed vessels. After 2 weeks woven bone formation is more pronounced and surrounds the whole implant mixed with old bone which is a clear sign of osteogenesis. Osteoclast formation is evidenced and contributes to bone remodeling.
- Four weeks after implant insertion, newly formed mineralized bone extends from the prepared bone surface to the implant coating. Primary bone marrow can be seen rich in vascular structures and mesenchymal cells.
- In 6–12 weeks, bone enters the remodeling phase, more mature bone with the presence of primary and secondary osteons is evident. Both lamellar and parallel fiber bone deposition are represented. Mature bone and bone marrow will remain in contact with the device surface at the end of the 12th week.

In general, the same sequence of events could be described for the polished surface but some major differences need to be outlined. First, roughened implants showed higher bone-to-implant contact (BIC) compared with polished ones, and this was constant at different time

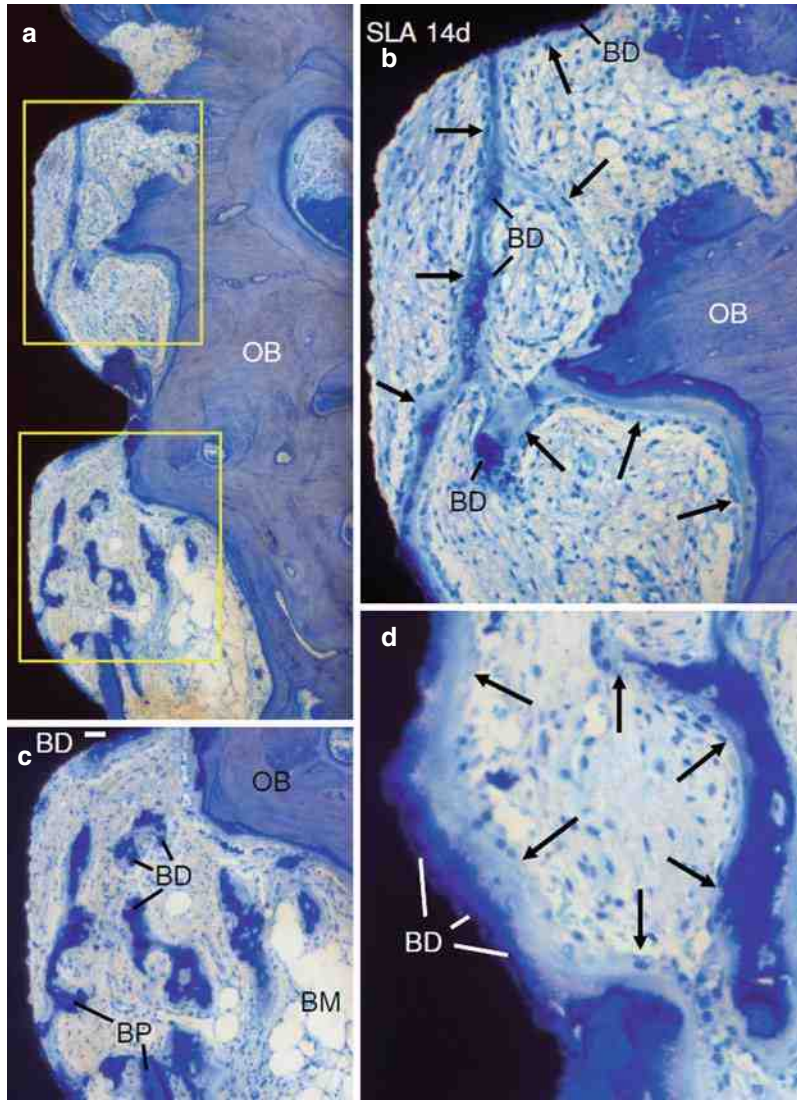

Fig. 4.10 Light micrographs illustrating the implant-tissue interface and the peri-implant tissues of an SLA implant after 14 days of healing. The upper and lower rectangles in (**a**) are enlarged in (**b**) and (**c**), respectively. (**a**) The old bone (*OB*) is in point contact with the pitches of the thread, whereas the interthread portion is filled with a provisional soft tissue matrix and newly formed bone. (**b**) The newly formed bone (*arrows*) forms a trabecular network connecting the surface of the old bone with that of the implant. Note that the trabecular network follows the paths where bone debris (*BD*) is present in the matrix of the provisional soft tissue and on the implant surface. (**c**) Initial bone apposition on the implant and initial bone formation in the soft tissue is associated with bone debris and bone particles. Note the presence of bone marrow (*BM*) close to the old bone. (**d**) A higher magnification illustrates initial bone formation (*arrows*) in the provisional soft tissue matrix and on the implant surface. Note the presence of bone debris on the implant surface, which are more intensely stained than the mineralized matrix of the newly formed bone. The adjacent osteoid is weekly stained (Reproduced with permission from Bosshardt and col.)

points. Second, bone formation on roughened surfaces was characterized by the so-called *contact osteogenesis*, in other words a direct contact between the roughened surface and the newly formed bone. On the other hand, on the polished surfaces only *distant osteogenesis* occurred, with

newly formed bone extending from the old bone toward the implant surface.

It is important to recall that a dog model, although giving very important clues on how bone healing around dental implant occurs, could not reflect the exact temporal sequence of events that occur in humans. Actually, it is known that healing processes in dogs occur at a faster rate compared to humans.

Interesting insights in the process of osseointegration may come from studies using in vivo gene expression profiles on rats. Donos and col. [34] evaluated the gene expression profile of bone on micro-rough surface (SLA) versus machined surface implants inserted in rat's calvaria defects at 7 and 14 days. While after 1 week, the differences in gene expression were minimal between the two groups, after 14 days a large number of genes have been shown to be expressed at different rates in the SLA group compared to the machined one. In particular, regeneration-associated genes like Notch-1 were upregulated in the SLA group. The same was true for mesenchymal cell differentiation genes typically expressed during craniofacial development like Fgfr-1, Fgfr-2, and Sox9. Angiogenesis genes and skeletal development genes were overexpressed as well.

Anyway, the major pathway that was differentially upregulated in the SLA group was the Wnt, which is thought to be a major regulator of regenerative response to different Ti surfaces.

The results of this study corroborate the hypothesis that bone response to implant surfaces is differentially regulated according to the surface characteristics, especially after 2 weeks the genes associated with bone healing and regeneration are preferentially expressed on micro-rough surfaces [35–38].

4.3.1 Implant Stability

Adequate stability of the implant is considered to be crucial for appropriate healing and osseointegration [39]. It is possible to define a *primary stability* which occurs at the time of implant placement and a *secondary stability* which instead occurs after bone regeneration and remodeling at the implant surface have taken place (see above).

One of the main objectives at the moment of implant placement is to obtain high values of primary stability, as measured immediately after insertion, which allows the implant to mechanically lock to the host bone until secondary stability is achieved.

Micromotion consists of relative movement between the implant surface and the adjacent bone during functional loading. *Primary stability* affects the resistance to micromotion and has been shown to ensure proper bone healing and osseointegration [40].

There is no consensus regarding minimum or maximum recommended values of primary stability. Clinical studies report that the stability should be such to avoid implant mobility at clinical evaluation immediately after the insertion.

Methods for objectively assessing the stability of the implant are the *periotest* (PT) and the *resonance frequency analysis* (RFA). PT gauges temporal contact of the tip of the device during repetitive percussions on the implant. PT values (range varies from 8 to 50) are the signals produced by the tapping that reflect the values of mobility of the implant.

RFA applies the basic vibration theory in which there is a transducer applied to the top of the implant which is then excited over a range of frequencies. The resultant resonance frequency values are dependent on the stiffness of the structure, so that a decrease in frequency is related to a decrease in stability.

Even if RFA techniques have been found to be more accurate in depicting the primary stability values, there are no clinical studies today that allow to state that the use of this instrumentation leads to higher success rates.

A more diffuse and practical way to assess primary stability is the measurement of insertion torque values (ITV) during implant placement and seating which can be evaluated with implant motors that allow to set the torque values in N/cm and finally the use of a manual wrench with torque control. It has been shown that ITV reflects bone quality and quantity, primary mechanical stability, and the bone-implant contact [41].

Torque values of >32 N/cm have been considered as minimal values in order to achieve high success rates in case of immediate loading [42].

Factors influencing primary stability are bone quality, implant design, and placement technique.

Bone quality is commonly evaluated using the criteria established by Lekholm and Zarb [43]. In this classification, bone quality is subdivided in four types, from type I which is the denser to type IV which is the softest.

This classification although very practical may suffer of some amount of subjectivity, and it is not clearly defined the way on how to measure the bone density. It is common for the clinician to determine it with the tactile perception at the moment of implant bed preparation. Nowadays, with the widespread use of cone beam computed tomography, it is now easier to perform a morphological and quantitative analysis of the bone estimating the bone mineral density in Hounsfield units (HU).

In the review by Marquezan and col. [44], a positive correlation has been found between high HU measured in preoperative CBCT and primary stability of dental implants, correlation coefficients ranged from 0.46 to 0.88, in other terms the association was considered to be moderate to high. Higher HU values correlated strongly with high insertion torques values.

Elias and col. [4] evaluated primary stability of dental implants experimentally on synthetic bone or natural bone (swine rib). Implants of different design and surface characteristics were evaluated for insertional and removal torques. The results showed that primary stability of dental implants is determined by the bone properties. Using the same surgical technique and implant design, when the implant was placed in a denser substrate, the insertional and removal torque values increased; in clinical terms, this means that as bone density increases, the primary stability increases proportionally.

Regarding the implant design, *larger diameter and longer implants* are associated with higher insertional and removal torque values; this suggests that, when it is feasible and especially in low bone qualities, larger and longer implants warrant a high primary stability. Also, tapered implants showed higher insertion torque when compared to conical shaped implants [45].

Surgical drilling technique seems to be more important than implant design, in the sense that decreasing the diameter of the last drill it is possible to increase the primary stability. An undersized preparation site of insertion increases the primary stability, and this is more evident in the case of low bone density.

Regarding the *implant surface*, anodized surfaces showed the best results in terms of primary implant stability when compared to acid-etched and machined implants [46].

4.3.2 Type IV Bone and Longevity of Dental Implants

It is assumed that implants inserted in type IV (soft bone) bone have reduced survival rates, given that such bone type confer reduced primary stability.

Goiato and col. [47] investigated if longevity of dental implants inserted in type IV bone is reduced compared to implants inserted in better quality bone. In their review including RCTs, retrospective and prospective studies, it was found that the cumulative survival rate of implants inserted in type IV bone was 88.8 %, which was lower compared to the survival rate of other bone types (97.7 %, 96.2 %, 96.4 %, respectively, for type I, II, and III). Although suggestive, these results suffer from the fact that just a small number of implant were inserted in type IV bone; moreover most studies did not clearly reported the jaw regions in which they were inserted. Lastly, results were not analyzed in subgroups regarding the type of prosthesis used, and this information should be of particular importance because it is likely that full mouth rehabilitation with implants splinted together could have less micro-movements and consequently improved rate of osseointegration compared to single implants. Nevertheless, analysis of the literature confirms the assumption that implant treatment in regions of poor bone quality may imply reduced implant survival rates compared to the other bone types.

4.3.3 Bone-Implant Contact

Bone-to-implant contact (BIC) is defined as the percentage of bone found in direct contact over the implant surface (Fig. 4.11); this parameter is considered to be important in defining the degree of osseointegration and may play a role in both short- and long-term treatment outcomes.

A meta-analysis evaluating BIC of dental implants in humans has been performed recently. Anatomic site, implant brand, loading state, and healing period were considered separately [48]. The authors concluded that BIC of implants in the mandible (68.8–73.8 95 % CI) is 25 % higher than those located in the maxilla (49.8–56.6 95 % CI); moreover the anterior mandible shows 10 % higher BIC than the posterior mandible. The lowest values of BIC were found in the posterior maxilla. This is consistent with the fact that BIC is dependent on bone density at the moment of implant placement, and in fact the anterior mandible has the densest bone, followed by posterior mandible, anterior maxilla, and finally posterior maxilla.

Another interesting result was that BIC values looks to be more dependent upon anatomic site than surface chemistry or topography. In essence, better performing surfaces (read previous chapters) are important especially in low-quality bone areas which will show inevitably lesser degree of osseointegration.

The loading state of the implant has important effects on BIC values. Conventionally loaded implants (i.e., at least 3 months after insertion) show higher BIC than immediately loaded implants, but this does not seem to impair long-term success rates.

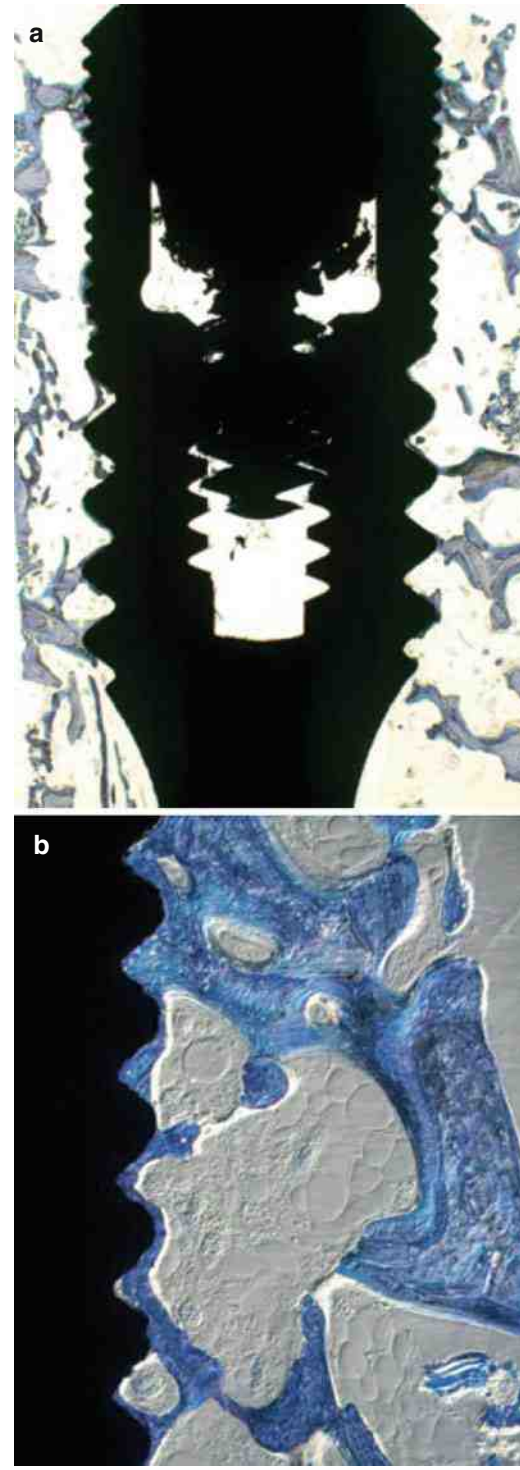

Fig. 4.11 Bone healing at 3 months after placement showing high bone-implant contact. Toluidine blue 16× magnification (**a**), 50× magnification (**b**) (Reproduced with permission from Donati and col.)

4.4 Implant Overload

Bone is a dynamic tissue able to respond to the external forces with the adaptation process of remodeling itself. Mechanical loads provoke a stress and a consequent *strain* on the tissues. *Strain* is defined as the deformation that follows a stress application, defined by the letter ε. 1000 με corresponds to a 0.1 % deformation.

Frost defined four levels of mechanical strain on long bones but these categories can be extended to the mandible and maxilla [49]. The four microstrain zones are *disuse (<200* με), *steady state (200–2500* με), *physiological overload (2500–3500* με), and *pathological loading (>3500* με). It is important to remark that this classification applies to static loads; therefore for the mandible and maxilla, this is a very wide generalization considered that the forces exerted on these bones are usually cyclic. Moreover, the definition of "overload" in dentistry is not clear, and anyway models simulating the amount of load on a prosthesis do not take into account the stress produced at the bone-implant surface, because it cannot be measured directly in vivo. Finite element analysis can simulate it, but it is based on too many assumptions regarding the human bone physical properties. Today the stress produced at the bone-implant interface in the different loading situations remains unknown.

Overloading of dental implants is considered to cause loss of osseointegration, but evidence that confirms this claim is still lacking. Chang and col. [50] reviewed both animal and clinical studies on this argument. Lack of RCTs is obvious, given that they would be considered unethical, but other sources of evidence are sparse as well.

All the available experiments on animal, in particular on monkeys and dogs, showed no significant implant loss when static or dynamic overload was applied. Instead, regarding the BIC evaluation, a static load on dental implants seemed to increase the remodeling activity of peri-implant bone [51].

Clinical observations coming from case reports and cohort studies gave no strong evidence that excessive load was the cause of reported implant failure, mainly because the definition of overloading itself was considered to be totally subjective and changing in the different studies [52].

Marginal bone loss has been reported in retrospective studies as a result of overload, but it was not clear if this showed that it was caused by an actual excessive load or other causes, like poor oral hygiene, played a role.

The review of Naert and col.[53] concluded that it seems that overload coming from experimental supra-occlusal contacts did not seem to have an impact on osseointegration when good oral hygiene was maintained. On the other hand, the same kind of overload seemed to increase the peri-implant bone resorption caused by plaque-induced inflammation.

At the current state, it is impossible to state with certainty which is the role of excessive load on peri-implant bone. Animal studies seem to indicate that overload should not be a common cause of loss of osseointegration, but at the same time, it can contribute to speed up the plaque-induced bone resorption.

Given the uncertainty of the biological and clinical effects of cyclic and static overload on the peri-implant bone, general recommendations of avoiding precontacts and careful treatment planning in parafunctional patients remain anyway valid.

4.5 Immediate Placement of Implants in Infected Sites

It is a common occurrence that a tooth that needs to be extracted exhibits a periapical or periodontal pathology.

Worries exist that implant survival could be impacted by the presence of residual bacteria in sites of chronic inflammation and infection. It has been shown that even after careful debridement of the infected tissue and irrigation of the socket, pathogenic bacteria may still persist in healed bone [54]. Retrograde peri-implantitis may therefore develop, although its occurrence is just sparsely reported in the literature.

Animal studies conducted in dogs attempted to evaluate the osseointegration and BIC values of implants placed in experimentally created periapical lesions. Novaes and col. [55] in a study on dogs created large periapical lesions exposing the canal space to the oral cavity for 9 months; BIC values measured around immediately placed implants were not different compared to the healthy ones.

The same was true in another study on experimentally created chronic periodontal lesions on dogs in which immediate implants were placed and then analyzed after 3 months of healing [56].

A systematic review on this topic showed that survival rates of implants placed in endodontically or periodontally affected sites were similar to implants placed in healthy sites [57]. In fact, analysis of prospective and retrospective studies showed that, once primary stability is achieved, immediate implants in infected sites did not lead to an increased rate of complications or failures. Suggested protocols to treat the infected tissue before implant placement included deep debridement, systemic or topic antibiotic administration, and GBR with or without grafting. Also chlorhexidine rinse was suggested in the postoperative period in order to reduce the frequency of infective complications [58].

The limited short-term data available from both animal and human studies suggest that high survival rates and normal marginal bone changes can be obtained with implant placement in infected sites given that appropriate clinical procedures are adopted before placement. No comparisons are available in regard of the best way to clean and debride the infected socket or the ideal use of systemic antibiotics. Nevertheless it can be generally assumed that deep debridement with curettes, systemic antibiotic administration, irrigation with antibiotic or H2O2, and chlorhexidine 0.12 % rinses in the postoperative period should guarantee good results similar to implants placed in noninfected sites [59, 60].

4.6 Bone Response and Implant Placement with Piezosurgery

Piezosurgery instrumentation is based on the piezoelectric effect, in which some ceramics and crystals deform when an electric current passes through them. The deformation causes the ceramic to oscillate and produce an ultrasonic frequency. These oscillations are then transferred to the vibration tip connected to a handpiece which will be applied by the clinician to the tissues.

When the tip comes in contract with the bone, the so-called cavitation effect causes a mechanical cutting of the mineralized tissue. Ultrasound frequency is in the range of 25–30 kHz which lead to the formation of microvibrations of 60–210 μm of amplitude, generating a power level of 5 W. Piezosurgery requires adequate irrigation in order to avoid overheating of bone and the following necrosis; this can be obtained preferably with continuous irrigation with saline solution precooled at 4 C° [61].

Minimal pressure of the tip on the area of interest guarantees the greatest cutting efficiency; oppositely a greater pressure limits the amount of cutting and generates more heat. Therefore, the best clinical results are achieved with delicate pressure and continuous movement of the tip.

Piezosurgery is particularly useful when delicate structures such as mandibular nerve or Schneiderian sinus membrane are at risk of damage; this is because direct exposure to the piezoelectric tip does not cause dissection of the soft tissues. Piezosurgery also provides a clear surgical field because the cavitation effect at the air-water interface leads to production of gas bubbles that are considered to wash away blood from the field [62].

Different tips are available for the various uses in oral and maxillofacial applications, from endodontic surgery to implant site preparation and others. Also, different modes can be set for the various uses: low mode for apical surgery, boosted mode for osteoplasties and osteotomies, and high mode for cleaning and smoothening bone borders.

Potential advantages of implant site preparation resides in the fact that use of piezoelectric preparation tips should cause less trauma to the prepared bone compared to conventional preparation burs. Moreover, when implant site preparation is close to delicate structures, the use of the Piezosurgery should reduce the risk of surgical complications [63].

Vercellotti and col. [62] evaluated the osseous response to Piezosurgery in a dog model compared to conventional burs. Histologic results after 56 days showed an osseous repair of the surgical sites, while the site treated with carbide or diamond burs exhibited some amount of bone loss.

Another animal study on minipigs in which implant sites where prepared with Piezosurgery or conventional drilling showed a more consistent osteogenesis in terms of increase of BMP-4 and TGF-2 expression for piezo group [63].

There is a lack of RCTs comparing Piezosurgery preparation techniques with conventional ones. On the other hand, observational studies showed the safety for the various clinical applications of the piezoelectric technology.

Stacchi and col. [64] evaluated in an RCT the implant stability (in ISQ values) using different site preparation techniques. ISQ measurements were performed at specific time points up to 90 days. Results showed an initial decrease and early increase of ISQ values in the piezoelectric group, which were always higher than the conventional preparation group. This was considered suggestive of faster bone healing probably thanks to the reduced bone trauma and the consequent lowered inflammation and bone resorption. Anyway, it should be remembered that just 40 patients were included in the study and that a single operator performed all the procedures. Larger trials are needed to confirm these positive results.

One of the reported disadvantages of Piezosurgery is the relative lack of cutting efficiency on the cortical bone, but this is counteracted by the reduced risks of traumatizing the bone and the soft tissue structures [65]. Also, the greatest surgical safety is paid back in terms of increased working time [66].

Although quantitative reviews or meta-analysis are not feasible yet due to the lack of properly designed studies, it is clear that Piezosurgery technology is a very promising tool for applications in oral surgery and implantology (Fig. 4.12). Soft tissue protection is one of the main advantages, but also the reduced bone trauma, clean surgical field, and potential greater primary stability are all factors that are every important for implant surgery applications [67]. Well-designed studies are needed to confirm if these positive aspects are also reflected in greater implant survival and success rates when compared to traditional surgical techniques.

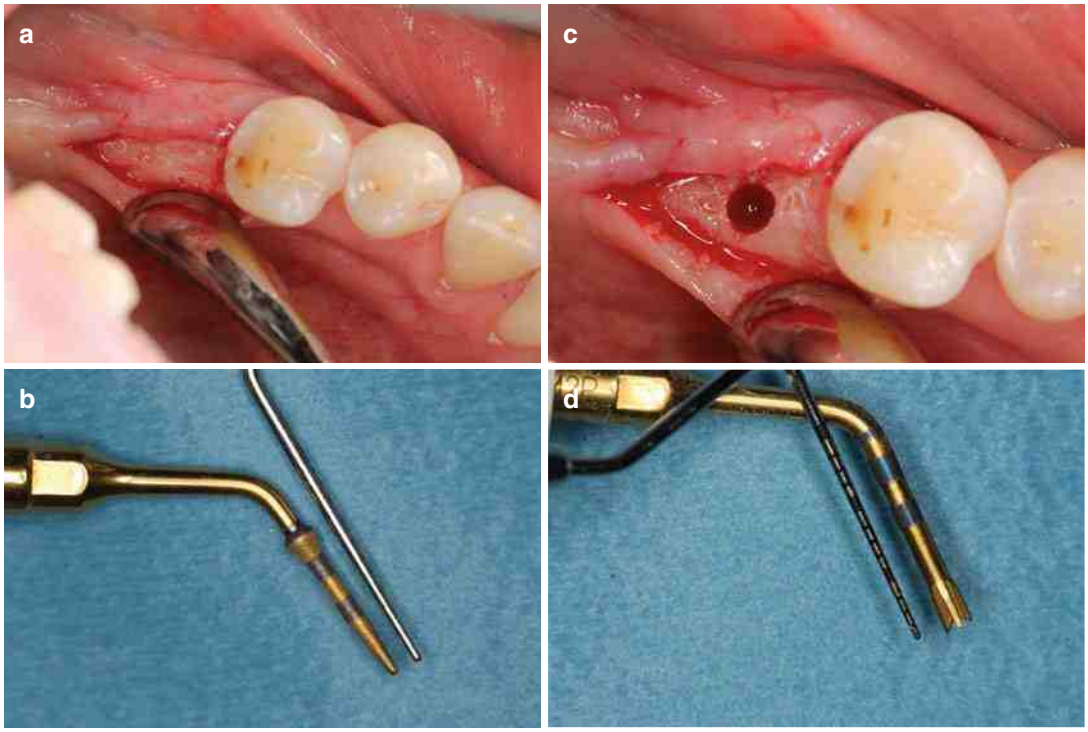

Fig. 4.12 (**a–k**) Sequence for implant site preparation with Piezosurgery tips. Bone crest exposed (**a**), first tip for initial bone penetration (**b, c**), second tip for site negotiation (**d, e**), third tip for coronal bone enlargement (**f, g**), final tip and implant insertion (**h–k**)

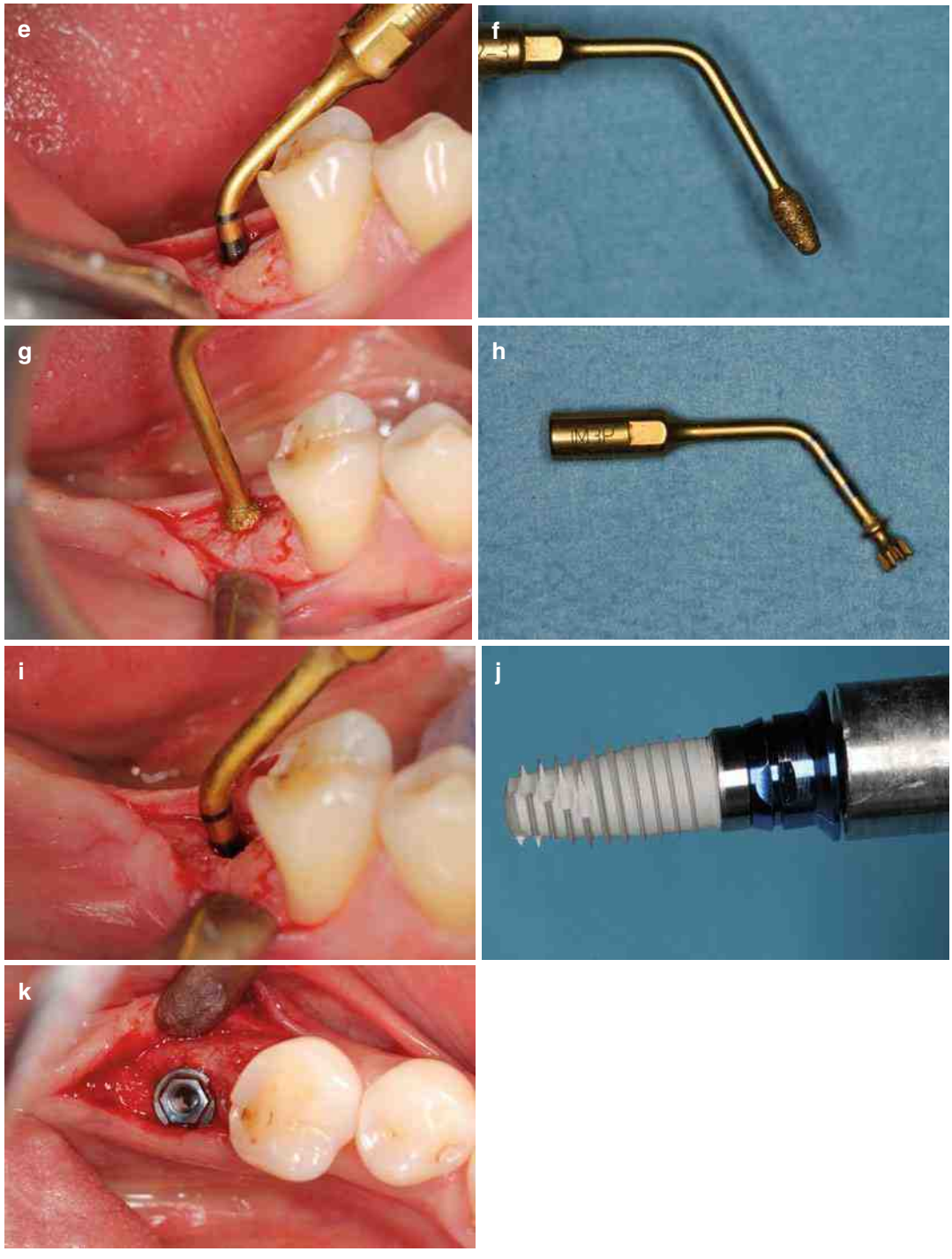

Fig. 4.12 (continued)

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Implant Placement and Loading Time

5

Oreste Iocca and Simón Pardiñas López

Abstract

The first protocol proposed by Brånemark extended the treatment time to more than 1 year after extraction. Since then a tendency toward an acceleration toward the final prostheses delivery has been made possible by the development of new implant designs and surfaces and by an increased understanding of the processes of osseointegration.

The knowledge of the physiologic mechanisms of socket resorption after extraction allows to reliably place an immediate implant. Moreover, in the majority of the situations, immediate placement and loading can give esthetic outcomes comparable to conventional protocols. Also, immediate placement in previously infected sockets may be possible after accurate debridement and antibiotic use.

Regarding the loading time, early or immediate protocols seem to give comparable results to the conventional ones.

One important aspect to consider is the possibility of accelerating the loading time of implant overdentures (OVD), which is advisable due to the prompt restoration of function and esthetics in the vulnerable elderly population.

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5.1 Implant Placement and Loading Time

The first implant treatment protocol defined by Brånemark and coll. in 1969 recommended a healing period after extraction up to 12 months, insertion of the implant, and delivery of the prostheses after ulterior 3–6 months.

This treatment sequence has been historically successful and was considered the standard of care for many decades. Anyway, improvements in implant design, surface treatment, and better

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understanding of bone healing processes and osseointegration have led to development of protocols for immediate insertion and immediate or early loading. Some confusion still exists regarding the exact definitions of terms; therefore, it is better to give some definitions commonly accepted in the dental literature [1]:

Conventional (*delayed*) *placement* any implant inserted at least 2 months after tooth extraction

Conventional (*delayed*) *loading* any implant-supported prosthesis loaded at least 2 months after implant placement

Immediate implant placement any implant placed in fresh extraction sockets after tooth extraction

Immediate loading any implant-supported prosthesis loaded earlier than 1 week subsequent to implant placement

Early placement any implant placed in healing extraction sockets within 1 week and 2 months after extraction

Early loading any implant-supported prosthesis loaded between 1 week and 2 months following implant placement

The main advantages of shortened protocols are (a) reduction of treatment time which has an impact on the satisfaction levels of the patient; (b) in the case of immediate insertion, avoidance of a second surgical procedure; and (c) possibility to maintain a good esthetic appearance soon after the extraction in case of immediate loading.

However, there is a need to critically review the existing literature on this topic because potential problems may arise if shortened placement/loading protocols are adopted, and although much research has been produced, some conflicting evidence emerges from the literature.

5.1.1 Placement Protocols

When extraction of one or more teeth is performed, it would be preferable for both the patient and the clinician to reduce the treatment time and the invasivity of the procedures. *Immediate placement* in fresh extraction sockets gives the advantage of reducing the number of surgical procedures, and, if possible, immediate delivery of a provisional restoration so that esthetics is maintained and the patient does not suffer psychologically for the loss of his/her dentition.

On the other hand, potential complications include an increased risk of infection from residual bacterial niches in the extraction socket or poor esthetic outcomes that may follow the exposure of the implant following the unpredictable amount of alveolar wall resorption.

As discussed in the previous chapter, a significant reduction in alveolar width and height occurs following tooth extraction. It has been a matter of debate if immediate insertion of an implant into the fresh extraction socket can prevent the loss of soft and hard tissue at the extraction site. Recently a series of experimental studies on dogs clarified that immediate implant placement is not able to prevent the physiologic resorption of the alveolar bone, though can reduce it by a variable amount. Also, at sites where teeth with intact periodontal tissues are present, the height of interproximal bone can be maintained, and the resorption is limited to the buccal bone [2]. For this reason it was suggested to place the implant lingually compared to the center of the crest just to prevent the exposure of the implant surface.

Subsequently, several clinical prospective studies have provided clinical data confirming the observations on animal model [3, 4].

More lingual placement of the implant creates a gap between the implant and the buccal alveolar wall. This gap can be of different dimensions according to the morphology of the socket and the diameter of the chosen implants. Considered that the buccolingual width reduction can approximate 50 % of the ridge, it is advisable to leave at least a gap of 1 mm in order to prevent implant exposure (Fig. 5.1). It has been a matter of debate if healing of the gap can be improved with some kind of graft [5]. Many studies have showed that the defect heals optimally without the need of intervention; only in the presence of a dehiscence,

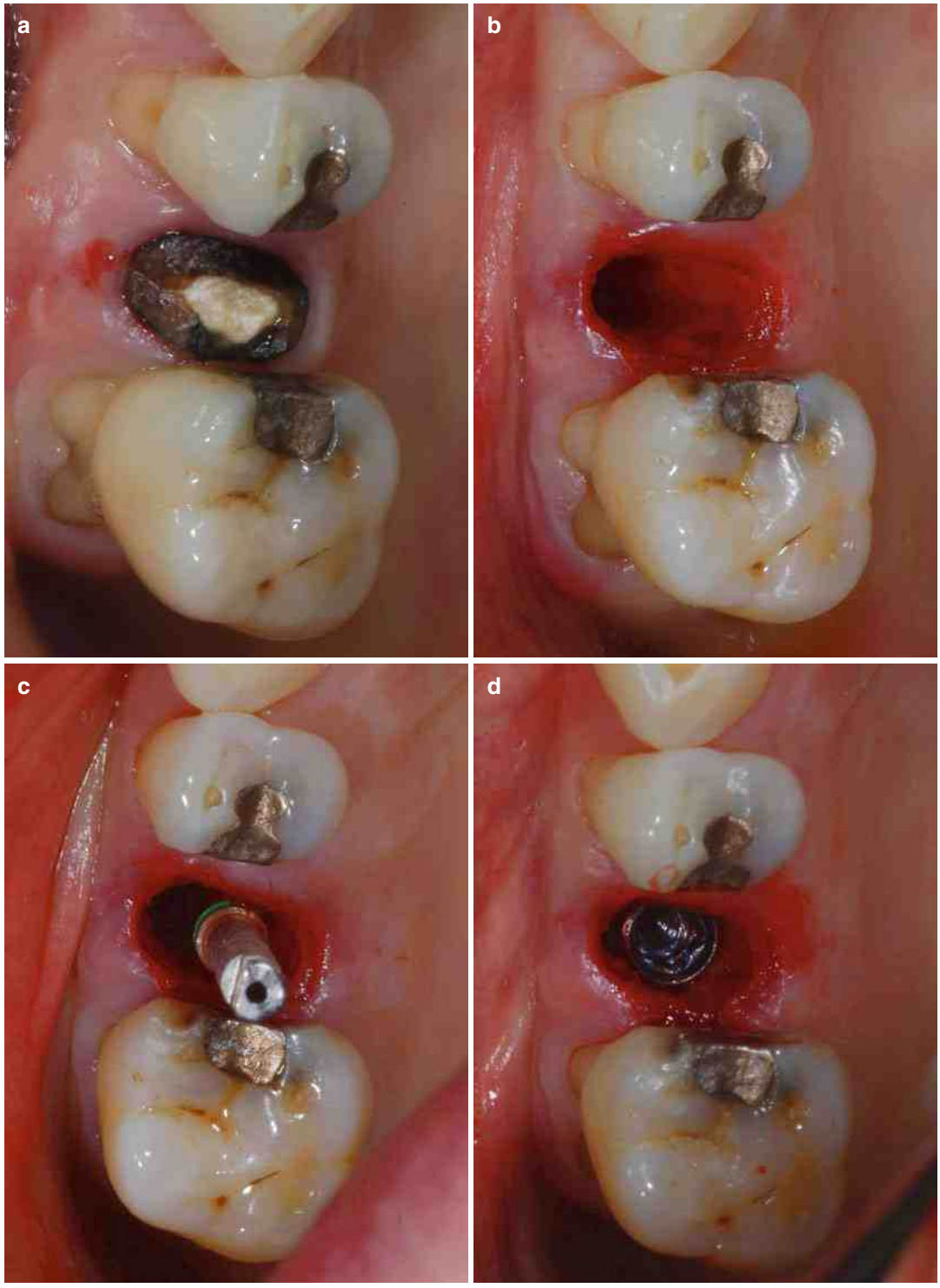


Fig. 5.1 (**a**–**d**) Immediate implant placement tooth #15. Root fragment is extracted (**a**, **b**), immediate implant placement leaving a buccal gap of at least 1 mm (**c**, **d**)

a graft with alloplastic material seemed to confer some benefits [6].

One aspect to consider for immediate placement protocols is the specific anatomical region of the arch in which the implant is placed. In theory, it is expected that the grater loading forces exerted on the molar and premolar regions may have a detrimental effect on the implant, but no evidence exists that immediate placement of implants in the posterior location leads to inferior survival rates or increased risk of complications.

Survival rates of immediately placed implants are well above 90 % in the majority of available studies (Tables 5.1, 5.2, and 5.3). The meta-analysis on RCT by Esposito and coll. [7] did not show any statistical difference between immediate and delayed placement, even if a trend favoring this last one was suggested.

Conversely, another meta-analysis [8] arrived at the conclusion that in the maxilla, the failure rate was higher than in the mandible. Moreover, regardless of the site of placement, immediately placed implants showed higher failure rates than conventional ones. Of course, this is accentuated in the maxilla where primary stability is frequently more difficult to achieve due to the poor bone quality.

The authors compared also immediate *single implants* versus immediate *full-arch restorations*; failure rates were found to be higher for implants supporting a single crown.

This can be explained by the fact that full-arch prostheses allow splinting of the implants to one another, reducing the micromovements and the stress at the bone-implant interface.

5.1.1.1 Soft Tissue and Esthetic Outcomes

There is some reason to believe that immediately placed implants may have a role in preservation of optimal soft tissue contours. However, studies have shown that this may be true at a short-term evaluation, but after 1 year of function, there are no appreciable differences

Table. 5.1 Meta-analyses evaluating different loading time protocols – implant failure

	Included studies	Effect size	*Immediate loading* versus *conventional loading* Results (95 % CI)	Clinical meaning	Statistically significant
Esposito and coll. (2008) ≥1-year follow-up after loading	RCT	RR	1.92 (0.70–5.22)	In favor of conventional loading	No
Sanz-Sanchez and coll. (2014) ≥6 months of follow-up after loading	RCT	RR	1.92 (1.04–3.54)	In favor of conventional loading	*Yes*
Atieh and coll. *Single crown implants only* ≥1-year follow-up after loading	RCT, non-randomized trials	RR	5.00 (2.0–12.84)	In favor of conventional loading	*Yes*
Benic and coll. (2014) *Single crown implants only* 1-year follow-up after loading	RCT	OR	0.77 (0.31–1.93)	In favor of conventional loading	No
Engelhardt and coll. 2015 ≥1-year follow-up after loading	RCT	RR	0.82 (0.35–1.94)	In favor of conventional loading	No

Table. 5.2 Meta-analyses evaluating different loading time protocols – implant failure

	Included studies	Effect size	*Immediate loading* versus *early loading* Results (95 % CI)	Clinical meaning	Statistically significant
Esposito and coll. (2008) ≥1-year follow-up after loading	RCT	RR	0.65 (0.26–1.63)	In favor of immediate loading	No
Schrott and coll. ≥1-year follow-up after loading	RCT, non-randomized trials	RR	0.9 (0.30–2.70)	In favor of immediate loading	No
Xu and coll. (2014) ≥1-year follow-up after loading	RCT	OR	0.32 (0.064–1.61)	In favor of conventional loading	No

RR relative risk

Table. 5.3 Meta-analyses evaluating marginal bone level change

	Included studies	Effect size	*Immediate loading* versus *conventional loading* Results (95 % CI)	Clinical meaning	Statistically significant
Esposito and coll. [16] ≥1-year follow-up after loading	RCT	MD	–0.10 (–0.24 to 0.04)	In favor of conventional loading	No
Sanz-Sanchez and coll. [18] ≥6 months of follow-up after loading	RCT	WMD	0.046 (0.043–0.049)	In favor of immediate loading	*Yes*
Suarez and coll. [22] ≥1-year follow-up after loading	RCT, non-randomized trials, retrospective studies	MD	–0.09 (–0.27 to 0.09)	In favor of immediate loading	No
Benic and coll. [21] *Single crown implants only* 1-year follow-up after loading	RCT	MD	–0.05 (–0.041 to 0.31)	In favor of conventional loading	No
Engelhardt and coll. [17] ≥1-year follow-up after loading	RCT	WMD	0.01 (–0.05 to 0.08)	In favor of conventional loading	No

MD mean difference (measured in millimeters), *WMD* weighted mean difference (in millimeters)

between immediate and conventional placement protocols. Considered that one of the main objectives of immediate or early placement is to achieve optimal esthetic results, it is important to establish if this is actually possible.

It is well known that esthetic outcomes depend largely on a healthy soft tissue, a healthy bone, and a properly manufactured prosthesis. In particular, interproximal papillae and marginal gingiva play a fundamental role in terms of esthetics and patient perception of beauty; in other words,

the papillae adjacent to the implant and the mid-buccal gingiva should mimic those of a healthy tooth. When analyzing the clinical studies reporting the esthetic outcomes, it is important to take in mind that subjective measurements are frequently adopted and a lack of standardized techniques in esthetic evaluation and reporting is a common pitfall of many implant studies [9].

Pink esthetic score (PES) was proposed for evaluation of gingiva, tooth, and implant restoration esthetics. This is a visual evaluation in which a score going from 0 (poor esthetics) to 10 (excellent esthetics) is assigned to mesial and distal papilla, facial mucosa, root convexity, and tissue color and texture. In this case, the problem is that few studies adopt this score for reporting the esthetic outcomes and anyway it is liable to a certain degree of subjectivity.

For these reasons, surrogate end points of the esthetic outcomes are adopted; these are the clinical soft tissue height variation and the radiographic marginal bone level (MBL) change.

A recent review [10] on immediately placed implants in the anterior maxilla evaluated the main risk factors for poor esthetic outcomes. Because of underreporting, in the included studies, no esthetic indexes were considered for review. Instead, mean bone level changes after 1 year of loading were considered, and the results showed that delayed provisionalization, use of a flap, and use of connective tissue grafts were significantly associated with bone loss >0.50 mm.

Khzam and coll. [11] analyzed studies evaluating the soft tissue outcomes of immediately placed implants in anterior maxilla. Regarding papilla modification, a mean loss of 0.23 ± 0.27 mm occurred after 3 months, but a papillary rebound was evidenced after 1 year of crown placement; this means that interdental papillae around definitive restorations tend to regrow and compensate for the initial loss. Mid-buccal gingival recession instead gave a mean of 0.27 ± 0.38 after at least 1 year of follow-up. The authors also reported that around 11% of the studies showed important mid-buccal recessions (>1 mm).

The systematic review and meta-analysis of Chen and coll. [9] arrived at the conclusion that acceptable esthetic outcomes may be achieved for single implants placed following tooth extraction even if higher frequency of recession >1 mm of the mid-buccal mucosa was reported when compared to delayed placement. Regarding papilla recession, the authors concluded that 0.5–1 mm of papilla loss is to be expected regardless of flap or flapless surgery.

Considered that the majority of the studies show a lack of uniformity in the assessment of the esthetic result and that the esthetic indexes are infrequently adopted, it is difficult to arrive at an objective quantification of the esthetic outcomes.

In general terms it is possible to conclude that immediate implant placement gives acceptable results in terms of esthetics (Fig. 5.2), but long-term studies comparing immediate with conventional placement are needed in order to arrive at definitive conclusions.

5.1.1.2 Immediate Placement of Implants in Infected Sites

It has been a matter of controversy if it is safe to place an implant in a fresh extraction socket which is site of inflammation or infection deriving from endodontic or periodontal pathology. Some clinical reports suggested that a history of periodontal of endodontic disease can be a predictive marker of implant failure. A situation considered to be at high risk of developing the so-called retrograde peri-implantitis is that one in which residual bacterial niches typical of periapical pathosis, such as *Bacteroides* species, persist around the implant and cause peri-implant infection and ultimately treatment failure [12]. Also previous periodontal pathology has been considered the cause of similar problems due to the persistence of periodontal pathogens and subsequent inflammatory response around the implant which can impair osseointegration.

Anyway, these problems were evidenced only in case series or case reports, contrasting with the fact that animal studies in which proper debridement and prophylactic use of antibiotics allowed to obtain proper osseointegration after immediate implant placement. For this reason in the last few

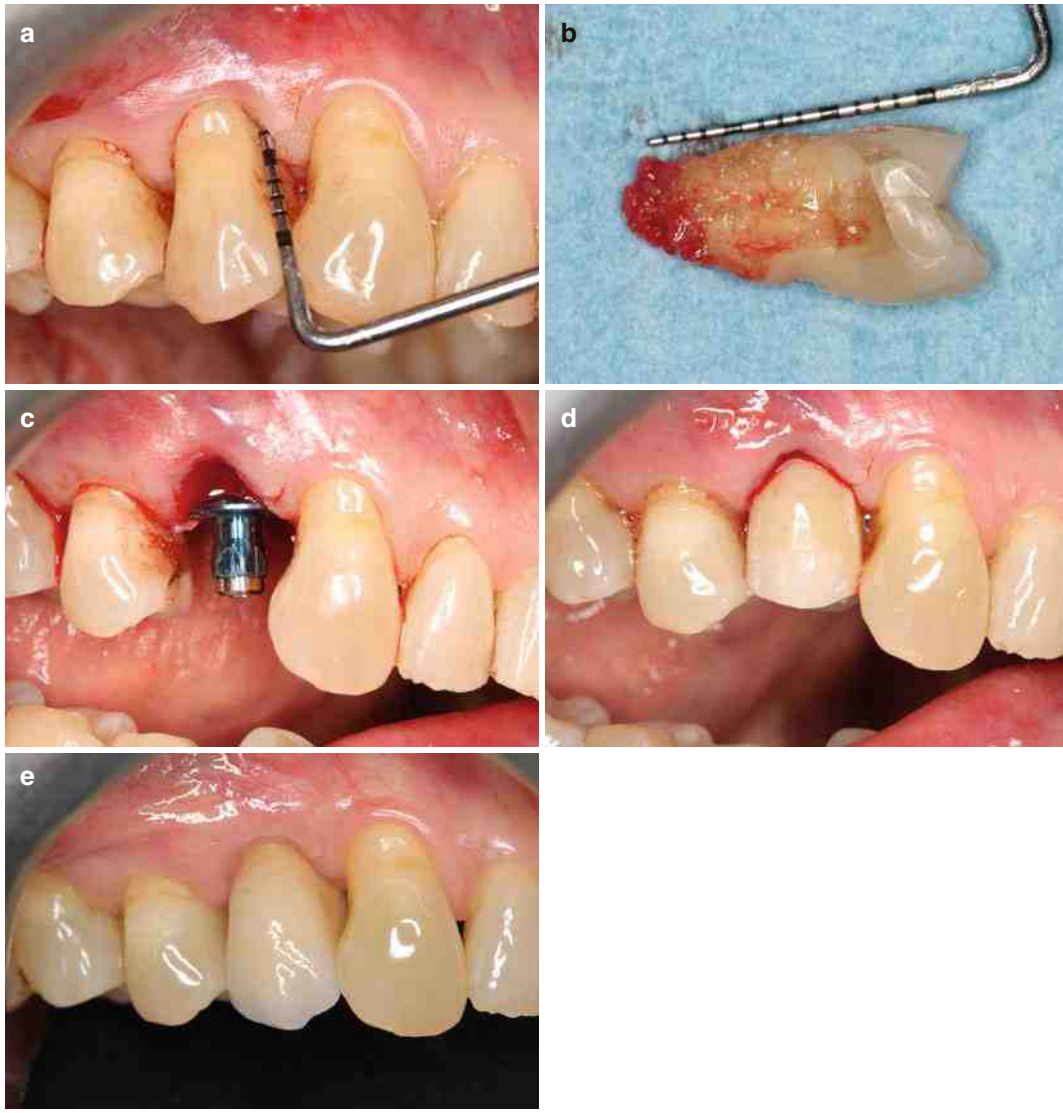


Fig. 5.2 Tooth #14 needs to be extracted due to the presence of a vertical fracture (**a**, **b**). Immediate implant placement is performed and provisional crown is applied (**c**, **d**). Optimal esthetic outcomes at 3 months follow-up (**e**)

years, a number of reviews have been published in order to clarify this issue.

A recent review based on retrospective studies, prospective studies, controlled clinical trials, and randomized clinical trials [13] arrived at the conclusion that immediate implant placement in infected extraction sockets can be successful after thorough debridement and postoperative care with antibiotics and chlorhexidine rinses. Even if definitive recommendations on which type of antibiotic and dosage could not be drawn considered that no study has been found comparing specifically the use of different antibiotics and dosages in case of immediate placement. Also the use of antibiotic irrigation prior to implant placement remains unclear.

Another review [14] based on human case series and one randomized trial gives weak evidence that patients with residual inflammatory lesions and infections can be treated with immediate implant placement after debridement and use of systemic antibiotics.

The same conclusions are drawn by Alvarez-Camino and coll. [15]. They found no contraindications in recommending immediate implant placement in infected sockets.

In conclusion, on the basis of the available literature, it is possible to state that placement of immediate implants into infected extraction sites is possible without fear of much higher failure rates when compared to implants placed in healthy sockets (Fig. 5.3). On the other hand, the lack of well-designed RCT on this topic does not allow to draw definitive conclusion regarding the perioperative management of the patient in this situations. It is anyway reasonable that a full course of systemic antibiotics and deep debridement of the socket before implant placement may confer some protection from complications and failures.

5.2 Loading Protocols

Immediate or early provisionalization and loading of dental implants are aimed at reducing the period of time in which the patient remains without tooth replacement. In other words, the aim of accelerated prostheses delivery is to reduce the discomfort of the patient attaining immediate function and esthetics (Fig. 5.4). It is clear that this becomes particularly important for the fully edentulous patient who, if treated with the conventional protocols, needs to wear a removable denture for months before uncovering, provisionalization, and loading of the definitive restoration.

Therefore, it is important to understand if accelerated loading protocols are comparable in terms of survival and success rate to conventional treatment solutions. Also, it would be desirable to know if implants loaded in the maxilla or the mandible give different results.

The Cochrane review of RCT by Esposito and coll. [16] analyzed immediate, early, and conventional loading strategies between each other. The results of the meta-analysis, although no statistically significant, were suggestive of lower survival rate for immediately loaded implants when compared with the conventional loaded ones. No significant difference for prosthesis success, implant success, and MBL were observed. Also, there was a trend suggestive of higher failures for the early loading when compared with the immediate loading. This was explained by the fact that early loaded implants may impair the healing process of bone around the implant just in the period when primary stability drops, and secondary stability is not fully established yet. The analysis attempted to investigate if occlusal versus non-occlusal loading

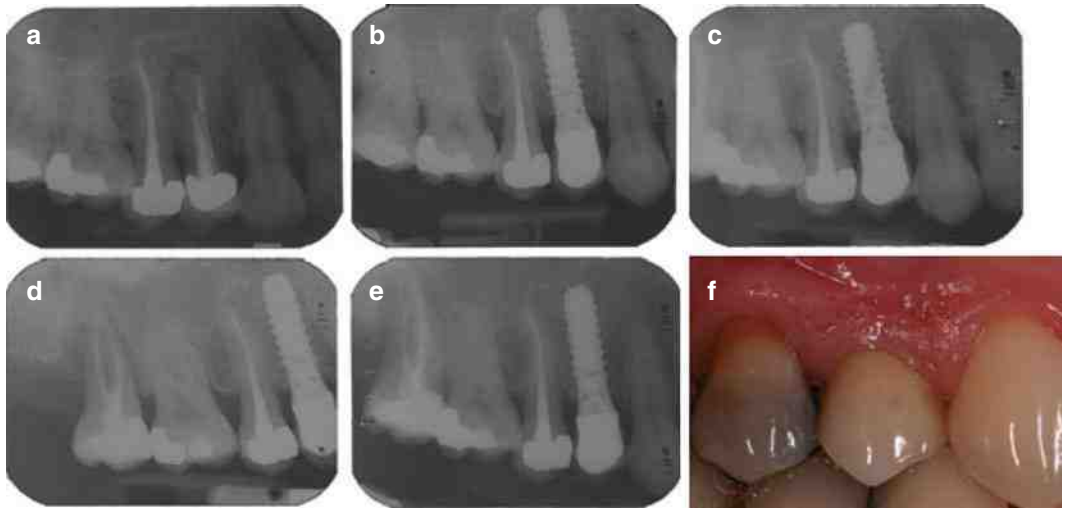


Fig. 5.3 (**a**–**f**) Implant positioning on a previously infected site (tooth #14). At baseline (**a**), after 3 months (**b**), at 1 year (**c**), at 3 years (**d**), and at 5 years after placement (**e**, **f**) (Reproduced with permission from *Jung and coll.*)

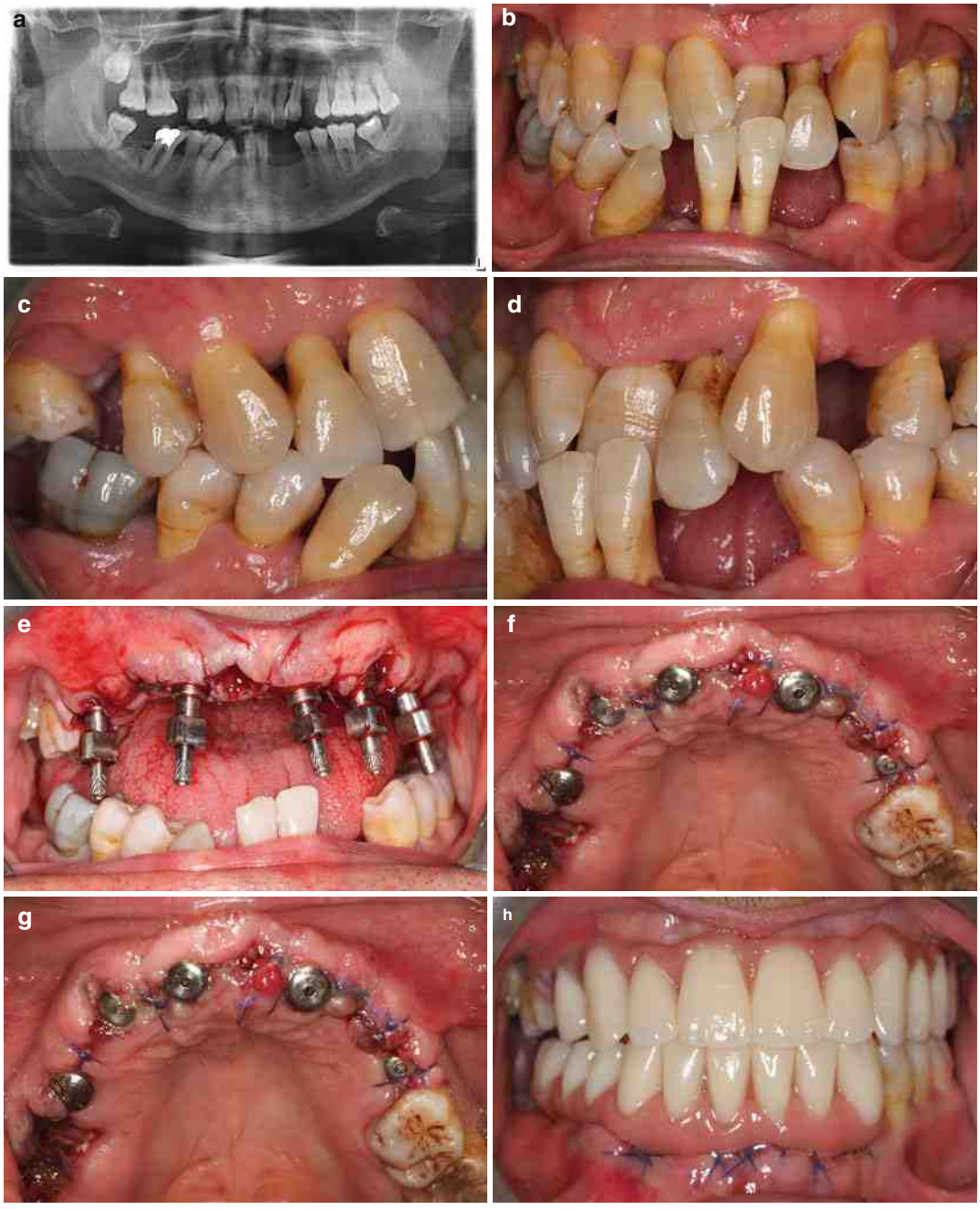
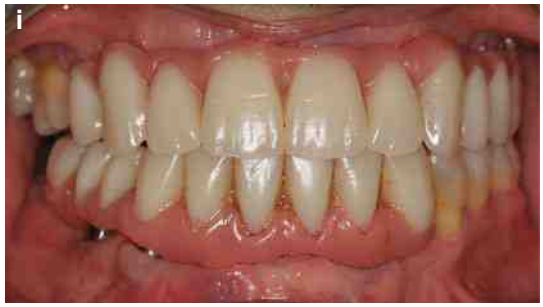


Fig. 5.4 (**a**–**j**) OPT showing the necessity of extraction (**a**), intraoral examination (**b**–**d**), extraction and immediate implant placement (**e**), appearance of implants and delivery of prosthesis the day after surgery (**f**), control at 1 year (**i**–**j**)



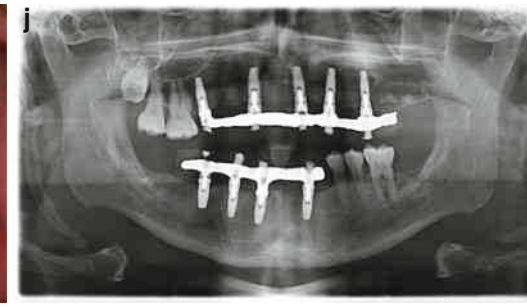


Fig. 5.4 (continued)

yields different outcomes, but just one RCT was found studying this hypothesis, and the sample size was too small to reach any conclusion.

At the end, the success rates were considered to be high for all the treatment options in the majority of the published trials; therefore, it was concluded that it is possible to plan an immediate or early loading protocol with confidence. At the same time, the patients need to be informed about the slightly higher risk of failure for implants loaded early or immediately if compared to conventionally loaded ones.

Another meta-analysis examining RCT and expanding the inclusion to non-randomized trials [17] showed that the vast majority of implant failures of immediately loaded implants occurred within the first 3 months after loading. A likely explanation for this is that failures occurring after 12 months of loading are probably caused by factors other than loading protocols. The meta-analysis also showed no statistically significant difference in survival between maxillary and mandibular implants even if the significant heterogeneity of the included studies suggest caution in drawing definitive conclusions on this matter.

It was concluded that there is insufficient documentation and very limited scientific evidence supports the adoption of immediate loading protocols. Therefore, careful patient selection was recommended in case of immediate loading, in particular evaluation of good bone quality and good primary stability, parafunctions, and smoking habits.

The systematic review by Sanz-Sanchez and coll. [18] evidenced high success rates for both immediate and conventional loaded implants. On the contrary compared to other reviews, a statistically significant higher risk of implant failure was found for immediate loading. These results can be explained by the fact that the analysis included studies comparing immediate versus conventional loading, excluding the early loading protocols.

Also, immediate loading of single teeth implants seemed to have higher risk of failure compared to multiple restorations. These results can be explained again by the splinting effect that occurs with extended restorations.

The authors also tried to answer the question if immediate occlusal vs. non-occlusal loading gave different outcomes, but no definitive conclusions were considered feasible. Regardless of this it seems reasonable to create a condition of under-occlusion for a single crown implant in order to avoid excessive stress on it.

When the focus is shifted exclusively on single-implant crowns, it seems clear that better results in terms of survival are achieved with conventional loading. In fact, a thorough review of randomized and non-randomized studies arrived at the conclusion that a statistically significant difference was found between immediate and conventional loading in favor of this last one [19].

One point that merits a discussion is whether any difference exists between immediately loaded implants in fresh extraction sockets or healed ridges. The meta-analysis by Del Fabbro and coll. [20] showed that immediate placement/immediate loading was subject to higher risk of failure compared to immediate loading in healed ridges.

This was consistent with the fact that implants placed in a fresh extraction socket are exposed to higher risk of complications and failure.

In summary, a low number of well-designed RCTs and small prospective studies are one of the major drawbacks that emerge from the various systematic reviews. Also, most studies have short follow-up, the majority less than 1 year. Anyway this last point is not a big issue when immediate or early placement is considered, given that the majority of implant losses usually occur in the first year after loading; after this period of time, complications are probably independent from the loading time.

It is possible to state that with careful patient selection, immediate/early loading is a treatment protocol that gives high rates of success comparable, even if slightly lower, to conventional loading.

Again, given the clear advantage in terms of patient's comfort and function, it is the responsibility of the clinician to decide when accelerated loading protocols are appropriate and advantageous. Without any doubt, proper communication with the patient is of paramount importance when discussing the opportunity of tooth extraction, immediate implant placement, loading time, and the type of restoration.

5.2.1 Esthetic Outcomes of Accelerated Loading Protocols

In the same fashion as for immediate placement protocols, in order to evaluate the esthetic results of the different loading protocols, it is better to rely on quantification of marginal bone level change and soft tissue status instead of the poorly reported esthetic indexes.

The majority of the available reviews point out that there is no statistically significant difference in terms of MBL and mucosal level changes of implants between immediate and conventional loading [21]. For this reason, it is possible to consider a theoretical advantage for immediately placed implants, but this refers just to the fact that the patient receives a restoration without the need of waiting long healing time before the final delivery. At long term, the different loading protocols seem to give the same esthetic results between each other.

5.2.2 Loading Protocols for Implant-Supported Overdentures

Treatment modalities for fully edentulous jaws traditionally have included conventional removable dentures; they are reliable methods for restoration of function for many patients, especially in the elderly. On the other hand, removable prostheses are associated with psychological and functional limitations.

The use of osseointegrated implants can improve the outcomes of removable dentures and at the same time maintains their cost-effective benefits. Implant-supported overdentures (OVD) possess a great increase in stability and high degree of patient satisfaction [23].

Mandibular retained OVD showed high success rates and cost-effectiveness. Immediate loading of implant-supported OVD gives the advantage of conferring to the patient an immediate stabilization and a quick restoration of function. One of the aspects to consider when planning an OVD placement regards the soft tissues; these are traumatized the day of surgery and tend to change morphology during the following weeks. Therefore, relining and adjustments are frequently necessary before achievement of optimal results. This can be a cause of additional costs and multiple visits [24].

Early loading can therefore be considered a good compromise because it eliminates the necessity of large readjustments after delivery of the prosthesis given that soft tissues are allowed to heal after surgery and before prostheses delivery.

Schimmel and coll. [25] conducted a meta-analysis of RCT comparing immediate, early, and conventional loading of two-implant OVD. The analysis was suggestive of a superior implant survival at 1 year of follow-up for early and conventional loading in respect to immediate protocols, but the results were not statistically significant. Also, the majority of the studies focused on man-

dibular OVD and clear statements on maxillary solutions were not considered possible.

The conclusion was that the three loading protocols applied to mandibular OVD seems to give good clinical results, but a slight tendency toward higher implant failures for the immediately loaded OVD was noted.

A particular issue discussed in the review was the use of splinted or unsplinted implants for immediate loading. In theory, considered that micromovements may impair the process of osseointegration, a splinting bar should increase the success rates of immediately loaded OVD. In reality, the studies included in the review allow to draw interesting conclusions. In particular, mandibular unsplinted implants gave a mean survival rate at 1 year in the range of 96.6–100 %, which was similar to the splinted group (96–100 %). The same observation was done for the maxillary OVD, with a mean survival range of 97–98.1 % for the splinted group and 98–99 % for the unsplinted group.

The conclusion that can be drawn is that splinting does not give an advantage compared to unsplinted implants when immediate loading protocols are adopted.

Alsabeeha and coll. [26] analyzed both RCTs and non-randomized studies with a minimum of 2 years of follow-up. Both early and immediate treatment protocols were considered to have similar success rates when compared to conventional loading OVD. Other reviews show similar results.

It is thus possible to state that immediate/early protocols for mandibular OVD are a predictable treatment modality when careful patient selection is performed. Good periodontal health, achievement of a primary stability of at least 30 N/cm, and creation of a balanced occlusion are all factors that allow to obtain optimal results [27].

The problems associated with conventional removable dentures, such as instability, improper occlusion, and pressure ulcers, cannot be overcome due to excessive resorption of the alveolar crest.

Implant-retained OVD have resolved such issues in the majority of the cases. At the current state, maxillary rehabilitation with immediately loaded OVD is questionable due to lack of longitudinal studies.

We need to consider that OVD treatment in the vast majority of the cases is performed in the elderly population where there is an increased incidence of systemic diseases, fragility, and reduced compliance. Also, it must be taken into account that the geriatric patient is predisposed to undernutrition, and therefore a rapid regain of a proper masticatory function is of paramount importance.

In particular, the adoption of shortened treatment protocols may help the patient to acquire immediately a better retention and stability of the prosthesis, in this way avoiding the risk of acquiring a poor nutritional status.

In conclusion, if a tendency exists toward slightly higher failure rates of immediate/early OVD in comparison to conventional loading protocols, this is balanced by substantial benefits in terms of rapid return to a normal social life, proper chewing capacity, absence of pain, and discomfort. This might be important especially in old age when the majority of OVD are placed (Table 5.4).

Table 5.4 Meta-analysis evaluating the survival of implants used as support to OVD

	Included studies	Effect size	*Immediate loading* versus *conventional loading* Results (95 % CI)	Clinical meaning	Statistically significant
Schimmel and coll. [25] ≥1-year follow-up after loading	RCT	RR	0.03 (−0.03 to 0.08)	In favor of conventional loading	No
Schrott and coll. [27] ≥1-year follow-up after loading	RCT, non-randomized trials	RR	0.67 (0.0.071–6.25)	In favor of immediate loading	No

RR relative risk

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Implant Design and Implant Length

6

Nicholas Quong Sing

Abstract

Implant Design is a fundamental aspect of successful implant treatment. Its evolution has led to the development of 1000s of implant types manufactured by an ever increasing number of companies in both industrialized and developing countries. Implant body shapes can generally be classified into threaded,tapered or stepped designs and further subdivided into surface chemistry and material composition.

Improvements in implant design and its composition has prompted a rethink of selection criteria for different clinical scenarios, an example being the use of short implants to avoid the need of advanced bone grafting techniques.

Objective analysis if data from the used of short and varying implant diameter need to be carried out to allow a fair comparison of this trend and how it compared to the long term predictability that has been achieved with traditional implant lengths.

6.1 Implant Design: General Review

Implant design has always been a fundamental feature that has facilitated the successful long-term osseointegration of these endosseous restorative platforms. This fact has been further emphasized by how changes in implant macro- and micro-design has improved implant survival rates when placed across varying bone types, prosthetic loading times, and patient comorbidities. Implant design has continually evolved over the years, as well as the surgical protocols required for their placement, with many of the axioms that influenced their selection being challenged.

The evolution of implant design has lead to over 1300 dental implant types [1] and more than 250 implant manufacturers worldwide. This vast selection of implants can be intimidating when choosing an implant (Fig. 6.1), as there have been no well-documented studies that show the superiority of one implant system over another [2] and most studies focusing on one implant system and its success. A review by Esposito et al. shows no evidence to suggest that one implant system led

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Fig. 6.1 Common implant designs and surface characteristics according to the manufacturer (Reproduced with permission from Barfeie and coll.)

to fewer implant failures or less bone loss than another [3]. What is definitive is that implants in general, as a restorative therapy, are a reliable treatment option for the replacement of single or multiple missing teeth [4, 5].

Dental implants are unique when compared to other implantable devices in the human body, as its design has to take into account that it is additionally connected to a prosthesis which is exposed to the oral cavity and therefore subject to two environments. This prosthetic interface on the implant body, where the implant abutment connects, can either be external or internal in nature. There are however exceptions, with some implants having a solid connection to the abutment (one piece). The most common external and internal connections are hexagonal or octagonal in shape, but can be an external spline or internal Morse taper. Studies by Bernardes SR et al. have shown that there is no statistical difference in stress concentration levels, in the peri-implant region, between internal and external connections when centralized axial loads (directed through the implant center) are applied to implants. Off-center loads however showed the lowest stress concentrations in internal hex connections, intermediate stresses in internal tapered connections, and the highest stresses in external hex and one piece connections [6]. External connection platforms were used among the first Branemark implants; however, there has been a gradual shift to internal connections due to their advantages offered, such as less screw loosening, improved aesthetics, improved reliability with narrower abutment diameter [7], and reduced bacterial leakage in internal Morse tapered connections [8]

Implant design can be classified broadly into macro- and microstructural features. Macro-design features include body shape, threads, anti-rotational features, and thread design (pitch, depth, angle, thickness, thread helix), while micro-design features comprise surface topography, material composition, and bioactive coatings. Most evolution in implant design is centered on the modifications of these features to achieve: high levels of primary stability, faster and better quality osseointegration, reduced peri-implant bone loss, and improved stress distribution during functional loading.

6.1.1 Implant Body Shape

Endosseous implant body shapes can generally be classified as threaded, stepped, or tapered. Threaded implants (Fig. 6.2) were introduced into implant design to improve the initial stability via mechanical friction with the surrounding bone [10], and it also served the purpose of increasing bone-to-implant contact area [11]. The stepped implant however was designed to mimic the natural root form, creating what was hoped to be a favorable load distribution, while tapered implants were created specifically in an attempt to reduce repetitive micro-strains at the crestal margins [8]. These micro-strains are thought to be the main cause of crestal bone loss, as first documented by Branemark et al. in 1977. This reduction in micro-strains is achieved in tapered implants by directing the stresses during function away from the dense cortical bone and toward the resilient trabecular bone. An extensive review by Esposito et al. [12], evaluating 13 different implant shapes over seven trials, showed no significant differences for implant failures after 1 year between the tested implant designs. This again enforces the point that there is no one implant design that is superior. The difference between implant designs are more pronounced in type IV bone due to low density and reduced primary stability. Design does not however seem to play a significant role in type I and type II dense bone.

Thread designs come in a variety of configurations due to differences in pitch, number of thread helixes, thread angulation, thread depth, and thread shape. Thread shape can be square, v shaped, buttress, reverse buttress, and spiral. Most implants have threads incorporated into their design as it reduces shear loads and increases functional surface area [13]. Shear loads have been shown to be the most detrimental force that affects bone strength, while compressive forces are the most favorable [14]. In square and buttress threads, axial forces are transmitted to the bone mainly via compressive forces, while in v-shaped and reverse buttress, load forces are transmitted to the bone by a combination of shear, tensile, and compressive forces [9] (Fig. 6.3). There are currently no well-controlled

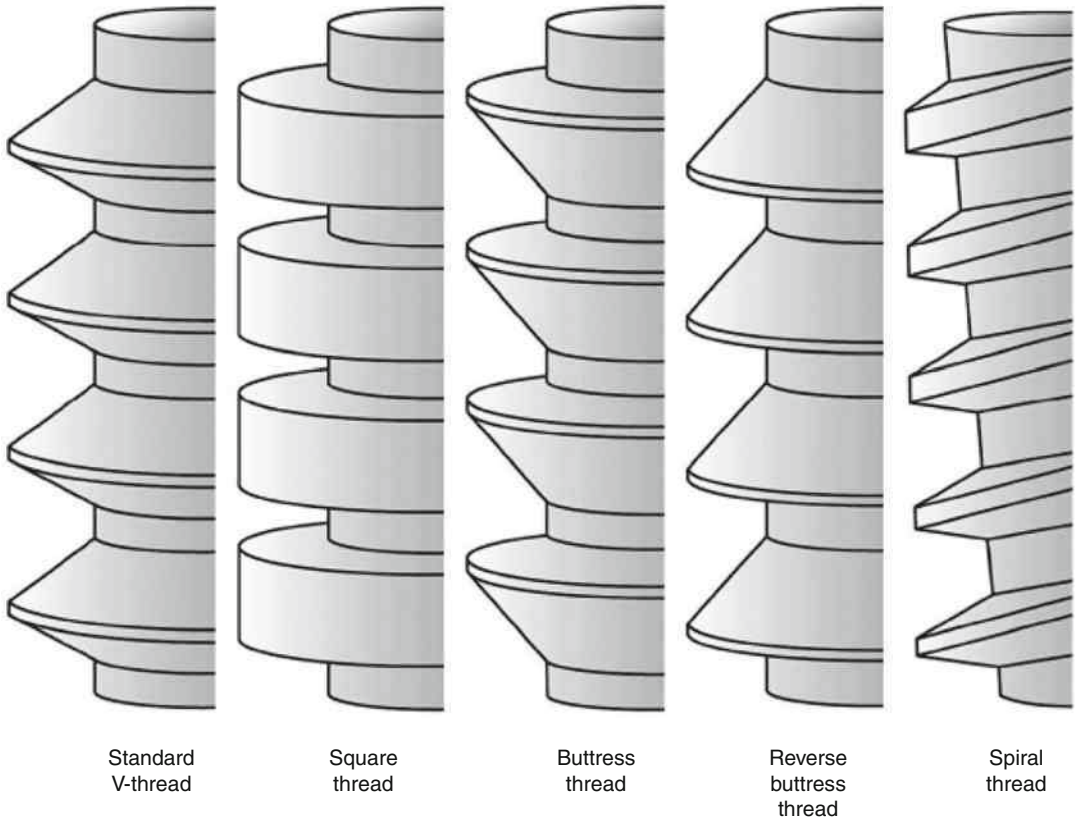

Fig. 6.2 Schematization of the thread designs (Reproduced with permission from Abuhussein and coll. [9])

prospective clinical studies that compare the different thread shapes, but finite element analysis of square thread profiles shows that it has an optimized surface area for intrusive forces and compressive load transmission, resulting in a lower strain profile [15]. Animal studies by Steigenga et al. have shown that these features of square threads have resulted in higher reverse torque when compared to v-shaped and reverse buttress implants [16].

Thread pitch is the distance from the center of a thread to the center of the next thread, measured along the major axis of the implant. Orsini E. et al. showed in their animal study that increased primary stability and bone-to-implant contact was gained from decreasing thread pitch, especially in cancellous bone, where it can prove critical to osseointegration [17]. Changing the thread pitch alters the thread depth, the area within the thread region, and the functional available for load transmission. Studies by Kong et al. considered 0.8 mm as the optimal thread pitch in cylindrical v-shaped implants [18]; however, this still remains inconclusive and requires further vigorous and expansive clinical trials. What can be certain is that as thread pitch decreases, bone-to-implant contact increases, leading to more favorable stress distribution.

6.1.2 Surface Topography

Modifying the implant surface is one of the means that has been used to increase both primary stability and functional surface area of implants. It plays an especially important role in short implants as discussed later in this chapter. Surface irregularities increase the metal sheer strength and decreases implant loosening, which facilitates better mechanical interlocking between

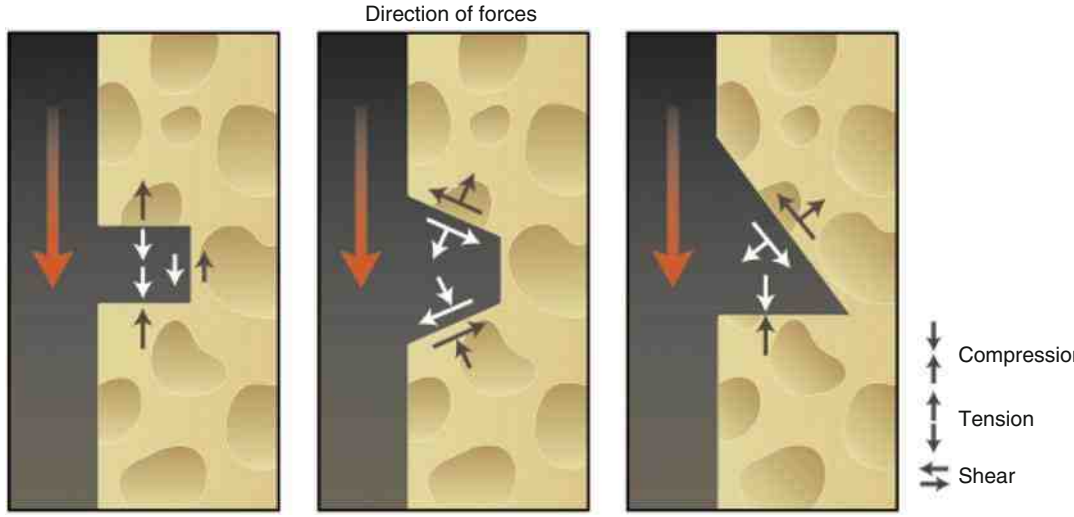

Fig. 6.3 Relationship between thread design, forces, and shear stress on bone (Reproduced with permission from Abuhussein and coll. [9])

bone and implant surfaces. This has resulted in better primary stability and faster osseointegration clinically [19]. Modification of surface topography can be carried out by an addition or subtractory process. Addition processes, which create convex surfaces, involve plasma deposition using hydroxyapatite or titanium particles, to give a uniform pattern. These coating layers are only functional if they adhere firmly to the implant surface. Subtractory processes however involve the use of sand blasting, shot peening, laser peening, acid etching, or a combination of these to create concave surfaces. A systematic review carried out by Wennerberg A. et al. noted that moderately rough surfaces (S (a) 1–2 microm) showed stronger bone responses than the smooth (S (a) <0.5 microm) or rough (S (a) >2 microm) in some studies. These roughened surfaces stimulate the bone healing process as noted by Soskolne et al.; however, there is currently no consensus among the literature on what degree of roughness would be ideal for the osseointegration process. Roughened implants conversely facilitate bacterial adhesion to its surfaces [20], which can facilitate peri-implantitis and a decrease in the long-term implant survival rate. Esposito et al.'s meta-analysis of different implant types showed a 20 % reduction in risk of turned (smooth) surface implants being affected by peri-implantitis when compared to rough surfaces at 3 year follow-up; however, 5- and 10-year data showed no difference.

6.1.3 Implant Materials

Currently the vast majority of implants are made with commercial pure titanium or its alloys, with a small percentage being hydroxyapatite-coated titanium, zirconia, or zirconia alloy. Titanium and its alloys have a proven track record as the material of choice for implant fabrication, given its biocompatibility and mechanical properties. The successful use of zirconia in the orthopedic field has seen it become a potential alternative material for dental implants, overcoming potential aesthetic and immunological complications of titanium use. Zirconia is an attractive material for implant fabrication given its toothlike color, low plaque affinity, good biocompatibility, high mechanical resistance, and its ability to be machined. Animal studies have shown that roughened zirconia implants have comparable bone-to-implant contact and osseointegration, with similarly shaped and roughened titanium implants [21, 22]. This was reflected clinically in similar removal torque values [23]. A 5-year review in humans by Oliva J. et al., of three

different roughened zirconia implant surfaces, showed an overall success rate of 95 %, with the highest success rate shown in zirconia implants that were acid etched. These results hold great promise for the future use of zirconia implants, but should be taken with caution as it is a medium-term review. Titanium and its alloys still are the material of choice for implant fabrication, having a greater body of evidence proving their long-term efficacy.

6.1.4 Implant Surface Chemistry

Implant surfaces can be modified with chemical coatings that aim to induce specific cell and tissue responses which help improve bone-to-implant contact and increase the rate of osseointegration. There are many experimental coatings such as strontium ions incorporated into titanium surface which promote the stimulation of osteogenesis and an inhibition of osteoclastogenesis [24] or the use of hydroxyapatite and bioactive glass coatings for their osteoconductive properties [25]. Surface chemistry can also be used to increase the hydrophilicity of implant surfaces, which modulates the biological cascade of events at the bone-to-implant interface, promoting faster osseointegration [26]. Modification of surface chemistry as a part of implant design is one of the many factors that can increase the speed and quality of osseointegration, but its benefit is mainly seen in type IV bone types where bone quality is poor and additional mechanisms are required to enhance integration.

6.2 Implants of Different Lengths

6.2.1 Clinical Outcomes

Implants are currently manufactured in a wide range of lengths, from short 4 mm alveolar implants to 53 mm zygomatic implants. Implant length selection is dependent on a patient's existing vertical alveolar dimensions. Implants of short length may be chosen for regions of atrophic bone, where patients are reluctant for advanced augmentation treatments and its associated prolonged treatment times, cost, and morbidity. Longer implants have been indicated for immediate extraction sites, where primary stability is required for successful osseointegration, or to engage the zygomatic bone in severely resorbed maxillary alveolar ridges. Short implants and their selection are discussed later in this chapter, as advances in implant design have shown them to have comparable survival rates to implants of standard length. This therefore raises the question of whether is it is really necessary to place the longest implant that can be accommodated, which has been the conventional wisdom. Results of a review conducted by Chung DM et al. concluded that implant length was the most important factor in maintaining implants over the long term [27]. The diameter of an implant, however, still remains more important in achieving primary stability [28] and reducing crestal strain than implant length [29].

6.2.2 Comparison of Short Implants Versus Bone Reconstruction Techniques

Implant-supported prostheses have been shown to be a reliable and predictable restorative option for single and multiple missing teeth; however, several challenges are faced in their placement. One factor is the lack of sufficient vertical alveolar dimension, especially in the posterior maxilla and mandibular regions. This can be attributed to the sinus pneumatization phenomenon after extraction [30] and resorption of the alveolar ridge due to prolonged periods of edentulism or periodontal disease.

Placement of what is considered standard length implants in these situations would compromise the maxillary antrum or inferior alveolar canal (Fig. 6.4). Therefore, advanced surgical techniques, such as block grafting, guided bone regeneration, distraction osteogenesis, sinus floor elevation, placement of angulated implants, or nerve repositioning, were developed to overcome these anatomical limitations. These procedures

do however come with their disadvantages, namely, increased treatment time, cost, post-surgical morbidity, complications, and being technique sensitive [31]. Lee SA et al. encountered complication rates of 7.6 % in short implant and 15.3 % in standard implants placed in augmented sites [32]. Postsurgical complications can range from severe postoperative pain, swelling, neurosensory disturbances, and graft resorption, all of which serve to decrease patient acceptability for bone augmentation procedures [22, 33] (Fig. 6.5).

Bone augmentation for implants can be carried out using autogenous bone, bone substitute materials, or a combination of both, none of which has shown to have any statistically difference when it comes to implant survival [35]; however, on the basis of total bone volume generated after grafting, autogenous bone is still considered the "gold standard" for augmentation procedures [36]

Short implants have been heralded as an option to avoid the need for bone augmentation, yet their placement contradicts what has been traditional implant protocol, which promoted choosing the widest and longest implant feasible to insure long-term implant survivability.

When discussing the topic of short implants, we firstly have to define what can be considered a short implant. This can prove to be a bit problematic, as there is no consensus in the literature for what length an implant has to be before it is termed short. All of the review literature agree that implants ≥10 mm in length are considered standard, with most indicating that implants less than 10 mm can be classified as short, with a smaller subset granting that classification to implants ≤8 mm. One review even further classified implants ≤6 mm as ultrashort [37], with the shortest commercially available implants being 4 mm.

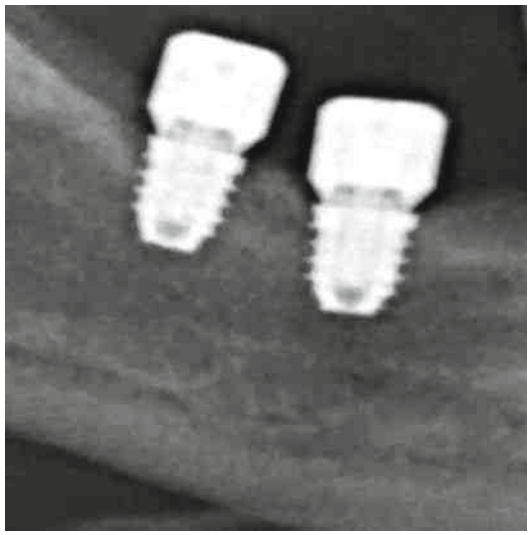

Fig. 6.4 Short implants may be useful in case of mandibular atrophy

Earlier studies, some of which had long-term follow-ups of more than 3 years, had shown that short machined (smooth) surfaced implants suffered from increased rates of failures when compared to machined surfaced implants ≥10 mm in length [38–40]. This decreased rate of survival was presumed to be because of several factors such as less bone-to-implant contact with short implants; short implants which were mostly placed in the posterior zone where the quality of the bone was relatively poor, especially in the maxilla [41]; and an unfavorable higher crown-to-implant ratio which was created due to the outsized crowns needed to reach occlusion in extensively resorbed ridges [42]

This evidence of higher failures in short machined implants would naturally bias most clinicians to augment bone in order to achieve enough vertical dimension for the placement of standard length implants and hence allow longer survivability of prostheses. If short implants were placed, it was suggested in some reviews that short implants be splinted to longer ones to reinforce their support [43] or to place wider diameter implants to increase the bone-to-implant surface area [44, 45].

More recent systematic reviews of short implants however have challenged the idea of increased implant failure when compared to longer implants. Short implants are now regarded as a safe and predictable treatment options with reduced failure rates, biological/prosthetic complications, and minimal bone loss [46]. This is due to the increased use of modified implant surfaces. Multiple systematic reviews, especially within the last decade, have concluded that there

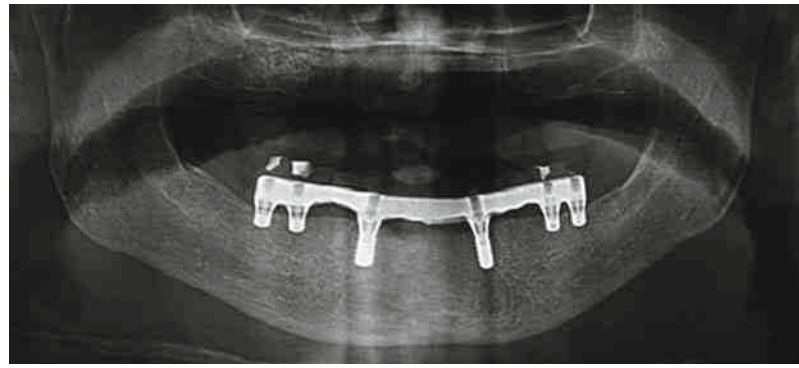

Fig. 6.5 Example of full mouth restoration with short implants (Reproduced with permission from Calvo-Guirado and coll. [34])

is no statistical difference between the survival of short rough surfaced implants in native bone and standard rough surface implants in augmented bone [47]. Roughened implant surfaces as mentioned above increase the mechanical interlocking at the bone-to-implant interface as well as provide increased functional surface area for transmission of compressive and shearing loads to the bone. All of which has resulted in clinically significant higher removal torque values [48] and increased implant survival rates in different bone types, especially type IV [19].

Successful osseointegration and its continued preservation for short implants depend on biological and prosthetic factors such as bone density, smoking habits, implant surface, crown-to-implant ratio, splinting, size of occlusal table, cantilever length, type of implant system, and opposing dentition [37]. In a systematic review carried out by Telleman G. et al. [42], sources of heterogeneity were explored to see whether there was any variation between some of the subgroups listed above.

6.2.3 Heterogeneous Factors and Their Effect on Short Implants

6.2.3.1 Bone Density

Multiple reviews have shown that short implants placed in the mandible had lower failure rates than those placed in the maxilla, which was also consistent with implants of standard length [40, 42]. A meta-analysis conducted by Monje A. et al. has shown a mean survival rate for short implants in the mandible and maxilla as being 94.9 and 92.7 %, respectively. This is attributed to the increased bone density of the mandible which imparts improved mechanical properties of the bone-to-implant interface, reduced stress concentration, and increased primary stability, all of which compensates for reduction in implant length. A systematic review carried out by Goiato. MC et al. showed how the survival rates of all implants in general varied according to bone type as follows: type I, 97.6 %; type II, 96.2 %; type III, 96.5 %; and type IV, 88.8 %. When implants were further classified according to surface roughness, the survival rate of treated surface implants inserted in low-density bone was higher (97.1 %) than that of machined surface implants (91.6 %) [19].

6.2.3.2 Smoking Habits

Smoking habits as it relates to short implants were analyzed by Telleman et al., with the estimated failure rates in studies where smokers were strictly excluded being twice as low, when compared to those studies where heavy smokers (≥15 cigarettes/day) were included. Strietzel FP et al. concluded that short implants should be considered cautiously in smokers, after similar findings of a significant association between heavy smoking (>10 cigarettes/day) and the frequency of implant loss. The association of smoking and increase implant failure was reviewed by Bain C. et al. over two decades ago, in which their study of Branemark implants over a period of 6 years revealed increasing tobacco

use correlating to an increased implant failure rate [49]. A review by Deluca S. et al. showed that patients who were smokers at the time of implant surgery had a significantly higher implant failure rate (23.08 %) than nonsmokers (13.33 %) and multivariate survival analysis showed early implant failure to be significantly associated with smoking at the time of stage 1 surgery and late implant failure to be significantly associated with a positive smoking history [50].

6.2.3.3 Crown-to-Implant Ratio, Splinting, and Occlusal Table

Short implants in resorbed areas usually have unfavorable crown-to-implant ratios, as a result of the tall crowns needed to attain occlusion with the opposing dentition. This increased crown-to-implant ratio would be problematic in natural teeth, and it was therefore suggested that short implants be splinted to better distribute occlusal forces [43].

Tawil G. et al. showed this precaution to be questionable in their review of how prosthetic factors influenced the survival and complication rates of short machined surfaced implants. It was concluded that increased crown-to-implant ratios and occlusal table values did not seem to be a major biomechanical risk factor, provided that force orientation and load distribution were favorable and parafunction was controlled [51]. There was an increase in complication rates for short implants in bruxers of 15 %, but the value was found not to be statistically significant by Tawil G. et al.

6.2.3.4 Implant Surface Treatments

Implant surface roughness is thought to be the main feature which allows short implants to overcome handicaps of length and poor crown-to-implant ratios in atrophic poor quality bone. The roughened surfaces have been shown to increase the osteogenic response, as observed in studies by Soskolne et al., who noted increased monocyte proliferation and adherence to rough titanium surfaces [52]. Laboratory trials by Conserva et al. displayed similar results when SaOS-2 osteoblast-like cells were used [53].

Pivodova V. et al. have shown that physical surface treatments (such as surface roughness) play a more important role than chemical modifications, although chemical modifications to implant surfaces can increase implant surface wettability and hence cell attachment [54].

6.2.3.5 Implant Diameter

Three-dimensional finite element analysis demonstrated that increasing implant diameter resulted in a 3.5-fold reduction in crestal strain compared to a 1.65-fold reduction in crestal strain when implant length was increased [29]. Increasing implant diameter therefore decreases the risk of peri-implant overloading and allows for better stress distribution. Increasing implant diameter also allows better engagement of the buccal and lingual cortical plates which promotes increased primary stability and hence osseointegration. All of these positive benefits holds true for standard length implants and confirmed by the meta-analysis results of Ortega-Oller I. et al. [55], who concluded that implants (<3.3 mm) had significantly lower rates than wider implants (≥3.3 mm). Yet for short implants, this does not appear to be the case as stated by Monje A. et al., who found that neither implant length nor width seemed to significantly affect the survival rates of short implants. The results of that meta-analysis were contradictory to studies of standard length implants, as failure rates of short implants increased with wider diameters.

Conclusion

Many reviews on the topic of short implants lacked large sample populations monitored over long periods of time and were retrospective studies or prospective studies not based on randomized clinical trials. This lack of robust long-term trials was mentioned by Lee SA et al. in their data search [32], leaving them with only four randomized control trials which satisfied the criteria for their meta-analysis.

Although many conclusions of articles on short implants recommended more evidence was required, the most important findings regarding short implant survivability and the factors that affect them are similar, that is that short rough surface implants is an effective treatment

alternative for the replacement of missing teeth in the totally and partial edentulous mouth where standard implants required advanced bone grafting techniques for placement.

Conclusions

From the review of the literature, it can be concluded that implant design remains a fundamental factor in achieving faster and better quality osseointegration of implants, especially in challenging situations of low bone density, immediate implantation, and high aesthetic demand.

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Platform Design

7

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Abstract

Implant platform is defined as the portion of the implant on which the abutment rests. Platform-switching design uses an abutment that is smaller in diameter than the outer edge of the implant neck. This particular design has been found to be associated with reduced marginal bone loss. It remains to be established if this favorable outcome occurs in all the clinical situations and with which extent. Possible factors that seem to contribute to the preservation of marginal bone in platform-switched implants are the shifting of the microbial leakage far from the bone or of the abutment-platform micromotion. Other cofactors may also contribute. Scalloped implant design is a new platform solution indicated in the esthetic zones, but although promising, more clinical studies are needed to confirm its validity.

7.1 Introduction

It is well documented in the literature that the crestal bone and the peri-implant mucosa heal around two-piece implants establishing a "biologic width." The crestal bone changes after implant placement (one-stage protocol) or abutment connection (two-stage protocol), and it resorbs apically if the implant–abutment interface is initially located at bone level or subcrestally. The peri-implant mucosa establishes a soft tissue attachment which seals the underlying bone and protects it from the contaminants of the oral cavity. The apico-coronal dimension of this soft tissue interface is called biologic width and has been studied histologically in animals and humans. It consists of two zones, a barrier epithelium coronally, about 2 mm long, and a supra-alveolar implant-connective tissue interface, about 1.5 mm high. The mucosa around dental implants presents several features in common with the gingiva around teeth. Both have a

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biologic width composed of an epithelial and connective tissue compartments, with similar heights. The main difference between the two resides in the quality of the supra-alveolar connective tissue: while in teeth are present attachment collagen fibers that are connected to the root cementum, in implants such fibers are orientated in a completely different manner and run parallel with the implant surface without any attachment to the metal body.

Which factors contribute to the stability of the peri-implant tissues and in what extent is still a controversial topic. Infection, loading forces, neck configurations, and microgap are some of the elements that have been studied as possible causes of early peri-implant bone loss.

Since the discovery of osseointegration in the 1980s, a number of devices and designs have been developed to overcome the biological and mechanical limitations of dental implants and to meet the prosthetic requirements for stable, esthetic restorations. The initial 0.7 mm-tall external-hexagon connection was developed based on the two-stage submerged surgical protocol introduced by Branemark. The platform design was developed giving priority to surgical rather than prosthetic requirements: the concept of biologic width was not yet completely understood, and there were no esthetic needs since implants were used only to restore edentulous arches. The purpose of the external hexagon was to allow the engagement of the fixture mount during the surgical placement of the implant. At the second-stage procedure, the purpose of the implant connection was merely to connect the transmucosal attachments used to stabilize the prosthesis. The external hexagon was not engaged since no antirotational features were required for the prosthesis.

Following the introduction of the two-stage protocol for edentulous arches developed by Branemark, implant dentistry developed rapidly. Implants begun to be utilized for fixed partial dentures and single tooth restorations, in esthetic areas and in conjunction with grafting procedures. The broader use of implants and their application to single restorations entailed several consequences. First of all, the concept of implant connection changed: originally intended only for rotational torque transfer mechanism during the surgical placement, it soon became an important prosthetic component with indexing and antirotational purposes. The whole implant dentistry evolved to a "restoration-driven" philosophy. Secondly, new mechanical and esthetic failures emerged and needed to be addressed. The 0.7 mm-tall external-hexagon connection could not satisfy the esthetic requirements and withstand the increased occlusal forces of single and multiple fixed restorations, since it was not designed for such purposes. Thirdly, dental implants became accessible to the large dental community; therefore, there was the need to simplify the clinical steps required to restore them. And finally, several studies investigated the concept of biologic width around implants, the peri-implant bone loss patterns, and the connection microleakage. This research led to the idea that a better seal and different connection configurations could prevent peri-implant bone loss and improve peri-implant tissue stability.

The initial changes were made to overcome the mechanical problems and involved the introduction of different external-hexagon heights and configurations, together with different screw and abutment designs. The purpose of such changes was to improve the connection strength, increase the horizontal and rotational stability, and improve components precision. In the late 1980s, the internally hexed connection was introduced to convey the loading forces inside the implant body, strengthen the connection, and reduce the bacterial microleakage. Since then, every company developed various designs of indexing feature, connection width and length, internal tapering, locking and sealing mechanism, seating verification mechanism, abutment emergence profile, materials, and surface characteristics.

In the early 1990s, a fortuitous finding led to the introduction of the concept of platform switching. Wide-diameter implants were introduced and used without matching wide-diameter prosthetic components, resulting in an implant–abutment interface horizontally shifted inwardly and away from the outer edge of the implant platform. Radiographic evaluation after abut-

ment connection of these implants showed a reduced crestal bone loss compared to the platform-matching implants. Further clinical and histological studies confirmed the reduced pattern of bone loss with platform-switched implants.

The implant–abutment interface is currently one of the most researched areas in implant dentistry. The biological and mechanical behavior of the implant connection and the peri-implant tissues determines the functional and esthetic success of the restoration. It is important to understand that there is no such thing as the perfect connection. The clinician needs to evaluate the different qualities and defects of each design and use the connection properties in his or her advantage, choosing the implant–abutment combination that better fits the single case. For anterior restorations, the priority often is given to marginal bone preservation, soft tissue support, and the choice of esthetic materials. In posterior restorations instead, strength and stability during function are usually prioritized. During the initial period of loading, every design seems to work efficiently. However, long-term success can be achieved only with the careful choice of the most convenient and reliable implant design [1].

7.2 Definition of Platform Switching

The implant platform is defined as the portion of the implant on which the abutment rests. The platform-switching design is based on the use of an abutment that is smaller in diameter than the outer edge of the implant neck Fig. 7.1. In this type of connection, the junction between the implant and the abutment is moved toward the center of the implant axis and away from the bone crest. The discovery of the effect that the platform-switching design has on marginal bone preservation was fortuitous. Since then, several studies have analyzed the biomechanical properties of this design, primarily to understand if the marginal bone is actually preserved, in which extent and for which reasons.

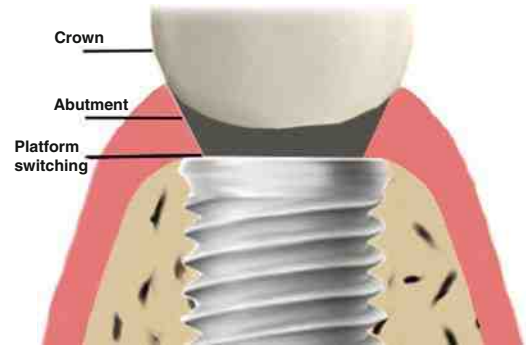

Fig. 7.1 The platform-switching concept involves an abutment of lesser dimension compared to the implant platform

7.2.1 Does Platform Switching Reduce Marginal Bone Loss?

A recent meta-analysis [2] selected 28 publications with a total of 1216 platform-switched implants and 1157 platform-matched implants. The eligibility criteria included clinical human studies, either randomized or not. The study reported a significantly reduced marginal bone loss in platform-switched implants compared to platform-matched implants (mean difference: −0.29 mm). The article showed also an increase of the mean difference of marginal bone loss between platform-switched and platform-matched implants with the increase of follow-up time: from a mean difference of −0.13 mm in the subgroup with ≤3 months' follow-up time to a mean difference of −0.60 mm in the subgroup with ≥3 years follow-up time. The same increase of mean difference of marginal bone loss was also noticed with the increase of mismatch between the implant platform and the abutment.

Another systematic review [3] included nine randomized controlled trials and prospective comparative clinical trials with a minimum follow-up of 1 year. Seven out of the nine selected studies reported a beneficial effect of platform switching in reducing peri-implant marginal bone loss compared to platform-matching, while two studies reported no significant differences. The overall conclusion of the article was that platform switching is effective in preserving marginal bone compared to platform-matching.

A systematic review and meta-analysis [4] selected ten randomized controlled trials with a minimum follow-up of 1 year and a total of 933 analyzed implants. Six of the ten studies identified a statistical significant difference in marginal bone loss between platform-switched and platform-matched implants, three studies reported just a slight difference, and one study did not test the results for statistical differences. The meta-analysis showed a mean difference in marginal bone loss between the platform-switched and platform-matched groups of −0.55 mm. The study reported an overall lower degree of marginal bone loss with the platform-switched implants compared to the platform-matched implants, with a more evident marginal bone preservation effect with increasing the extent of implant–abutment mismatching.

Another systematic review and meta-analysis [5] included ten randomized controlled trials and controlled clinical trials with a minimum follow-up of 1 year. A total amount of 643 platform-switched implants and 546 platform-matched implants was analyzed. Seven out of ten articles reported a statistically significant reduction in peri-implant bone loss around platform-switched implants compared to platform-matched implants, while three studies failed to show any statistical difference. The meta-analysis showed a mean difference in marginal bone loss between the two groups of −0.37 mm. The article conclusion was that platform switching is effective in preventing crestal bone loss when compared to platform-matching.

Systematic reviews and meta-analysis about this topic present several limitations, and the obtained data need to be evaluated carefully. Confounding factors of the analyzed articles may have affected the results. Every selected article presented different implant systems, surface textures, connection types and prosthetic designs, timings of implant placement and loading, presence or absence of grafting procedures, implant locations and angulations, types of opposing dentition, and patient-related local risk factors. Most of the articles used a small sample size and short follow-up period. Several articles also presented methodological issues and biases. Considering all the limitations, there is evidence to suggest that overall the platform-switching design is effective in preventing peri-implant marginal bone loss (Figs. 7.2, 7.3, and 7.4). Moreover, the increase of time and extent of implant–abutment mismatch seem to magnify the beneficial effect of platform switching in preserving crestal bone. However, the marginal bone preservation phenomenon of the platform-switched design has still to be considered a hypothesis since there is not enough reliable data to proof causality. The extent of marginal bone preservation related to the amount of implant–abutment mismatch is still not clear. It is also important to underline that all the studies reported no difference in survival rates between the platform-switched and platform-matched implant groups (Tables 7.1 and 7.2).

7.2.2 Why Platform Switching Seems to Preserve Marginal Bone?

It is still unknown why platform switching seems to preserve marginal bone. Several hypotheses have been formulated to explain this phenomenon.

The most accredited explanation relates the bone loss pattern to the presence of bacterial microleakage [6]. Implant platforms are available in numerous designs, but they all have in common the presence of an interface between the implant and the abutment called microgap (Fig. 7.5). The design of the implant platform, together with the size and location of the microgap, seems to play an important role in the crestal bone remodeling and in the soft tissue architecture. Peri-implant bone resorption only begins once the implant is uncovered and exposed to the oral environment. In vitro studies have shown that bacteria colonize the microgap causing inflammation of the peri-implant tissue. Animal and human histological studies confirmed the role of bacterial leakage from the microgap in the crestal bone resorption (Fig. 7.6). The

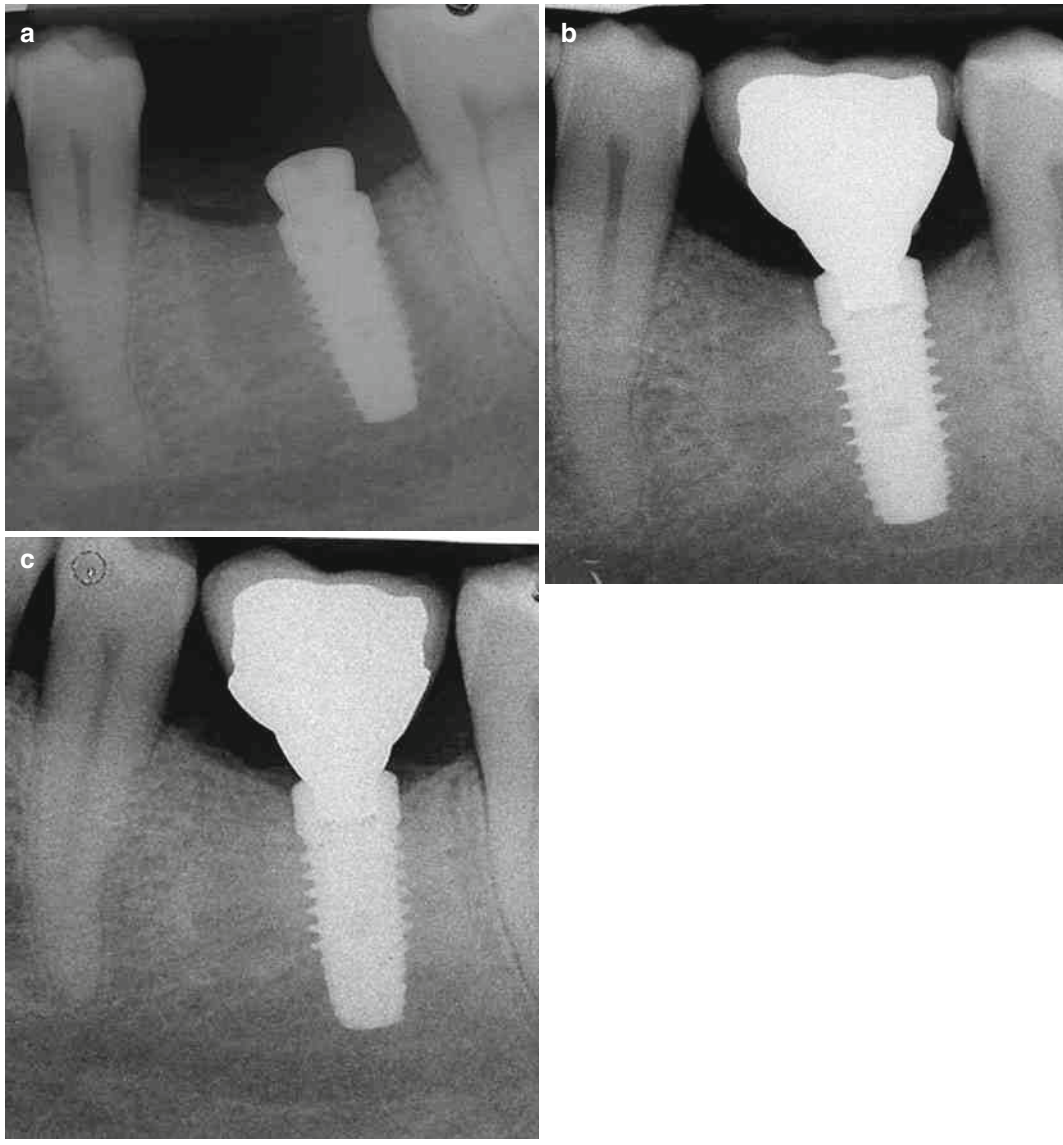

Fig. 7.2 Radiographic appearance of a platform-switched implant (Reproduced with permission from Del Fabbro and coll.)

platform-switching design carries the microgap away from the implant shoulder, therefore shifting the inflammatory cell infiltrate toward the implant central axis and reducing bone resorption.

Another possible factor seems to be the micromotion of the abutment-platform interface. Such interface is considered to be the area of maximum biomechanical stress and has been linked to peri-implant bone resorption [7]. The platform-switching design would again keep these micromovements away from the implant shoulder therefore reducing the stress on the peri-implant crestal bone.

The inward shifting of the implant–abutment connection appears to also change the spatial distribution of the biological width: the medial repositioning of the soft tissue attachment leads to the establishment of the biological width horizontally instead of vertically. This results in less resorption of the crestal bone.

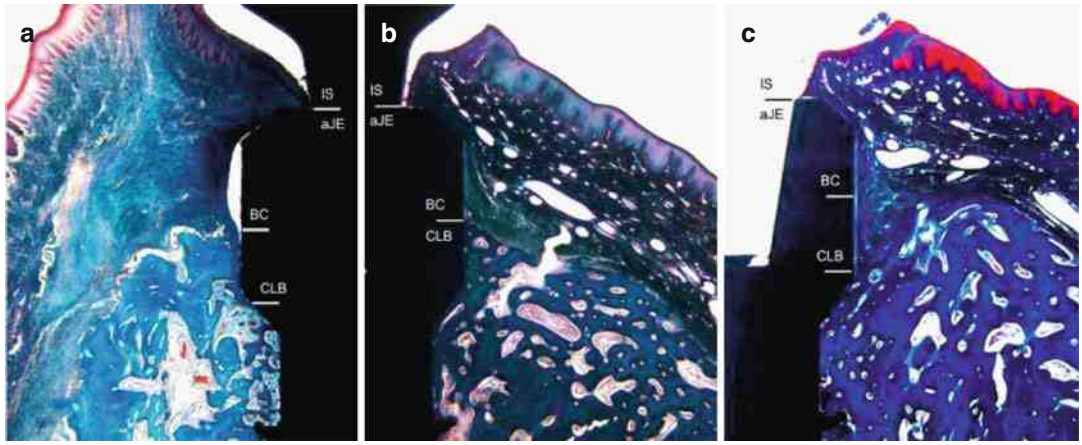

Fig. 7.3 (**a–c**) Representative histological views (Masson-Goldner stain) of crestal bone changes at matched implants in dogs (original magnification 40×). (**a**) 7 days (buccal site), (**b**) 14 days (lingual site), and (**c**) 28 days (buccal site). *IS* implant shoulder, *aJE* the apical extension of the long junctional epithelium, *CLB* the most coronal level of bone in contact with the implant, *BC* the level of the alveolar bone crest (Reproduced with permission from Becker et al.)

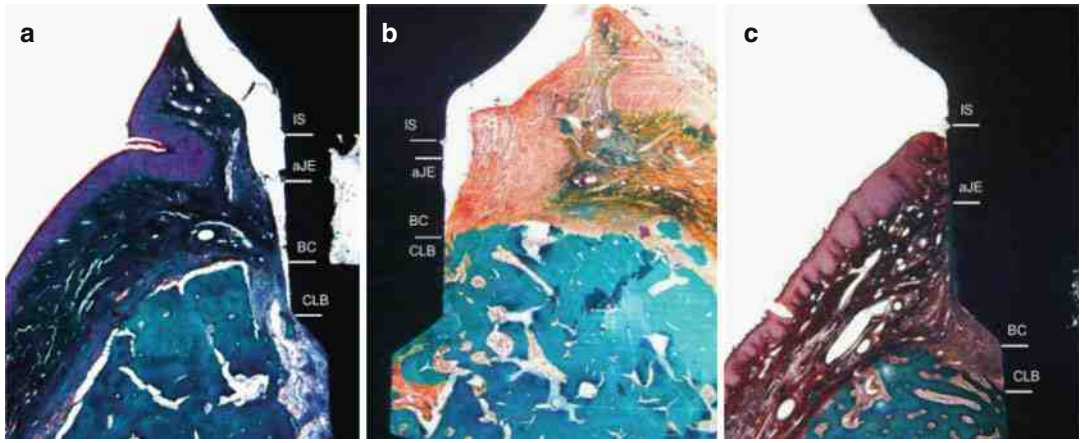

Fig. 7.4 (**a–c**) Representative histological views (Masson-Goldner stain) of crestal bone changes at platform-switched implants (original magnification 40×). The circumferential horizontal mismatch of 0.5 mm was able to prevent the apical downgrowth of the barrier epithelium over an observation period of 28 days. (**a**) 7 days (buccal site), (**b**) 14 days (lingual site), and (**c**) 28 days (lingual site). Landmarks for histomorphometrical analysis: *IS* implant shoulder, *aJE* the apical extension of the long junctional epithelium, *CLB* the most coronal level of bone in contact with the implant, *BC* the level of the alveolar bone crest (Reproduced with permission from Becker et al.)

Table 7.1 Meta-analyses comparing *marginal bone loss* (*MBL*) of platform-switched vs. platform-matched implants

	Effect size	Platform-switched vs. platform-matched implants (95 % CI)	Statistically significant	Clinical meaning
Chrcanovic et al.	RR	−0.29 (−0.38 to −0.19)	+	In favor of perio healthy patients
Atieh et al.	MD	−0.37 (−0.55 to −0.20)	+	In favor of platform switching
Annibali et al.	MD	−0.55 (−0.86 to −0.24)	−	In favor of platform switching

RR relative risk

Table 7.2 Meta-analysis comparing *survival* of platform-switched vs. platform-matched implants

	Effect size	Platform-switched vs. platform-matched implants (95 % CI)	Statistically significant	Clinical meaning
Atieh et al.	RR	0.93	–	In favor of platform switching

RR relative risk

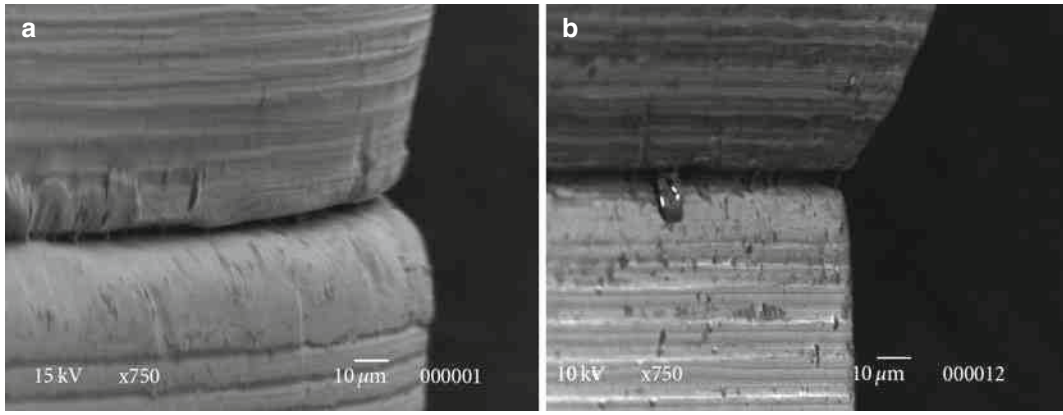

Fig. 7.5 (**a–b**) The microgap of two different implant types is evident at SEM analysis. (Reproduced under CCC permission from Lorenzoni and coll)

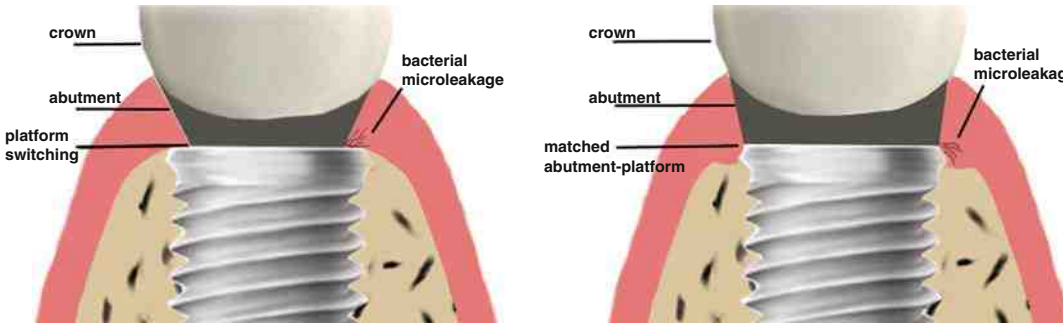

Fig. 7.6 The presence of bacterial micro leakage from the connection is considered to be the main cause of the different crestal bone resorption patterns between platform switching and platform matching implants

7.2.3 What Are Other Possible Cofactors That May Influence the Marginal Bone Resorption?

Several factors have been studied as contributors to the marginal bone loss in relation with the platform switching.

7.2.3.1 Abutment Disconnection Times

It has been proposed that the abutment connection/disconnection may increase the amount of marginal bone loss [8].

Koutozis et al. [9] evaluated the effect of healing abutment disconnection and reconnection on soft and hard peri-implant tissues in a prospective randomized controlled clinical trial.

They indicated that implants receiving a final abutment at the time of implant placement exhibited minimal marginal bone loss and were similar to implants subjected to abutment disconnection and reconnection up to two times.

In the study of Degidi et al. [10], the abutments were removed a total of four times, and compared to other group of patients using the "one abutment at one time concept," reported that over a period of 36 months no significant differences were observed between the two groups of patients with regard to vertical bone level changes.

Vigolo et al. [11] reported the longest follow-up period (5 years). He suggested that the greatest amount of bone changes occurred between surgery and crown/abutment placement, after which the changes were minimal.

Becker et al. [8] also concluded, and within the limitations of an animal study, that repeated manipulation of the abutments may be associated with dimensional changes of peri-implant soft and hard tissues formed at both mismatched Ti and ZrO_2 abutments. In both Ti and ZrO_2 groups, a repeated abutment dis-/re-connection at 4 and 6 weeks was associated with an increased apical extension of the junctional epithelium and subsequently crestal bone level changes after 8 weeks of healing.

As an opposite finding, another study [12] with short-term data (4-month post-loading) showed that repeated abutment changes do not alter bone levels significantly.

Alves et al. [13] concluded, within the limits of this animal study, that the connection/disconnection of platform-switching abutments during prosthetic phase of implant treatment does not induce bone marginal absorption. Furthermore, it may present a negative influence in the buccal connective tissue attachment that becomes shorter anyway preventing marginal hard tissue resorption, especially in thin biotypes.

As a practical implication, the clinician should carefully consider the detrimental impact of a repeated abutment dis-/re-connection on soft and hard tissues during the initial phase of peri-implant wound healing (4–6 weeks).

7.2.3.2 Micromovements

Additional bone resorption seems to be correlated to micromovements at the abutment–implant interface. The platform-switch approach may keep away the micromotion between the implant and abutment from the bone.

This theory, supported by finite element analyses, suggested that this design reduced the stress at the bone–implant interface and in the crestal region of cortical bone by shifting the stress to cancellous bone during loading [14–17].

Hsu et al. [18] confirmed the hypothesis, reporting a 10 % decrease in all the prosthetic loading forces transmitted to the bone–implant interface.

Maeda et al. [19] noticed that this procedure shifts the stress concentration away from the bone–implant interface, but these forces are then increased in the abutment or in the abutment screw.

All these findings are also supported by another study [20], in which a greater risk of implant fracture with platform-switched implants than with conventional diameter-matched implants. High-strength abutments should be chosen to prevent fracture.

7.2.3.3 Laser Microtextured Collar

A different strategy proposed is to promote the attachment of bone and connective tissue to the implant collar surface and, it is claimed, help to transfer stress from the implant to the crestal bone [21, 22].

Based on this strategy, the collar surface is laser microtextured with 8- and 12-μm grooves. Tissue culture studies have demonstrated cellular attachment by osteoblasts and fibroblasts to laser-microgrooved surfaces [23, 24]. In addition, it has been hypothesized that crestal bone levels adjacent to implants with microtextured collars may achieve more coronal attachment than implants with machined collars.

Botos et al. [25], based on a case control study of 15 overdenture patients with immediately loaded implant designed with laser-microtextured and machined collars, determined that:

1. The presence of a laser microtextured implant collar did not increase the plaque or sulcus bleeding indices.
2. The probing depth and the crestal bone loss adjacent to the laser-microtextured collar implants were statistically significantly lower

than those observed adjacent to the machined-collar implants.

A recent human clinical trial evaluated two similar implant types differing only in the surface texture of the neck and showed no significant influence on marginal bone level changes [26].

Linkevicius et al. [27] concluded that both laser microtexturing of implant collar or platform-switched implant–abutment connection did not eliminate crestal bone loss, if at the time of implant placement vertical soft tissue thickness was ≤2 mm. However, laser-microtextured implants may present less proximal bone loss than platform-switching implants in the period before implant loading.

7.2.3.4 Amount of Mismatch

It has been suggested that the inward positioning of the implant–abutment interface allows the biologic width to be established horizontally, since an additional horizontal surface area is created for soft tissue attachment. This meant that less vertical bone resorption is required to compensate for the biologic seal. Furthermore, this design might increase the distance between the inflammatory cell infiltrate at the microgap and the crestal bone, thereby minimizing the effect of inflammation on marginal bone remodeling [28, 29].

Moreover, it was observed that increasing the distance between the implant–abutment interface and adjacent bone may increase the anti-bone-resorptive effect of the platform-switching concept.

However, it has been speculated that the findings of reduced bone remodeling accompanying a larger implant–abutment difference may be due to an increased implant diameter rather than to the platform [30], because a bigger mismatch is often caused by the use of a wider diameter [31].

Canullo et al. [32] are also supporting these findings, for whom the effect of platform switch on marginal bone level seemed to be "dose dependent." He demonstrated that the greatest platform–abutment mismatch resulted in the least marginal bone loss.

Cocchetto et al. [33] evaluated the biologic effect of using a wide platform-switching restorative protocol in human. The results indicated that patients receiving wide platform-switched implants may experience less crestal bone loss than that resulting from the use of regular platform switching.

Atieh et al. [5] also reached similar results. They observed that the degree of marginal bone resorption is inversely related to the extent of the implant–abutment mismatch.

Radiographically, the influence on marginal bone remodeling of a mismatch of 0.25 up to 0.5 mm was demonstrated with several prospective studies [34–36].

As an opposite finding, another study [37] failed to show significant differences in both hard and soft tissue dimensions when a mismatch of 0.25 mm was applied between the implant shoulder and the abutment (platform switching).

7.2.3.5 Size of the Microgap

Many authors have identified the presence of a microgap at the implant–abutment interface, resulting in bacterial colonization of implant sulcus, the possible etiologic mechanism for crestal bone resorption.

It is likely that there is a bacterial leakage within the implant system, after its prosthetic connection, with subsequent penetration of bacteria and their products within the microgap between implant and abutment. This would cause an inflammatory process close to the crestal bone, resulting in bone support loss [6, 38–41].

It was pointed out, however, that the resorption resulting from biological processes after prosthetic restoration changes with the use of a platform-switching model [42]. These findings were related to a decreased microgap in the connection interface whenever using platform switch.

Berberi et al. [43] investigated in vitro the leakage at implant–abutment interface of implants connected to original and compatible abutments. The original components were showing significantly better results than the compatible ones. It can be assumed that the source of the abutment used can also result in bone loss.

7.2.3.6 Connection Type

The cone Morse taper internal connection, designed to be completely stable with absence of

micromovements between the parts during function, seems to be able to resist more to the bacteria penetration due to of their self-locking characteristics.

A study confirmed the very low permeability to bacteria of the conical implant–abutment connection and the high prevalence of bacterial penetration of screw-retained implant–abutment assemblies [44].

The aim was to evaluate with an in vitro study the leakage observed in internal hexagon and Morse taper implant–abutment connections. The results of their in vitro study showed that bacterial contamination occurs in different types of implant–abutment connections, even if with different percentages. Furthermore, it must be pointed out that in the conical implant–abutment connection, the bacterial contamination occurred quite lately during the course of the experiment (on the 22nd day), whereas the contamination was always earlier in the butt-joint connection implants.

Jaworski et al. [45] compared external-hexagon and Morse taper implant systems. They concluded that both implant designs showed leakage, but the Morse taper connection provided a better bacterial seal than the external-hexagon design of the implant system used in the study.

7.2.3.7 Microthreads

Some studies have shown that microthreads help to preserve peri-implant marginal bone [46–48].

In addition, the study reported that the location of the microthreads on the implant platform may have influenced the degree of marginal bone loss encountered.

Song et al. [49] indicated that the closer the microthreads were to the top of the implant, the less marginal bone loss would occur. As a consequence, the presence of microthreads might mask the true effect of PS on marginal bone preservation.

7.2.3.8 Polished Neck or Rough Neck

Every study includes implants with different surface treatments. Titanium implants with different surface modifications shows a wide range of chemical, physical properties, and surface topographies or morphologies, depending on how they are prepared and handled [50–52], and it is not clear whether, in general, one surface modification is better than another [53]. The texture of the implant's surface may play a major role in marginal bone resorption [54]. It has been shown, for example, that implants with a roughened surface that extends closer to the abutment-platform junction tend to have less alveolar bone loss [40].

7.2.3.9 Inward Inclined Platform Switch

In the literature, the platform-switching concept has been performed with horizontal flat or outward-inclined mismatching. However, a study [55] tested the benefits of an inward oblique mismatching. They evaluated the hard and soft tissue responses around a new implant concept with an inward inclined platform, which is believed to amplify the platform-switching concept, and compared them to the tissue response around an external-hexagon implant restored according to the traditional prosthetic concept. In their study, it is described a better outcome of this type of design compared to the traditional external-hexagon matching connection. A comparison with a regular platform-switching implant was missing in the study.

7.2.3.10 External vs. Internal Connection

Rodriguez-Ciurana et al. [56] in a two-dimensional biomechanical study involving platform switching integrated into the implant design failed to obtain peri-implant bone force attenuation values as high as those reported in the earlier studies, when comparing platform expansion with a traditional restoration model. In addition, the authors concluded that force dissipation in the platform-switching restoration is slightly more favorable in an internal than in an external junction, since it improves distribution of the loads applied to the occlusal surface of the prosthesis along the axis of the implant.

Several implant neck configurations have been implemented to preserve marginal bone level. No evidences have been found about the effectiveness

of these configurations in the preservation of marginal bone level. Marginal bone loss in the implant neck area seems to occur regardless of all the efforts to eliminate it. In conclusion, there is a need to further understand the mechanisms by which the peri-implant bone remodels at the marginal level and how to preserve it before evaluating the effectiveness of a specific implant neck configuration.

7.3 What Are the Risks and Benefits of Platform Switching?

The reported crestal bone preservation properties of the platform-switching design would be useful in several clinical situations. Based on the assumption that the design reduces vertical and horizontal crestal bone loss compared to the traditional platform-matched design, implants can be placed closer to natural teeth and to each other. Single implants can be placed in narrower mesiodistal spaces, for example, in the maxillary lateral incisor or the mandibular incisor positions, without causing bone loss and apical migration of the papillae. Similarly, narrow ridges can receive implants avoiding, in some cases, grafting procedures and buccal soft tissue recession. These properties represent a major advantage in the esthetic region, where papillae preservation and facial recession are often very challenging problematics. In the posterior region, platform switching can be combined with short implants, allowing greater bone–implant surface contact, essential for the mechanical stability of implants with reduced surface area. However, the implant design must be carefully planned and tested by the manufacturer. The clinician has also to understand the different properties of the platform-switched implants. The implant–abutment mismatch causes a different emergence profile of the restoration, with a thinner apical base. The appropriate implant and abutment sizes have to be chosen depending on the loading forces and final prosthetic design. Often a slightly more apical position of the implant is required to allow for an appropriate and cleansable emergence profile.

7.4 Scalloped Implant Design

The dental implant design at the platform level has been modified throughout the past 25 years. The most important variations introduced so far have been the internal connection and the platform-switching design. The original implant design with a flat implant–abutment interface was intended for edentulous patients, which present a significantly different bone and soft tissue morphology compared to the partially edentulous patients. The bone contour of the edentulous patients is described as flat, while the bone contour of partially edentulous patients presents various degrees of interproximal scallop. A scalloped morphology is described as a bone crest which presents more tissue coronal to the bone interproximally than facially (Fig. 7.7). An implant with a classic flat collar design placed in a crest with a scalloped contour of bone and soft tissue will not be able to fully maintain the alveolar bone crest. In such situations, the implant platform is placed at the level of the lower facial alveolar bone crest, therefore causing interproximal bone loss and eventually the possible loss of the interproximal papilla. In order to preserve the scalloped bone and soft tissue architecture and preserve the papilla level especially in the esthetic region, in 2003 a new scalloped implant design was introduced in the market [57].

Very few studies have been conducted so far about the clinical efficacy of the scalloped implant design, and with contradictory results. Most studies reported more crestal bone loss in the scalloped design than the flat design and therefore the failure of the scalloped implants in maintaining the bone and soft tissue architecture [58–62]. Only two studies reported a positive outcome [63, 64]. All the available articles but one present a low evidence level due to confounding factors, small sample size, short follow-up periods, and poor study design. A recent randomized clinical trial with 5-year follow-up

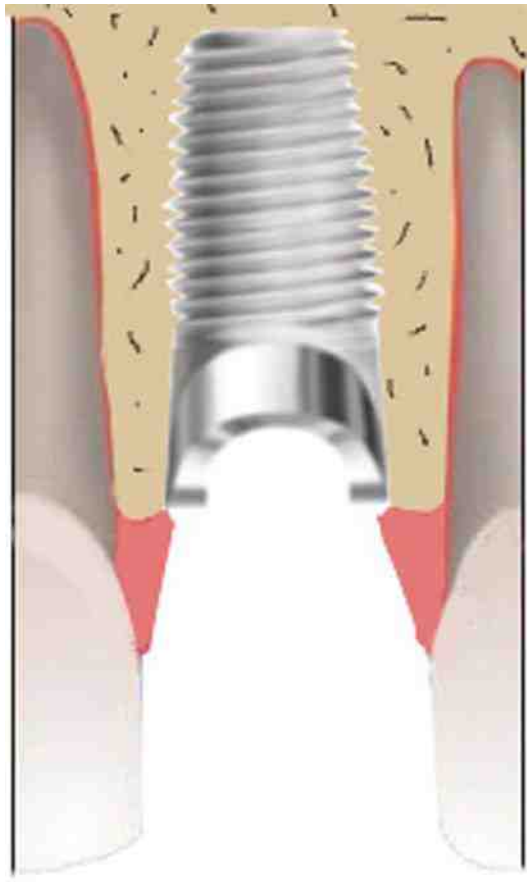

Fig. 7.7 Example of scalloped implant. This design should preserve the scalloped bone in the interproximal area and soft tissue architecture and in this way the papilla morphology

analyzed the clinical outcome of the scalloped design in the esthetic region [65]. The study reported greater bone loss, inflammation and bleeding of peri-implant soft tissue, and probing depths around scalloped implants than around flat implants. The interimplant papilla showed similar results in both the scalloped and flat designs. The study concluded that the scalloped design had no beneficial effects compared to the classic flat design in the esthetic region. Previous reviews [66, 67] couldn't establish recommendations based on clinical evidence about the efficacy of the scalloped design since further long-term, prospective, controlled studies were required to have reliable data.

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Implant Abutments

8

Oreste Iocca

Abstract

Abutments are important for the success of the implant treatment. Histologic studies show that the peri-implant mucosal barrier forms around the abutment and acts as a protective seal between the oral cavity and the underlying bone. Biocompatibility is fundamental in order to ensure an appropriate formation of the mucosal seal. Given the increasing esthetic requests, zirconia has emerged as an alternative to titanium abutments. Both materials seem to give similar performances in terms of biocompatibility and incidence of complications.

The abutment screw is an important component that serves to secure the abutment to the implant. The preload, depending by the torque, is the initial load and elongation of the screw that is important for optimal holding of the components together. An optimal preload is a prerequisite for preventing screw-related complications such as screw loosening and stripping.

Regarding the types of connections, when internal versus external typologies are compared, it seems that internal connection gives best results in terms of lower rate of complications.

Finally, the use of angled implant abutments is necessary in some situations, which increases the stress around the peri-implant bone at the same time does not seem to impair the clinical results.

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8.1 Implant Abutments

Dental implant abutments play a fundamental role in the success of implant treatment. Abutment may have a huge impact on the functional and esthetic outcomes. In order to discuss this topic, it is important to define the different segments

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that characterize the structure of a generic abutment:

- The *superior portion* of the abutment is the one that connects to the prosthesis.
- The *inferior portion* connects with the implant.
- The *transgingival portion* is the part in contact with the mucosa above the implant platform.

Moreover, abutments can be subdivided in two categories:

- *Prefabricated* usually manufactured by the same company that produces the adopted implant
- *Customized* fabricated as cast custom or with CAD/CAM technologies

According to the clinical indications, the majority of manufacturers offer the possibility to choose between *straight* and variably *angled* abutments.

Various materials are used for abutment manufacturing [1].

Pure titanium (Ti) is widely adopted and has shown good mechanical properties and biocompatibility. *Titanium nitride* (TiN) can be used in challenging esthetic cases because the plasma-coating process with Ti and N ions confers to the abutment's surface a gold color that helps in achieving an esthetic mimicry with the overlying gingiva. A flaw of this modification is that it does not allow any adjustment due to the fact that the coating is usually less than 0.5 μm thick; therefore, even a minimal modification of the abutment would damage it.

Grade 5 titanium (Ti-6Al-4 V) is also used in manufacturing of dental abutments considered that it is stronger than pure Ti.

Gold abutments have been generally abandoned. They were used mainly as customized abutments but the introduction of reliable prefabricated solutions and CAD/CAM technology led to progressive reduction in their use.

Zirconia (ZrO2) has also been adopted as an abutment material due to its high esthetic properties and excellent biocompatibility. In the same fashion as for implant manufacturing (see Chap. 4), the use of ZrO2 needs a thorough review of the scientific evidence in order to be sure of its mechanical properties in clinical practice.

Poly-ether-ketone (PEK) is normally used in fabrication of temporary abutments. It is a material easily modifiable at the chair side, white in color, and with good mechanical properties. Anyway it is not suitable as a definitive solution.

8.1.1 Mucosal Attachment at Different Abutments

The peri-implant mucosal barrier can be considered a protective seal that forms between the oral environments and bone (Fig. 8.1). In the natural dentition, this seal is ensured by the presence of

Fig. 8.1 Representative histologic image of the peri-implant mucosal margin (*PM*), junctional epithelium (*JE*), and the most coronal bone in contact with the implant (*CBI*) (Reproduced with permission from Iglhaut and coll.)

the junctional epithelium which attaches to the tooth structures via hemidesmosomes.

At the implant-abutment interface, there is no formation of the same histologic structure [2]. The first difference is that peri-implant soft-tissue dimensions are enlarged (mean dimensions of 3–3.5 mm of biologic width compared of the mean 2.5 mm around natural dentition). Second, hemidesmosomes are also present, but usually there are no collagen fibers running perpendicular to the abutment surface; instead parallel fibers are present. Also the quality of connective tissue is different; approximately 60 % of collagen fibers and 10–15 % of fibroblasts are evident around natural teeth, whereas around implants it is possible to find around 85 % of collagen fibers and just 2–3 % of fibroblasts.

It has been stated that the mucosal connective tissue around an implant resembles a scar (Iglahut 2014) [3] rich in fibrous tissue with scarce cellularity and reduced vascular supply. Considered that with an implant there is the absence of the periodontal vascular plexus, the vascular supply is provided mainly by the supraperiosteal vessels (Fig. 8.1).

Abrahamsson and coll. [4] evaluated the mucosal attachments of different abutments in dogs. The experiment examined titanium, ceramic (Al_2O_3), and gold alloy abutments installed in the mandibles of beagles. The histometric analysis took in consideration the distance between PM-CBI at 3 months of healing; measurements gave mean results of 3.32 mm for Ti, 3.36 for ceramic, and 2.55 for gold. It was concluded that with gold abutments the length of junctional epithelium and connective tissue attachment was smaller compared to the other two; this happened because soft tissue receded and ultimately bone resorption occurred in a great quantity than the other two materials.

These results were confirmed in another experiment by Welander and coll. [2] which evaluated titanium, zirconia, and gold abutments with the same methodology. In this study was also performed a qualitative assessment of the tissue around the abutment. Polymorphonucleate leukocytes and other inflammatory cells were present due to the presence of microorganisms in the sulcus, and after 2 months of healing, the percentage of leukocytes was similar in all three observed abutments with a range of 5.2–6.8 %. After 5 months the percentage had decreased to 3.5–4.5 %. For this reason, reduced performances of gold abutments were supposedly caused by other factors than induced inflammation. In particular, titanium and zirconia seem to favor a proper healing around the abutment, whereas gold does not constitute an ideal material for soft-tissue integration.

The comprehensive review of Iglhaut and coll. [5] outlined the fact that controversial results exist in terms of soft-tissue healing around different materials. But sufficient evidence has been accumulated such that gold abutments seem to favor a detrimental mucosal downgrowth when compared to Ti and ceramic materials.

Another issue that may have some importance in the soft-tissue adaptation is the disconnection and reconnection of the implants. It's been shown experimentally that abutment disconnection and reconnection can have some influence in increased epithelial downgrowth. Abrahamsson and coll. [6] showed that repeated disconnected and reconnected abutments five times every month showed greater bone resorption than abutments left untouched.

Also some clinical studies showed that placement of the definitive abutment at the time of implant uncovering helps in the maintenance of the soft-tissue levels. Anyway, these observations need to be validated by large randomized clinical trials.

In summary, titanium and ceramic materials like zirconia can be considered equivalent in terms of biocompatibility and soft-tissue adaptation and seem to warrant better results when compared to gold cast alloys [7].

8.1.2 Titanium Versus Ceramic Abutments: Clinical and Esthetic Results

From the clinician standpoint, it is important to understand which kind of implant abutment gives the best results in terms of survival, complication rates, and esthetics.

The meta-analysis by Zembic and coll. [8] analyzed the abutment survival rates, the incidence of biological and technical complications, and esthetic outcomes of single abutments made of different materials.

When titanium and zirconia studies were compared, no significant difference between the two materials was found in terms of abutment survival estimates at 5 years.

Regarding the technical complications, it was confirmed that the most common occurrence was abutment screw loosening (see Chap. 3), but the incidence of complications was not linked to the adoption of a particular material instead of another. On the other hand, there was a trend suggestive of higher incidence of biological complications for ceramic abutments compared to metal abutments which was in contrast to most studies showing a similar biocompatibility of titanium and ceramics.

Esthetic evaluation, although considered difficult for the lack of standardized methods of reporting and heterogeneity of the studies, evidenced no esthetic failures for the studies adopting ceramic abutments, while a 5-year estimate of esthetic complications was found to be around 0.9 % for metal abutments restorations. The authors concluded that no difference in technical or biological performances can be found. Esthetic outcome difference, in particular the tissue color change, was found to be worst for metal abutments.

Another systematic review on the performance of ceramic and metal abutments supporting fixed implant reconstruction concluded that in the majority of the studies, the information regarding ceramic abutments is limited by the low number of abutments analyzed and the short follow-up time and it cannot be excluded that this has a role in the results of the analyses.

Linkevicius and coll. [10] conducted a meta-analysis on the only three RCTs available about specific esthetic results of zirconia versus titanium abutments. In particular, an objective evaluation of the buccal gingiva color with a colorimeter was used as a term of comparison between zirconia and titanium abutments at 1 week after placement and healing. The results obtained with a colorimeter or spectrophotometer are expressed in numerical as ΔE values (change in color between the peri-implant gingiva and tooth gingiva). The higher the difference between adjacent tissues, the lower is the esthetic outcome. The meta-analysis showed that lower values emerged for zirconia abutments (ΔE, 8.48; CI 95 %, 7.71–9.94) compared to titanium (ΔE, 10.88; CI 95 %, 10.11–11.64); the results were statistically significant.

This further strengthens the consideration that zirconia gives better esthetic results compared to titanium [11–13].

On the basis of the available data, titanium and zirconia abutments seem to give good clinical results in terms of survival and risk of complications (Fig. 8.2). No clear advantage in the use of one material over the other can be showed analyzing the current evidence, although better esthetic outcomes emerge with the adoption of zirconia as implant-abutment material. On the other hand, it needs to be pointed out that many long-term studies are available in the case of titanium, but the same thing does not occur with zirconia. Considered that mechanical strength concerns arise when a ceramic material is used for restoration, more information from long-term follow-up studies will help to draw definitive conclusions.

8.2 Abutment Screws

An implant abutment is secured to the implant by an implant screw. Considered that screw loosening is a common unwanted occurrence in implant dentistry (see Chap. 3), an attempt to describe the mechanics of the abutment screw may help to understand how to decrease the incidence of complications related to this prosthetic component.

8.2.1 Preload

The screw is retained to the implant by a tightening force that is dependent by the torque applied to the screw (in N/cm). The transformed

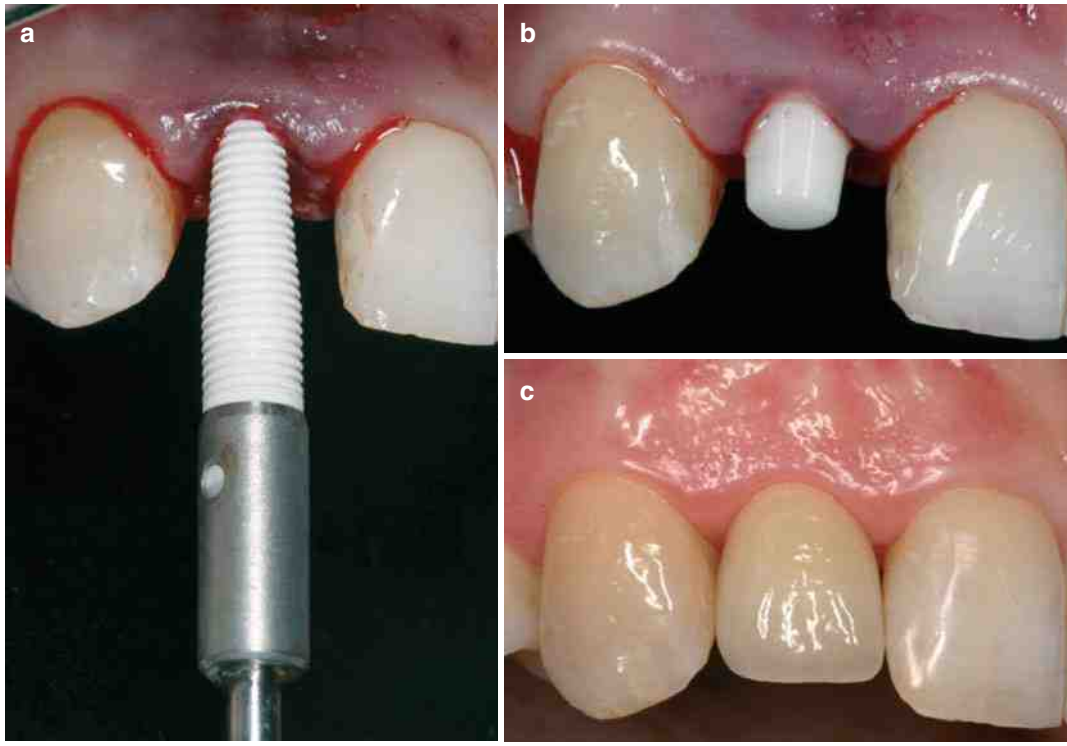

Fig. 8.2 (**a–c**) Zirconia implant placed in region #11 (**a**), zirconia abutment in place (**b**), esthetic results after 13 weeks (**c**) (Reproduced with permission from Kohal and coll.)

force is transmitted to the abutment screw threads and to the implant threaded surfaces accommodating the screw. This contact force produces a linear stretch of the screw that ultimately results in holding the components together. This initial load and elongation of the screw is called *preload* which is measured in newtons (N) (Fig. 8.3).

Preload is crucial in ensuring the clamping of the screw to the implant; it is dependent by the torque applied, the design of the screw, the material adopted, and the surface conditions [14].

There is a point in which optimal preload is achieved, this corresponds to the optimal abutment/implant stress interface, and above this point we have a plastic deformation of the screw, while below this point, we don't reach an optimal tightening.

There is an almost linear correlation between the torque applied and the preload achieved; usually the different manufacturers recommend to apply a given torque value which should allow to obtain the optimal preload for the specific screw.

Finite element analysis (FEA) studies have examined the dynamics of the preload development when specific torque values were applied. Lang and coll. [15] established the optimal preload value to be 75 % of the yield strength, while that for a common Ti screw is around 825 N. In their FEA study, it was stated that a torque of more than 35 N/cm was necessary in order to achieve the recommended preload values of at least 825 N.

Another FEA study by Bulaqi and coll. [16] arrived at the conclusion that the *coefficient of friction* of the surfaces and the *speed of tightening* are important in increasing the preload. In particular, reducing the *coefficient of friction*, either with surface modifications or with the use of a lubricant, may help in achieving optimal preload values. Also increasing the *tightening speed*, for example, from 15 rpm to 30 rpm, has a role in

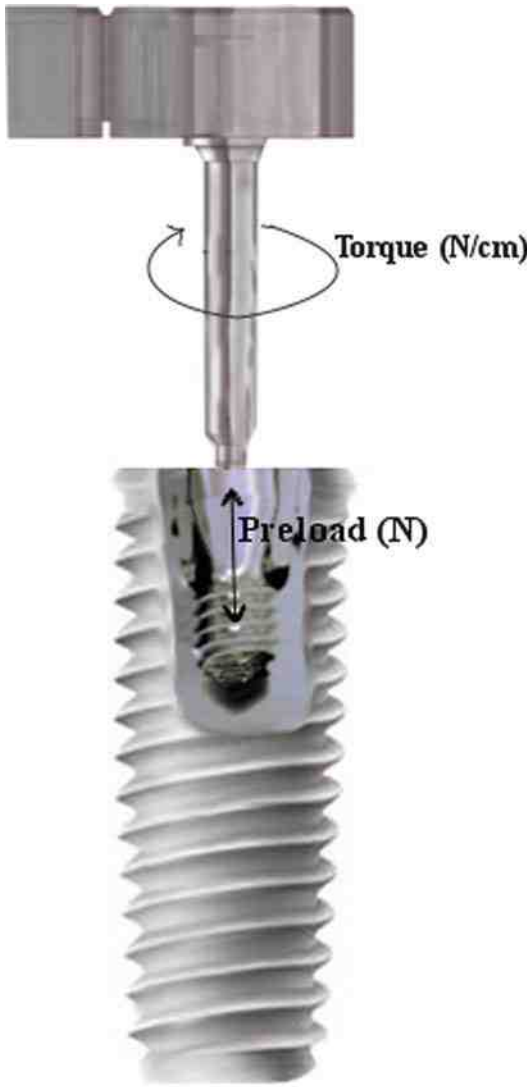

Fig. 8.3 Representation of the preload developed with the application of a torque on the abutment screw, this causes elongation of the screw and ultimately the clamping of the screw with the abutment

slightly increasing the preload because of its influence on the frictional resistance.

An important aspect to consider is that appropriate torque values cannot be obtained by hand-held screwdrivers. Numerous experiments have shown that the mean torque produced by manual wrenching is in the range of 10–12 N/cm, well below the required torque necessary to obtain ideal preload. On the other hand, torque-limiting devices can aid in achieving optimal torque values [17]. Electronic drivers have shown to be reliable in producing the nominal torque values, but in practice the most diffuse devices are the torque wrenches.

Toggle-type wrenches use a small ball that engages in the locking piece of the mechanism and compressed with a coil; when the desired torque is achieved, the ball rolls out of the mechanism, and the head of the wrench flips to the side thus impeding further torquing.

Beam-type wrench instead uses a beam that deflects increasing the torque; the deflection allows to visualize on an special marking the torque values achieved.

McCracken and coll. [18] evaluated the accuracy of the torque wrenches in producing a precise torque value. Brand new instruments actually produced accurate torque values, but some used devices produced very high values, not conform to the nominal values of 35 N/cm; this can be dangerous because excessive force transmitted to implant collar and marginal bone can lead to marginal bone loss. Moreover, the *toggle-type* wrenches tended to lose accuracy when speed of rotation was increased. *Beam-type* wrenches were not affected by speed of use. The study suggests that clinical use and autoclaving procedure may impair the mechanical properties of the instruments and reduce their accuracy.

8.2.2 The Settling Effect

Settling effect refers to a decrease in preload occurring variable time after abutment screw placement. This is due to the fact that no surface is completely smooth and the inevitable small imperfections do not allow two surfaces to stay in full contact. It follows that the main contacts stabilizing the screw occur at the level of the rough spots.

Already after few minutes after placement of the screw, the rough spots are compressed due to the pressure developed. This phenomenon is supposed to impair the stability of the screw to implant already after few minutes (Fig. 8.4).

Winkler and coll. [19] suggested that in order to reduce this mechanical phenomenon, it was

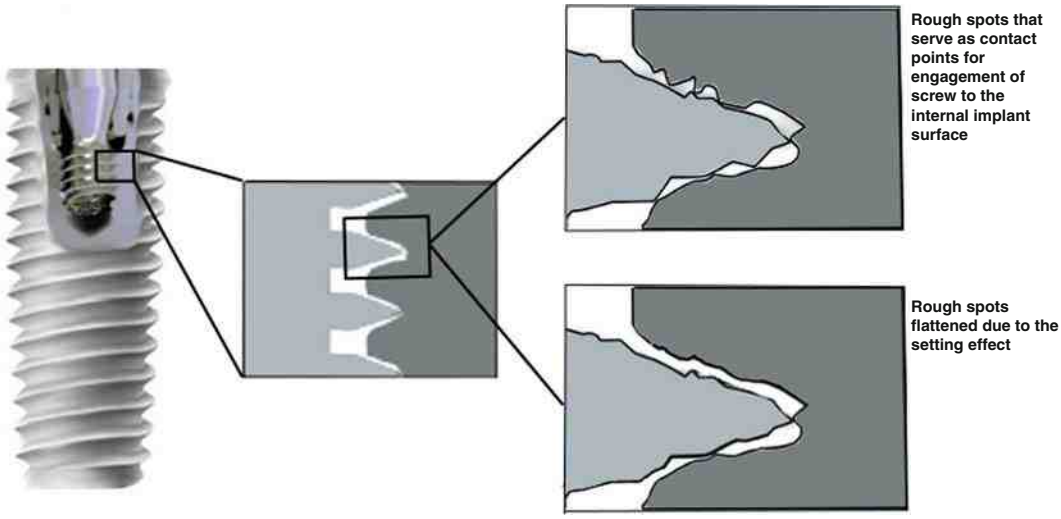

Fig. 8.4 Schematization of the settling effect showing the relation of the screw with the internal surface of the implant. After few minutes, the rough spots that serve as contact points are flattened out and can be a cause of screw loosening

sufficient to retighten the screw 10 min after placement, thus allowing the formation of new, stronger contact surfaces.

The FEA study of Bulaqi and coll. [20] evaluating the dynamic nature of screw retightening and the settling effect arrived at the conclusion that in order to increase the preload, a reduction of the coefficient of friction is more important than retightening.

On this basis, it is safe to assume that reduction of the settling effect is important in increasing the preload; in order to do so, a reduction of friction with a lubricant or selection of screws manufactured with the smooth surfaces is indicated. Also, the simple act of retightening 10 min after placement can help in reducing the incidence of screw-loosening complications.

Considered that torque loss is likely to develop over the course of the years, some authors recommend a periodical retightening at the follow-up visits as well [21].

8.2.3 Antirotational Features

The driver head engages the screw through a fitting site, this can have different shapes. The most common are the *slot* and the *hex* type. Experimental studies showed that it is easier to obtain an optimal preload with the *hex* type compared to the *slot* [22] (Fig. 8.5).

Different thread designs may have an impact on the risk of occurrence of screw loosening. A 30-degree V-shaped thread is the most common design adopted by manufacturers; the 30° angle allows to put a shear load on the material and allows the stretching of the screw responsible for an optimal development of the preload. No studies are available comparing different thread designs of abutment screws and their incidence of complications.

Screw diameter may play a role on the preload because a greater diameter corresponds to a greater surface of engagement.

Regarding the material composition, metals are universally adopted in fabrication of implant-abutment screw. Given the importance of the applied torque and friction coefficient in obtaining an optimal preload, metals employed should respond to prerequisites of high elasticity and adequate yield strength.

Gold is subject to plastic deformation; in consequence of this, once the torque is applied, it deforms irreversibly and becomes non-retrievable; for this reason, it has been replaced by titanium screws.

Grades 1–5 Ti have lower modulus of elasticity and lower yield strength when compared to

Fig. 8.5 The most common driver heads are the slot (*left*) and the hex (*right*)

titanium alloy (Ti-6Al-4 V); in consequence of this, pure Ti is not used anymore as screw material.

Titanium alloy is the most used material for this scope, given its ability to provide higher preload and low risk of fracture due to its high strength. Moreover, in order to decrease the friction coefficient, carbon-coated screws have been employed and gave promising results in experimental studies.

8.2.4 Screw-Related Complications

Screw loosening is one of the most common complications in implant dentistry (see Chap. 3). The causes of loosening of the abutment screw are discussed above, i.e., *insufficient preload* and development over time of the *settling effect*. A systematic review by Theoharidou and coll. [23] confirmed that abutment screw loosening can be prevented applying proper torque control and antirotational features.

Screw fracture is another possible complication, although less frequent [24] (Fig. 8.6). Common reasons of abutment screw fracture are found on the excessive torque applied at the moment of insertion, screw loosening over time and the consequent development of unfavorable forces on the screw, or material failure due to the overcoming of its yield strength. Whatever the reason, once the screw is fractured, it needs to be removed. An effective method might be to remove the most coronal portion with a driver and then try to move the apical fragment in a counterclockwise direction. This can be achieved with an ultrasonic tip actioned around the fragment or with instruments adapted for this scope [25]. This task can become difficult to accomplish if the most apical portion of the screw remains engaged. If retrieval is considered impossible, the clinician must decide if restorations are still possible leaving the fragment in place and with the adoption of a smaller screw. Otherwise implant removal becomes necessary.

Stripping of the head or threads may occur in a number of cases; this usually results after the use of the inadequate driver or excessive force exerted during placement. These complications must be resolved removing the stripped screw through creation of a contact point that allows rotation and removal [26]. This can be achieved using a high-speed handpiece but being careful of not damaging the implant.

To summarize, torque applied to the abutment screw is one of the main factors for producing an optimal *preload* and therefore optimal clamping of the screw to the implant.

Torque values of ≥35 N/cm seem to be necessary to develop an ideal preload and prevent screw loosening. Coefficient of friction should be reduced adopting modified screw surfaces or with lubricating materials.

Moreover, hand tightening with a manual screwdriver does not allow to achieve acceptable preload. *Toggle-* and *beam-type wrenches* are reliable in producing consistent torque values, but the clinician should be aware that deterioration

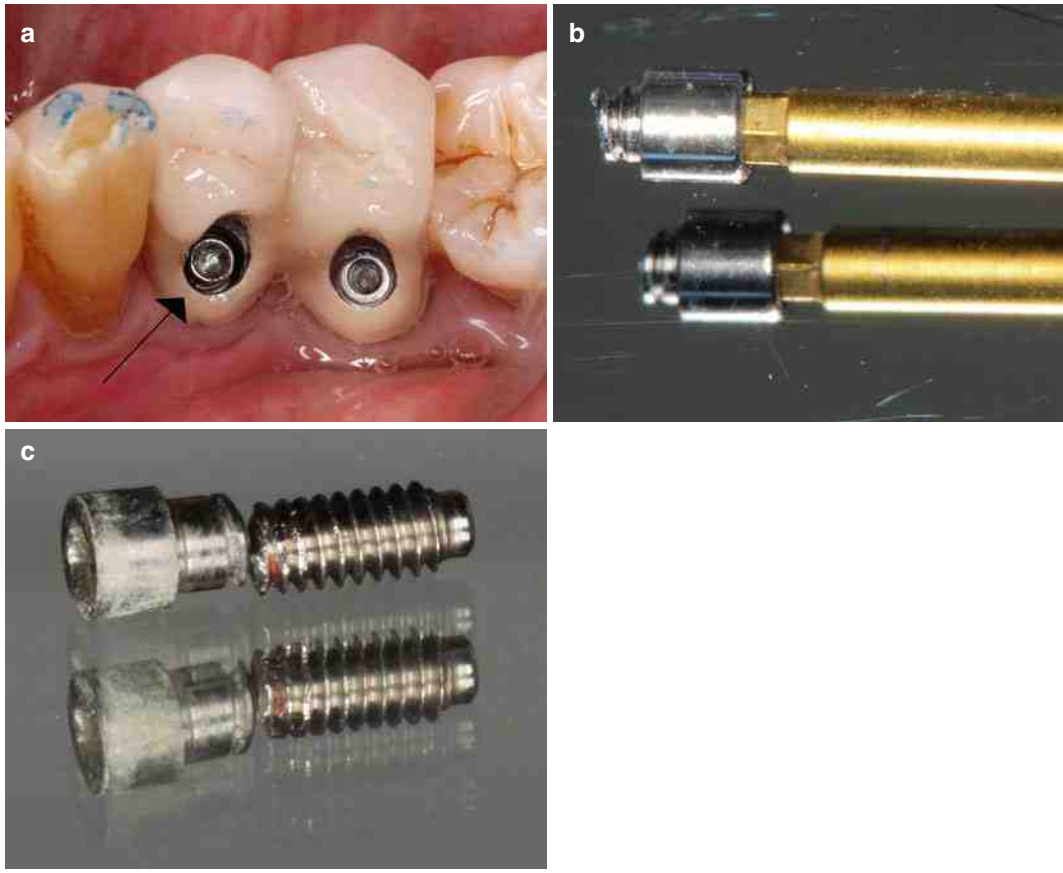

Fig. 8.6 (**a–c**) The *arrow* indicates a fractured screw (**a**); coronal fractured portion of the screw removed with a driver (**b**); it was possible to retrieve the apical portion with the use of an ultrasonic tip (**c**)

due to clinical use and sterilization processes may impair their reliability and lead to the necessity of recalibration or substitution.

Finally, in order to reduce the settling effect, retightening of the screw 10 min after placement and periodic retightening at the follow-up visits should reduce the incidence of screw-loosening events.

8.3 Internal Versus External Connection

The first implant introduced by Brånemark had a small external connection with the implant abutment that was designed primarily to facilitate the surgical placement of the implant instead of conferring stability and antirotational features. Only with the increasing use of dental implants, the clinicians and manufacturers started to understand the importance of implant-abutment connection for the long-term success.

External connection has an external component extending coronally. *Internal* connection instead is located inside the implant body (Fig. 8.7).

The shape of the connection is important because it contributes to the antirotational features. The most common for both the external and internal connections is the hexagonal. Another one is the *Morse taper* which can also be defined *biconical* and does not require an implant screw for retention given that the stability is ensured by mechanical engagement between the implant and the abutment.

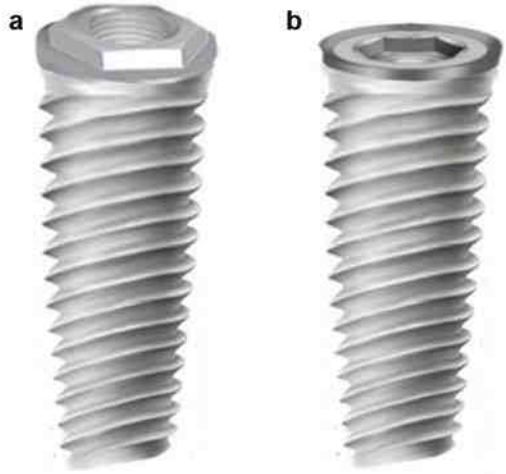

Fig. 8.7 External (**a**) and internal (**b**) connection

Reported disadvantages of external connection include a higher risk of screw loosening and a lower antirotational capacity due to a possible misfit between the abutment and the implant when compared to internal connections.

A synthesis of the available literature was brought by Gracis and coll. [27] who analyzed retrospective and prospective studies and RCTs evaluating the advantages and disadvantages of external, internal, and Morse taper connection systems. The review focused on factors that may generate impression distortions and the technical complications of the various connecting systems. The authors concluded that internal connection configurations have an intimate fit with the corresponding copings which can generate difficulties in impression removal and may increase the risk of generating distortions. On the other hand, reduced rate of screw loosening with internal connection systems is reported in the literature. Screw fracture complications were instead similar for both internal and external connection types.

Goiato and coll. [28] addressed the question if any difference exists regarding the mechanical, biological, and esthetical performances of the different connections.

Mechanical stability seems to be better achieved with Morse taper connection compared to internal and external hexagon. Also, the increased stability of Morse and internal hexagon connections may contribute to decrease the micromovements at the level of the marginal bone around the implant which may positively contribute to a reduction in the marginal bone level resorption rate. The biological evaluation was made measuring the level of bacterial leakage and bone loss around single implants; at this regard, the Morse taper seemed to be more efficient in providing a better bacterial seal responsible for the maintenance of the peri-implant bone.

In the end, from analysis of the literature, it emerges that internal and Morse taper connections give better clinical results in terms of incidence of mechanical and biological complications when compared to external connection.

8.4 Angled Implant Abutments

Implants should be positioned parallel to each other and be vertically aligned in order to produce axial forces. It can frequently occur that implants are placed in a more or less angled position, for example, in the anterior maxillary region, the natural conformation of the bone dictates an angled implant placement [29] (Fig. 8.8).

Many manufacturers provide pre-angled abutments available ranging from 10 to 35° of angulation. When a force is applied to an angled abutment, this acts as a lever, distributing the force to the implant-abutment connection, the peri-implant bone, and the prostheses. The stress produced with an angled abutment is greater than the stress created by a straight one.

It is important to understand if the increased stress created by the angled abutments may lead to worst clinical outcomes when compared to straight ones.

FEA studies can give some clues regarding the amount of stress generated by an angled abutment (Fig. 8.9), but, opposite for what happens on purely mechanical components (e.g., an abutment screw), biological factors such as stress on bone are difficult to be implemented in a FEA study [30]. The computer-generated simulation does not take into account the quality and quantity

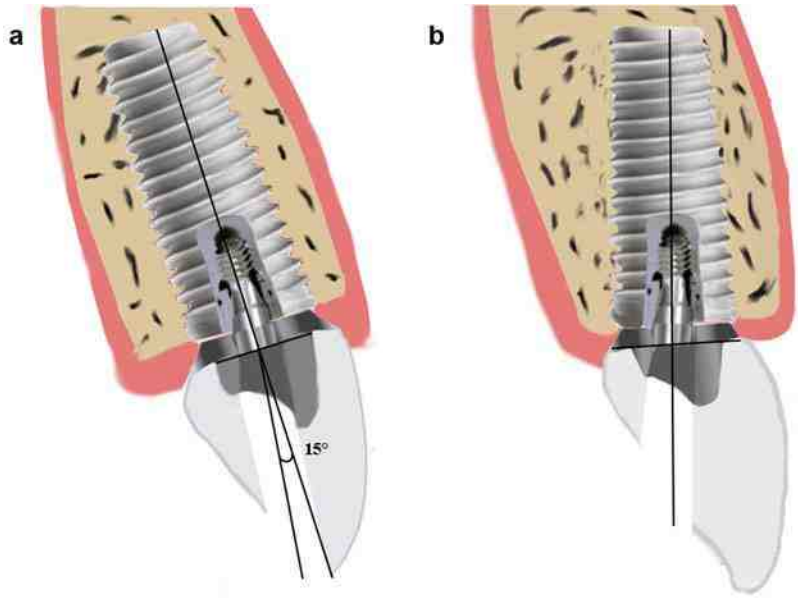

Fig. 8.8 Angled abutment may be necessary because of the placement of the implant at a certain inclination; in this case, this was dictated by the bone anatomy; and the screw access hole was almost at the level of incisal margin which can create some esthetic issue; in this case, a cemented restoration may be a better solution (**a**). In (**b**) the anatomy allowed an axial placement, and a straight abutment was sufficient; also the screw access hole is more palatal

of bone around the implant, the implant material, the bone cells' response to load, and the bone properties in general. For these reasons, any FEA simulation must be taken as a very general approximation of the magnitude of stress applied to bone with different angulations of abutments.

Cruz and coll. [31] performed a three-dimensional FEA of dental prostheses supported by straight and angled abutments. No difference in stress distribution patterns was evidenced for the two groups.

The influence of abutment angulation on micromotion and peri-implant bone stress was analyzed in another FEA study [32] in which abutments of 0°, 15°, and 25° angulations were compared. The results pointed out that the majority of the stress, independent of the angulation, is concentrated at the level of the cortical bone on the crest of the alveolar ridge. Compared with the 0° abutment, the stress increased of 12 % with angles of 15° and 18 % with angles of 25°.

Regarding the micromotion, it was considered to be into the safety limits for osseointegration, even if angles of 25° led to an increase in micromotion of 30 % compared to 0° abutments. This can suggest caution in applying immediate loading protocols when such angled abutments should be used.

These results were confirmed in other studies conducted with the same methodology.

When clinical studies are considered, only sparse data can be retrieved from the literature. Few prospective observational studies are available which can be analyzed in order to have some clue regarding the survival of implants and prostheses on angled and straight abutments [33].

The survival rate of implant with connected angled abutments up to 30° was above 97 % in all the studies analyzed; the survival of prostheses was above 95 %. These figures are comparable with those of straight abutments and suggest that the use of angled abutments is a reliable option when necessary (Fig. 8.10).

In conclusion, even if the stress placed on the peri-implant bone is greater around angled abutments and is directly proportional to an increase in angulation, it is safe to assume that it remains within biologically tolerable limits.

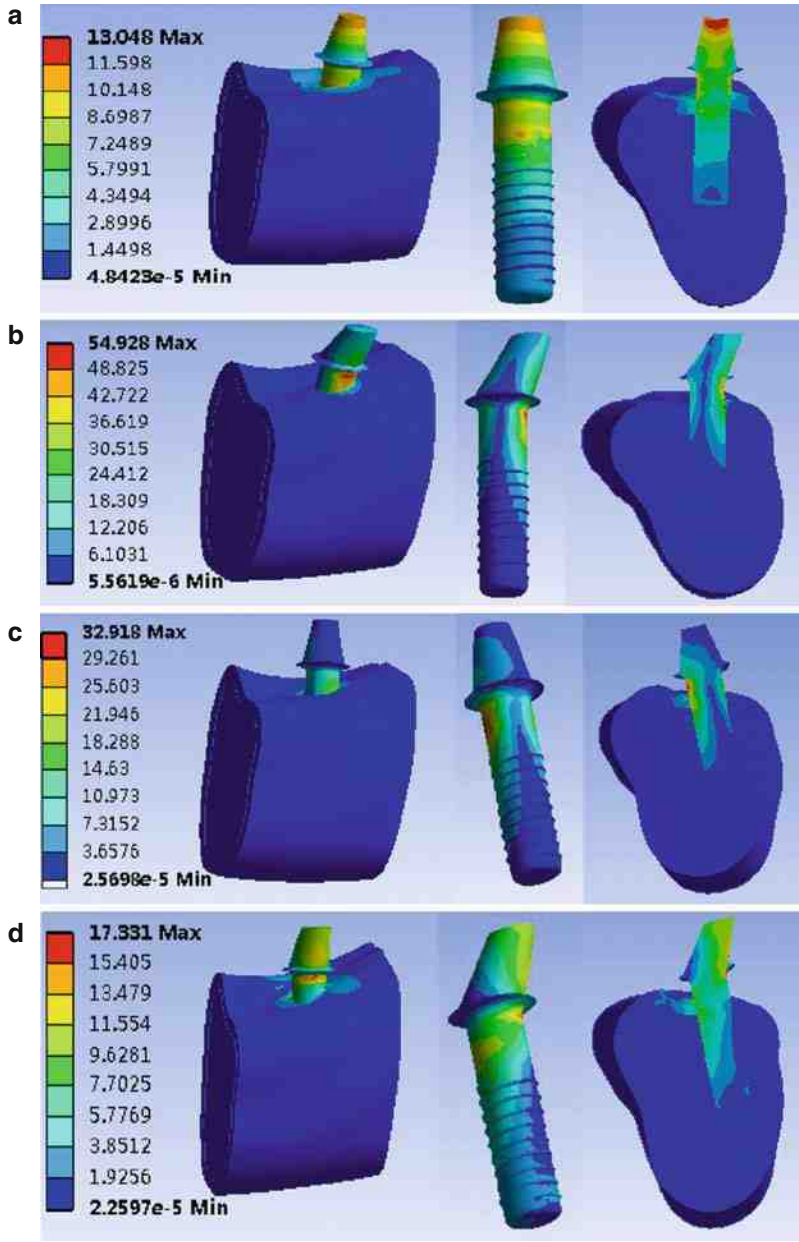

Fig. 8.9 FEA study showing the distribution of von Mises stress (MPa) in model (*right*), in implant (*center*), and the cross sectional view of the model (*left*). Various implant models are represented in **a**–**d**. *blue* to *red* color represents stress values from lower to higher (Reproduced with permission from Tian and coll [30])

The adoption of angled abutments does not seem to reduce the survival rate of implants and prostheses and can be considered a predictable modality of treatment when necessary.

Experimental results suggest precaution in adopting an immediate loading protocol when angled abutments, especially higher than 15°, are necessary.

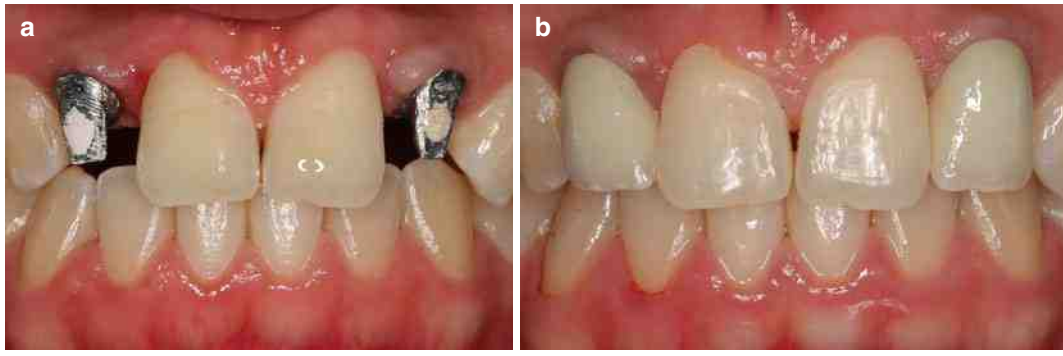

Fig. 8.10 (**a**, **b**) In this case the angled abutment on implant #12,#22 of dictated the access hole to be buccal instead than palatal (**a**). A cemented restoration was used and results were optimal (**b**)

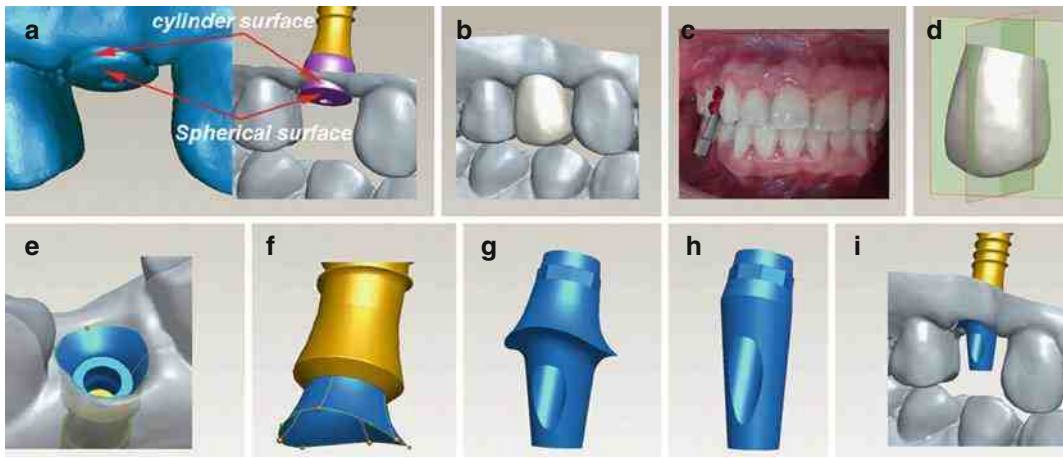

Fig. 8.11 Example of computer-aided design for an implant abutment (Reproduced with permission from Wu and coll.)

8.4.1 CAD/CAM Technologies for Implant-Abutment Construction

Computer-aided design and computer-aided manufacturing (CAD/CAM) is a technology that has been available in prosthetic and implant dentistry for at least two decades. Continuous improvement have rendered possible to think about a routine use of this technology in the everyday practice.

Different CAD/CAM systems are available on the market and allow to provide manufacturing of titanium, alumina, or zirconia abutments (Fig. 8.11).

Potential advantages in employing such techniques include (a) increased precision since there is no waxing and casting, (b) abutments are created by a software so the final work is less dependent by technician skills and expertise, (c) crown-abutment fit is potentially improved due to the precision methods of recording and manufacturing, and (d) the mechanical properties of the adopted material are improved because of the increased homogeneity deriving by manufacturing from a single block.

Anyway, while in vitro experiments have confirmed the validity of such techniques, the clinical outcomes are still being investigated [34].

Kapos and coll. [35] systematically reviewed the studies on CAD/CAM abutments. Two studies were included for the evaluation of single implants and single-unit restorations manufactured with

CAD/CAM techniques. The combined results of the two clinical trials included 53 ceramic abutments supported by 53 implants and no significant failures or complications were reported.

Another recent review by the same group of authors [36] was aimed at comparing implant prostheses fabricated with CAD/CAM versus conventionally manufactured restorations. Regarding CAD/CAM abutments, three RCTs, one prospective clinical study, one retrospective case series, and one case series were included for evaluation. A limited number of complications were reported and the survival rate was 100 %.

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Implant Prosthodontics

9

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and Simón Pardiñas López

Abstract

The goal of a prosthetic restoration is to provide good esthetic and functional outcomes on a long-term basis. For the clinician, implant prosthodontics poses many decision-making challenges.

Choice of screw- or cement-retained implant prosthesis is still a matter of personal preference, although some specific indications and contraindications are retrievable from the literature. Ease of manufacturing, risk of complications, cost, and chair time are all factors that need to be evaluated in the choice of a retention system.

Another doubt may arise regarding the adoption of cantilever prosthesis in place of more complex surgical or prosthetic options. Finite element analysis studies and clinical trials may help in providing survival and complication rates of cantilevers.

In selected cases, advanced treatment options are necessary. It is the case of zygomatic implants, which are useful when more traditional approaches are unfeasible. Considering the delicate structures involved and the surgical skills required, placement and restoration of zygoma implants should be performed in adequate structures by properly trained clinicians.

The All-on-Four™ is a prosthetic concept which employs four implants in the anterior jaw, of which the distal two are maximally angulated. The sparse evidence coming from the literature suggests that this can be a reliable option in selected cases.

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Another question that seeks for an answer regards the ideal number of implants to achieve optimal results. Clear indications are available for full-mouth fixed rehabilitations, in which minimum four implants in the mandible and six implants in the maxilla are considered the most reliable solutions.

Implant overdentures are still an important option for edentulous patients, especially in the elderly. Analysis of the various attachment systems and the number of implants can help in selection of the best treatment options.

Accurate impression taking is a fundamental step for achievement of optimal prosthetic results. Materials adopted should possess some fundamental basic properties. Regarding the impression techniques in implant dentistry, two options are available: transfer and pick up.

Finally, optimal esthetic results depend by numerous factors; it is the mimicry with the natural tissues that ensures the best outcomes. It is not easy to arrive at strong evidence-based conclusions on this topic, mainly due to the lack of RCTs and a poorly standardized way of reporting the esthetic outcomes.

9.1 Prosthetic Options in Implant-Fixed Prosthodontics

9.1.1 Cement-Retained Versus Screw-Retained Implant Reconstructions

Retention systems for implant prostheses can be obtained via screw retaining or through cementation. These two options gave distinct advantages and disadvantages in clinical practice, but doubts still exist if the choice of a retention system over another can give some improvement in terms of success and survival rates (Tables 9.1 and 9.2).

The choice one of the alternatives is still a matter of personal preference for many clinicians; therefore, an evidence-based approach should elucidate which are the main indications and problems of the two fixation methods in order to facilitate decision-making in the everyday practice (Fig. 9.1).

Sailer and coll. [1] systematically reviewed the survival and complication rates of cemented and screw-retained reconstructions, providing summary estimates at 5 years. The analysis included RCTs, prospective and retrospective studies on single crowns, FDPs, and full-arch restorations.

Regarding implant survival, no difference was found for single crowns between cement-retained and screw-retained groups, although for FDPs and full-arch prostheses, the incidence of implant loss appeared to be higher for cemented reconstructions. This is in line with precedent observations: cemented reconstructions are associated with a variable amount of cement excess around

Table 9.1 Screw-retained restorations

Advantages	Disadvantages
Ease of retrievability	Impossibility of placing a screw when the position of the screw-access hole lies on the incisal margin in case of excessively angulated implants
Decreased risk of biological complications because of the absence of cement	Slightly larger bulk of the prosthesis framework compared to cement retained; this is due to the necessity of accommodate the screw-access hole
Possibility of restoration even with limited crown space	

the implant which is the cause of inflammation and implant loss in some cases.

When survival of the prostheses was analyzed, in *single-crown* study, more reconstructions failed in the screw-retained group. Also the full-arch prostheses group showed a similar trend with higher reconstruction failures in the screw group. Anyway, these results were not statistically significant.

Table 9.2 Cement-retained restorations

Advantages	Disadvantages
A general ease of manufacturing and manipulation, due to their similarity with reconstructions on natural abutments	Difficulty in removal of excess cement, which is one of the main causes of biological complications
Reduced cost and less chair time	Difficult removal of the restoration if the abutment screw loosens
	Considering that cemented prostheses necessitate at least 5 mm to provide retention; in case of reduced occlusal space, adoption of a screw-retained restoration is the only choice

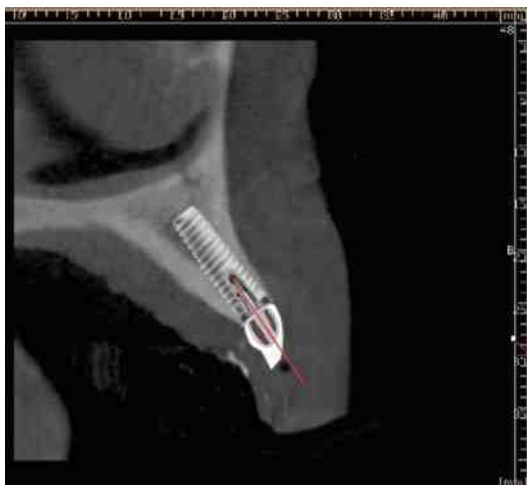

Fig. 9.1 This is a typical case in which an angulated abutment is necessary due to the bone anatomy; this situation usually occurs in the anterior regions. The use of a screw-retained restoration will result in an access hole on the buccal aspect (*red line*), which is contraindicated in the esthetic zone. For this reason, a cemented restoration is preferable

On the opposite side, *FDPs* showed a trend suggestive of greater prosthetic failure rates for the cemented group, but again results were not statistically significant.

The analysis outlined that technical complications were generally higher for the screw-retained reconstructions, in particular screw loosening and chipping/fracture of the ceramic. Regarding this last complication, one may ask why cemented prostheses suffer a lesser degree of ceramic damage; it is likely that the occlusal forces exerted on the cemented restoration simply lead to decementation. Oppositely, when forces are exerted on screw-retained prostheses, they are not dissipated, and consequently their full load acts on the ceramic, unless screw loosening occurs.

As expected, serious biological complications (bone loss exceeding 2 mm) were more frequent for cement-retained reconstructions; this is in line with the numerous studies about the incidence of peri-implantitis due to excess of cement around the implants. It is also expected that access to cement remnants is impaired with large reconstructions; this may explain the higher failure rates of implants under cement-retained restorations.

Technical complications were higher for the screw-retained group, the most frequent being loosening of the screw. It must be addressed that complications of this kind, although time-consuming and unpleasant for the patient, are usually resolvable within a single visit. On the opposite side, if the abutment screw loosens under cemented restorations, retightening of the abutment screw may become difficult/impossible and destruction of crown necessary in order to uncover the screw hole.

In the end, the authors concluded that cemented reconstructions exhibit less technical complications but more serious biological problems reflected in higher implant failure rates.

Specifically, for *single crowns*, incidence of complications was similar for both groups; therefore, both types of fixation methods can be recommended (Figs. 9.2 and 9.3), but when FDPs and full-arch restorations are employed, screw-retained reconstructions seem preferable for the

ease of retrievability and for the lower rates of biological problems (Fig. 9.4).

Another systematic review [2] analyzed the survival rates according to material type and type of reconstruction, giving estimates at 5 years.

Failure rates by reconstruction type put in evidence a not statistically significant higher survival for cement retained when compared to screw-retained single crowns, FDPs, and full-arch restorations.

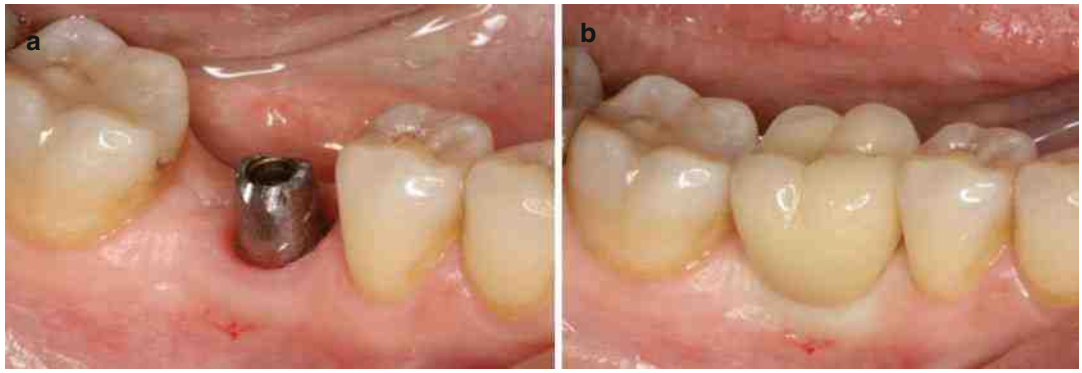

Fig. 9.2 Example of cemented restoration in the molar region; this is a case in which the choice of the retention system is a matter of clinician's personal preferences. A screw-retained restoration would have been feasible without contraindications

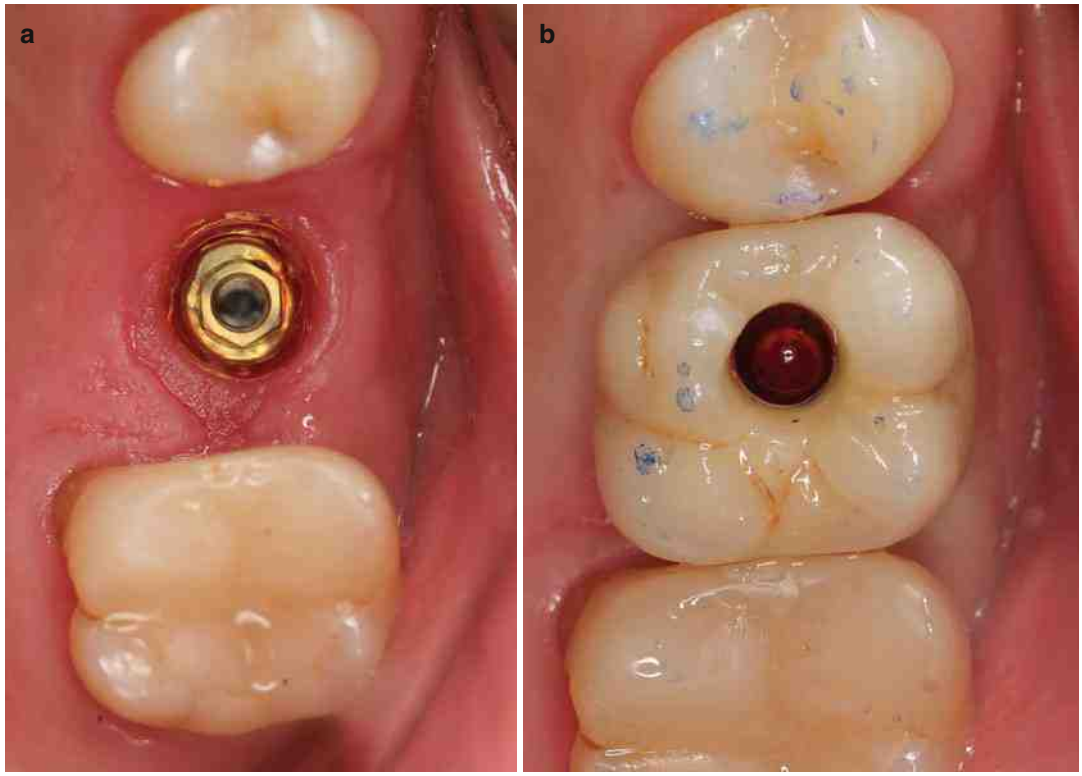

Fig. 9.3 Example of screw-retained restoration in the molar region (**a**, **b**)

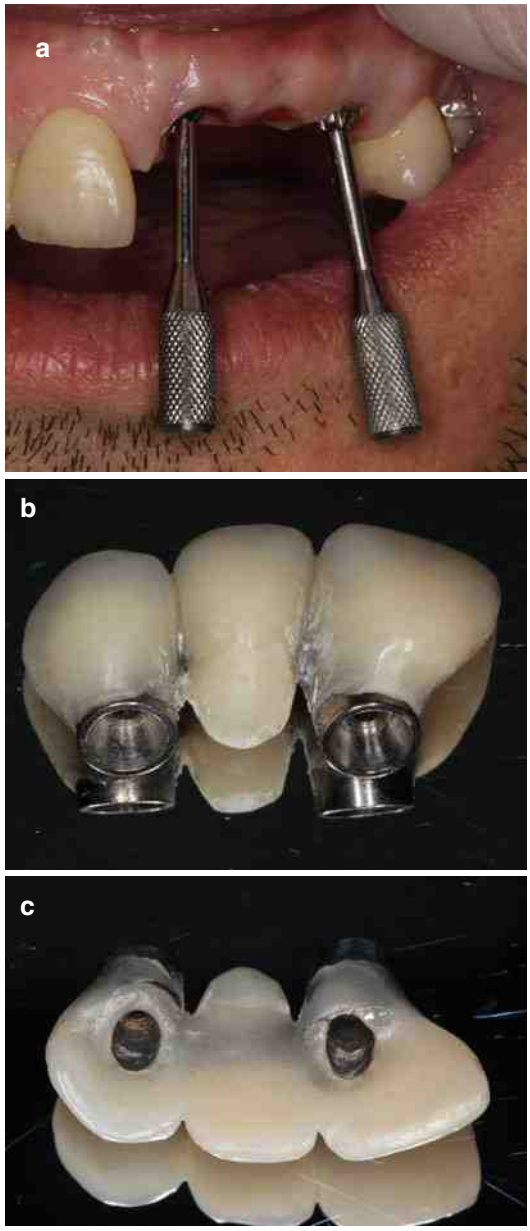

Fig. 9.4 (**a–c**) Example of screw-retained restoration for a three-unit implant prosthesis

When abutment material was analyzed, neither cemented nor screw-retained reconstructions showed a statistically significant difference with the different materials employed. Same result was obtained analyzing different prosthetic and cement materials.

Regarding the technical complications, a statistically significant difference was confirmed between the two groups. In particular, loss of retention and ceramic chipping/fracture were higher for the screw-retained group.

Specifically for the cemented group, an interesting comparison between the type of cement adopted and the loss of retention was performed. It showed the *ZOE* cements perform better than *resin* and *glass ionomer*.

Biological complications were significantly higher for the cement group, further strengthening the assumption that cement residues are one of the main causes of peri-implantitis and implant loss.

The authors draw the conclusion that the higher risk of implant loss and the limited possibility of reintervention after definitive cementation should lead to propension toward screw-retained restorations.

The review of Chaar and coll. [3] focused on cement-retained restorations only, subdividing the analysis in long-term (1–5 years of f-up) and short-term studies (>5 years of f-up). As expected, more technical complications were reported in long-term studies. Incidence of abutment screw loosening amounted to up to 4.3 % for the short-term and up to 10 % for long-term studies. An interesting observation was that more recent studies showed lesser incidence of *abutment* screw loosening, likely because of the improvement in manufacture and mechanical characteristics of implant components.

Loss of retention was the most common technical complication; the type of cement used can improve the clinical results, but controversies still exist on this matter. *Zinc phosphate* ensures the highest retention, but on the other hand provisional cements such as *ZOE* may work properly and at the same time provide retrievability if needed.

At the end, reliability of cement-retained *single-crown* restorations was deemed similar to screw retained. But the author concluded that for long-span FDP and full-arch restorations, the adoption of cement-retained restorations is not recommended.

An analysis on MBL changes around implant cement- or screw-retained restorations was performed by de Brandao and coll. [4]. Only two studies, out of a total of the nine included, were found to directly compare the two groups; the others described cement-retained and screw-retained MBL separately. Follow-up was in the range of 12–48 months. The pooled mean peri-implant marginal bone loss for the screw group was 0.89 mm (0.44–1.33), and for Cement group, it was 0.53 mm (0.31–0.76); this difference was not deemed statistically significant. It must be noted that the results might be biased by the fact that the majority of comparisons were not direct but instead an extrapolation from studies performed for other kind of evaluation. Moreover, it should be recalled that MBL may be influenced by many other factors than retention systems, such as smoking habits, poor oral hygiene, etc., and it is not known to what extent each one may have a preponderant role (Tables 9.3, 9.4, 9.5, and 9.6).

9.1.2 Cantilevers for Implant-Supported Prostheses

In some situations such as bone atrophy or the need of avoiding damage to anatomical structures (e.g., maxillary sinus, mental foramen), insertion of implants becomes possible only with more complicated implant treatment options; these may consist of bone augmentation procedures, use of short implants, or placing angulated implants. When all these alternatives cannot be employed or are excluded for any reason, a cantilever can be adopted [5]. A cantilever prosthesis is defined as a free-end extension retained by natural or implant abutments (Figs. 9.5 and 9.6).

Due to the particular design of this solution, i.e., a first-class lever, it was a matter of debate if the use of cantilevers could be the cause of excessive load over the supporting implants and if such design could lead to increased rates of complications such as framework fractures.

Table 9.3 Summary of the systematic reviews providing a quantitative analysis of reconstruction survival rates for screw-retained and cement-retained groups

	Screw-retained single crown	Cement-retained single crown	Screw-retained FPD	Cement-retained FDP	Screw-retained full-arch restoration	Cement-retained full-arch restoration
Sailer and coll. [1] 5-year estimate 95 % CI	89.3 % (64.9–97.1)	96.5 % (94.8–97.7)	98.0 % (96.2–99.0)	96.9 % (90.8–99.0)	95.8 % (91–97.9)	100 % (88.9–100)
Wittneben and coll. 10-year estimate 95 % CI	91.1 % (76.7–96.8)	96.3 % (93.9–97.8)	91.5 (%76.5–97.1)	94.6 % (85.8–98.1)	96.7 % (93.6–98.3)	/

Table 9.4 Summary of the systematic review providing a quantitative analysis of implant survival rates for screw-retained and cement-retained groups

	Screw-retained single crown	Cement-retained single crown	Screw-retained FPD	Cement-retained FDP	Screw-retained full-arch restoration	Cement-retained full-arch restoration
Sailer and coll. [1] 5-year estimate 95 % *CI*	98.6 % (96.6–99.4)	97.7 % (96.8–98.4)	98.7 % (97.6–99.3)	97.6 % (96.8–98.3)	98.4 % (95.8–99.4)	94.2 % (86.5–97.6)

Table 9.5 Summary of the systematic review providing a quantitative analysis of technical complication rates for screw-retained and cement-retained groups

	Screw-retained single crown	Cement-retained single crown	Screw-retained FPD	Cement-retained FDP	Screw-retained full-arch restoration	Cement-retained full-arch restoration
Sailer and coll. [1] 5-year estimate 95 % CI	Screw loosening 21.2 % (14.4–30.4) Chipping 9.6 % (2.5–33.8) Screw fracture (none)	Abutment screw loosening 3.9 % (2.8–5.4) Chipping 2.8 % (1.4–5.5) Abutment screw fracture 0.4 % (0.1–1.8)	Chipping 13.3 % (8.4–20.7) Screw loosening 11.0 % (7.2–16.7) Screw fracture 3.8 % (1.7–8.4)	Chipping 24.9 % (6.5–70.7) Screw fracture 0.0 % (0–5.6) Screw loosening 0.0 % (0–5.1)	Chipping 23.3 % (16.1–33.0) Screw loosening 9.4 % (3.1–26.6) Screw fracture 6.6 % (1.7–24.5)	Chipping 67.4 % (49.9–83.7) Screw loosening 3.1 % (1.5–6.4) Screw fracture 0.0 % (0–37.7)

Table 9.6 Summary of the systematic review providing a quantitative analysis of biological complication rates for screw-retained and cement-retained groups

	Screw-retained single crown	Cement-retained single crown	Screw-retained FPD	Cement-retained FDP	Screw-retained full-arch restoration	Cement-retained full-arch restoration
Sailer and coll. [1] 5-year estimate 95 % CI	Soft tissue complication 23.9 % (14–39.1) Soft tissue recession 0.0 % (0–36.9) Bone loss >2 mm 0.0 % (0–6.0)	Soft tissue recession 4.4 % (1.0–17.6) Soft tissue complication 4.3 % (3.0–6.1) Bone loss >2 mm 2.8 % (1.3–6)	Soft tissue complication 6.5 % (2–20) Bone loss >2 mm 2.5 % (2.3–4.7) Soft tissue recession (Na)	Bone loss >2 mm 6.5 % (4.6–9.1) Soft tissue recession 0.0 % (0–49.5) Soft tissue complication (Na)	Soft tissue recession 16.7 % (11.8–23.9) Bone loss >2 mm 11.4 % (6.7–18.9) Soft tissue complication (Na)	Bone loss >2 mm 34.7 % (18.5–54.3) Soft tissue complication (Na) Soft tissue recession (Na)

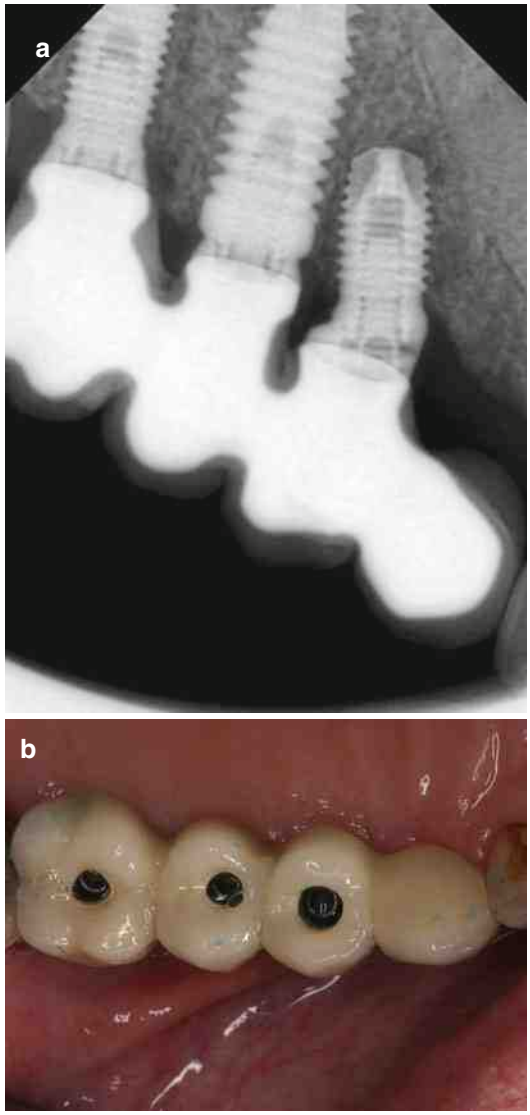

Fig. 9.5 (**a**, **b**) Example of mesial cantilever retained by three implant abutments. This configuration unlikely will give any problem considered that is the most favorable situation from a biomechanical point of view

Finite element analysis (FEA) tests have attempted to study the stress distribution on bone, implants, and prostheses in the presence of a cantilever.

Padhye and coll. [6] simulated a mandible model and six implants supporting a cantilevered fixed prosthesis; the length of the cantilever was simulated at 10, 15, and 20 mm from the distal part of the terminal implant. The distribution of loads around the peri-implant bone was studied. On application of vertical forces at the most distal point, the results suggested a direct increase of stress on all the components of the simulation every 5 mm increment in cantilever length. It was suggested that implants connected between each other in a rigid manner may help balance the tension developed where the force is exerted. Also, regardless of the cantilever length, the greatest amount of stress was placed around the most distal implant. In order of magnitude, the stress was greatest on the framework, the implant, and the cortical bone and least on the medullary bone.

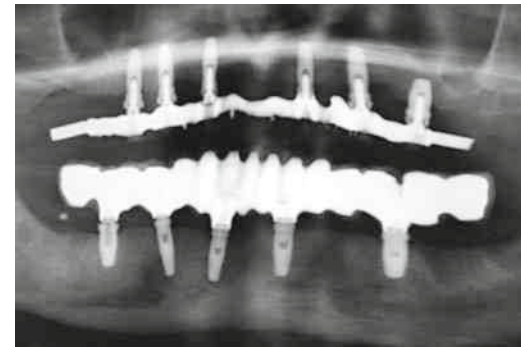

Fig. 9.6 Example of distal cantilevers in a full-mouth restoration. This can be considered a predictable solution although no strong evidence in this regard is available yet

A similar FEA was conducted by Park and coll. [7] for evaluation of stress distribution on a mandibular-cantilevered implant crown subjected to vertical and oblique loads. Vertical forces applied on the cantilever resulted in an increased stress upon the cortical bone which increased linearly in proportion to the distance of the applied load from the center of the crown. Instead, when oblique load was applied lingually at 30°, the least amount of stress on the bone and implant occurred when the force was exerted at 5 mm from the center of the crown. While going toward the center the stress increased on the buccal bone, moving toward the lingual side, the stress was greatest on the implant first and on the lingual bone going at a distance of 7 mm.

An attempt to simulate the bone remodeling induced by FPD with cantilever extensions was also performed. In the study of Wang and coll. [8], a 3D FEA models of the maxilla were

created, and bone remodeling equations were applied establishing a reference stimulus, an overload threshold, a remodeling coefficient for cortical and trabecular bone, and a lazy zone. In this way, it was possible to simulate, within the limits of computer-generated values, how the bone responds to different prosthetic designs. The model gave the results of a more distributed bone density induced by the non-cantilever configuration; the cantilever model resulted in a lower density around the implant neck indicative of increased bone remodeling due to the stress exerted by the loads of the cantilever model.

It must be pointed out that FEA studies attempting to evaluate what happens in a given clinical scenario are always a simplification of the real mechanisms occurring in a biological system.

Bacterial influence, bone cell response to different stresses, assumption that bone is an isotropic material when in fact it is anisotropic, these are all factors that are difficult or impossible to include in a FEA study.

Also, the simulated forces are simplified in respect to what happens in vivo because it is difficult to simulate the patterns of mastication loading.

Nevertheless, this kind of studies can help in giving orientations to the clinical research allows to understand some phenomenons difficult to evaluate in real-life situations.

Clinical studies on dental implant prosthesis cantilever have been conducted by many groups of research with some conflicting results emerging from the analysis of the literature. These controversies arise because of the high heterogeneity between the various studies and in general because of a paucity of well-performed RCTs.

Torrecillas-Martinez and coll. [9] performed a meta-analysis evaluating the marginal bone loss (MBL) and the prosthetic complications of implant-supported cantilevers. Only cohort studies were included with a follow-up range of 3–8.2 years. The amount of MBL was found to be less for the non-cantilever group, but the results were not statistically significant ($p = 0.47$). It was pointed out that MBL is anyway influenced by many factors other than the peri-implant stress caused by a cantilever extension; therefore, the results should be taken cautiously.

Regarding the technical complications, porcelain fracture was the most common, but its relation with the presence of cantilever was not clear; on the other hand, screw loosening for the cantilever group had a relatively higher incidence than the non-cantilever restorations.

It was possible to draw the conclusion that MBL does not seem to be related to the cantilever and that only minor prosthetic complications can occur when a distal extension is present.

A systematic review [10] of the survival rate and the biological, technical, and esthetic complications of cantilevered implant prostheses with a mean of 5 years of follow-up was performed.

Summary estimates at 5–10 years were calculated by the inclusion of prospective and retrospective studies.

Implant survival in implant-supported cantilever prostheses was estimated to be 91.1 % (CI 90.1–99.2), very similar to previous results on implant prostheses without cantilever extensions (see Chap. 3).

The authors also analyzed the component-related complications and the prosthesis complication. Cumulative incidence for implant fracture was again similar to other studies on non-cantilever restorations. The same was true for veneer fracture.

Regarding the biological complications, MBL did not seem to be influenced by the cantilever extension, while the incidence of peri-implantitis was not evaluated for poor reporting in the included studies.

In light of this, rehabilitation with a cantilever extension was not considered detrimental in terms of implant survival, complications, and bone loss when compared to non-cantilever group.

Similar results were obtained in a systematic review [11] including prospective, retrospective, and case-control studies, in which weighted mean of implant loss was higher for cantilever implant prostheses than non-cantilever group. The most common complication detected was chipping followed by screw loosening, and their

incidence was slightly higher in the cantilever group. The presence of cantilever seemed to have no effect on significant peri-implant bone loss. In the end, this review further corroborates the assumption that incorporation of cantilever prostheses may be associated with a slight increase in technical complications, but overall, it is safe to say that implant-supported short cantilever extensions may be considered an acceptable treatment option.

It seems clear that implant-supported cantilever extension can be considered a predictable and reliable treatment option. On the other hand, it should be noted that no study clearly defined the effect of mesial (Fig. 9.5) versus distal cantilever on the survival and complications rates of implants and prostheses; moreover, studies evaluating single implant cantilevers are scarce. Also, all the systematic reviews and meta-analysis point out that few studies and no RCTs are available, although a positive factor is that heterogeneity between the various studies is considered to be low.

Furthermore, numerous biases such as smoking, parafunctional habits, and oral hygiene can confound the results of the biological complications.

Within these limitations, the adoption of implant-supported cantilever restorations supported by two or more implants is a valid option that may be adopted when other, more complicated solutions are excluded from the treatment planning (Table 9.7).

9.1.3 Tilted Implants

The use of tilted implants represents another alternative in treatment of partial or complete edentulism. For example, the use of tilted implants inserted adjacent to the maxillary sinus wall can spare a sinus lift procedure (Fig. 9.7). In the mandible, the excessive bone atrophy of the posterior regions may render the placement of tilted implants in the intraforaminal area the only alternative to a bone grafting procedure.

The question is if the angulation of an implant may lead to unfavorable loading conditions and if this is related to worst clinical outcomes compared to axially placed implants.

Again, FEA studies may help in addressing the question if, in the presence of tilted implants, stress loads are increased on the bone and on the implant structures.

The FEA analysis performed by Bevilacqua and coll. [12] on a 3D edentulous jaw compared axially placed versus tilted implants at various degree of angulation. As expected, loading and

Table 9.7 Systematic reviews evaluating the effect of cantilever on implant-supported prostheses – *implant survival*

	Implant survival	Prostheses survival	Implant fracture complication	Screw or abutment fracture complication	Veneer fracture complication	Biological complications
Romeo and coll. [10] 5–10-year estimate 95 % CI	98.7 % (96.2–99.5)	96.5 % (94.8–97.7)	0.7 % (0.1–4.7)	1.6 % (0.8–3.5)	10.1 % (3.7–16.5 %)	5.7 % (4.2–7.6)
Zurdo and coll. [11] Weighted mean 5-year survival 95 % CI	97.1 % (95.5–98.6)	91.9 % (88–95.8)	/	/	/	/
Aglietta and coll. [50] Cumulative 5-year estimate 95 % CI	97.1 % (94.3–98.5)	84.1 % (–98)	1.3 % (0.2–8.3)	2.1 % (0.9–5.1)	10.3 % (3.9–26.6)	10.5 % (3.9–26.4)

tilting single implants increased the stress on the peri-implant bone. An interesting finding was that tilted implants supporting a shortened cantilever decreased the stress on both the bone and the prosthetic structure when compared to vertical implants supporting cantilever prostheses. This suggests that tilted implants may aid in decreasing the stress on the peri-implant bone and prosthesis because they allow a reduction of the cantilever length.

A two-dimensional FEA [13] arrived at the same conclusions, showing that although increased loading from the presence of cantilever cannot be eliminated, it is anyway reduced greatly with the inclination of the distal implants. These results encouraged the adoption of tilted implants in clinical studies in order to improve the prosthetic and biological outcomes.

Lan and coll. [14] simulated different combinations of angulations (vertical, mesial, or distal inclination) of two adjacent implants supporting a splinted prosthesis. It was found that the loading type (vertical or oblique) is the main factor in determining the stress on the peri-implant bone. Also, the parallelism or divergence of implant apices seemed of not having an influence of bone stress. Furthermore, the distal inclination of one implant and vertical position of the other resulted in peak of maximum stress: therefore, it was suggested to avoid this configuration in clinical practice.

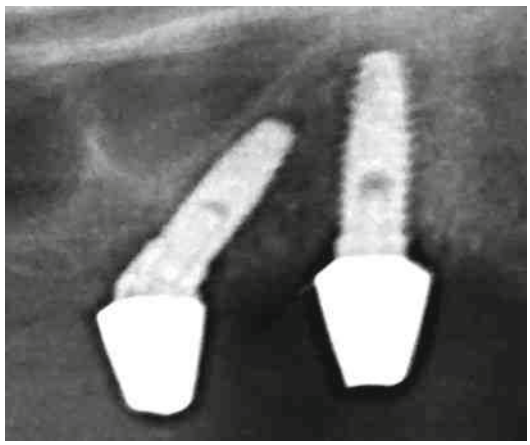

Fig. 9.7 Tilted implant placed in a patient that refused the sinus lift procedure

Systematic reviews and meta-analysis attempted to draw some conclusions from data retrieved by clinical studies specifically evaluating tilted implants.

A recent meta-analysis included 44 publications [15] on this topic, but only retrospective and prospective clinical studies were found, with no presence of RCTs. A positive factor was the low heterogeneity between the included studies.

Results showed that there was a not statistically significant difference regarding implant failure rates of tilted implants when compared to vertically placed. The authors performed a subgroup analysis in order to evaluate maxillary and mandibular implants separately; in the maxilla, a significant difference was found favoring the axially placed compared to tilted implants. Conversely, no difference was evidenced for the mandibular implants. This can be explained by the fact that maxillary bone, especially in the posterior regions, is of poor quality and consequently prone to suffer from the higher stress derived by tilted implants. This problem instead seems to not affect the denser mandible.

About MBL changes, no significant difference was outlined between the two groups.

Two other previous meta-analyses [16, 17] draw similar conclusions, but when subgroup analysis of mandibular and maxillary implants was done, no significant difference between the two was found, probably because in these analyses, studies with longer follow-ups were included (>1 year after loading), and this probably led to equilibrate the success and failures between the maxillary and mandibular groups.

A systematic review and meta-analysis addressed the question of immediate loading rehabilitation with tilted implants only of the maxilla [18]. No significant differences were found between axial and tilted groups regarding implant survival and MBL change. Therefore, immediate loading with tilted implants in the maxilla was considered a reliable procedure.

Limitations of these reviews and meta-analyses need to be considered. First, no RCTs evaluating the use of angulated implants in the mandible or maxilla were available for inclusion. Obviously, additional long-term studies are necessary. This

has direct repercussions on the inability to control confounding factors, especially smoking, parafunctional habits, and oral hygiene measures. Moreover, most studies are retrospective, which does not allow to have much control on the study in terms of record of information, missing data, and impossibility to set the participants of the study. Many clinical studies have small sample size and short follow-up period.

Finally, there is no consensus in the definition of the minimal angulation that allows to define an implant tilted or axially placed; moreover, it is difficult to standardize the angulation in the various clinical circumstances because this is dictated by the highly variable individual anatomy.

Nevertheless, the consistent results in various published reviews and meta-analyses suggest that angulation of dental implants in the mesiodistal plane does not seem to jeopardize the implant survival and the crestal bone level changes around dental implants (Tables 9.8 and 9.9).

9.1.4 Zygoma Implants

Anchorage of long implants to the zygoma bone is yet another alternative in case of extreme maxillary atrophy. Advantages of zygomatic implants include:

- Avoidance of bone grafting or complicated surgical procedures such as Le Fort I osteotomies or distraction osteogenesis.
- Eliminate the morbidity associated with these procedures.
- Allow implant rehabilitation in situations that normally would not allow to obtain good prosthetic outcomes, for example, after maxillary tumor ablation surgery.

Table 9.8 Meta-analysis comparison of tilted versus axially placed implants – *survival*

	Studies included	Effect size	*Tilted versus axially placed implants*	Favoring	Statistically significant
Menini and coll. [18] Maxilla only Risk ratio (95 % CI)	*Retrospective and prospective studies*	RR (95 % CI)	1.23 (0.66–2.30)	Axially placed	*No (p-value 0.575)*
Chracanovic and coll. Risk ratio (95 % CI)	*Retrospective and prospective studies*	RR (95 % CI)	1.89 (1.35–2.66)	Axially placed	*No (p-value 0.450)*

Table 9.9 Meta-analysis tilted versus axial – MBL change

	Studies included	Effect size	Tilted versus axially placed implants	Favoring	Statistically significant
Menini and coll. [18] Maxilla only	*Retrospective and prospective studies*	Mean difference in mm (95 % CI)	0.02 (–0.05–0.09)	Axially placed	*No (p-value 0.575)*
Monje and coll. [68]	*Retrospective and prospective studies*	Mean difference in mm (95 % CI)	–0.13 (–0.041–0.298)	Axially placed	*No (p-value 0.137)*
Del Fabbro and coll. [16]	*Retrospective and prospective studies*	Mean difference in mm (95 % CI)	–0.06 (–0.12–0.01)	Axially placed	*No (p-value 0.05)*
Chrcanovic and coll. Subgroup mandible	*Retrospective and prospective studies*	Mean difference in mm (95 % CI)	0.77 (0.39–1.52)	Axially placed	*No (p-value 0.450)*
Subgroup maxilla			1.70 (1.05–2.74)	Axially placed	*Yes p-value (0.03)*

Disadvantages are:

- Invasive surgery
- Risk of damaging delicate structures like the orbital cavity
- Need of sedation or general anesthesia compared to other implant surgery techniques

Zygoma implants are available in lengths up to 50 mm; the most common diameter is 3.75 mm. Traditional protocols include the placement of two zygoma implants associated with two to four traditional implants in the anterior maxilla. This is a protocol that can be followed when the anterior maxilla is not excessively atrophied; otherwise, placement of two zygoma implants per side will serve as the retention for the prosthesis.

Chrcanovic and coll. reported five different surgical techniques available for zygoma implant insertion [19].

The *classical approach* (Fig. 9.8) begins with the exposure of the maxillary bone up to the infrazygomatic crest, finally reaching the zygomatic bone for a complete visualization. After identification of the infraorbital nerve, a window at the sinus wall is made. The sinus mucosa is reflected, and the entrance from the maxillary crest with a round bur is made through the sinus. When the zygoma bone is reached and the implant site prepared, the implant is inserted manually to the proper depth.

The *sinus slot technique* (Fig. 9.9) is similar to the traditional approach, but instead of raising the whole sinus mucosa, a space or "slot" is created along the insertion path of the implant into the maxillary bone up to the base of the zygoma, such that the whole implant threads are exposed for visualization. The smaller antrostomy that results renders this technique less invasive.

The *exteriorized approach* (Fig. 9.10) does not include antrostomy; therefore, the implants are placed outside the sinus. Osteotomy is performed in the zygoma bone and widened progressively.

Custom-made drill guide (Fig. 9.11) is a minimally invasive technique that involves the use of a 3D model manufactured on the basis of a CBCT scan, and finally the drill guide is produced with stereolithography. This should allow positioning of the implant without antrostomy.

Computer-aided surgery involves the use of intraoperatory navigation system that can allow, in theory, to execute a flapless procedure.

The authors concluded that the choice of a technique over another is a matter of personal preferences due to the lack of comparative studies. On the other hand, there are situations that lead to prefer a given surgical approach. In detail, a severe resorption with a prominent concavity between the zygoma and the maxilla suggests the

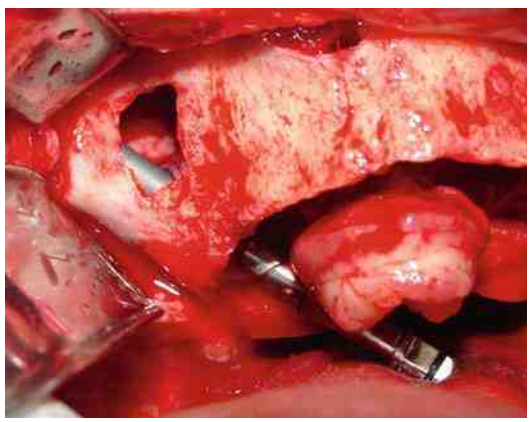

Fig. 9.8 Classical approach for zygoma implant placement (Reproduced with permission from Chrcanovic and coll.)

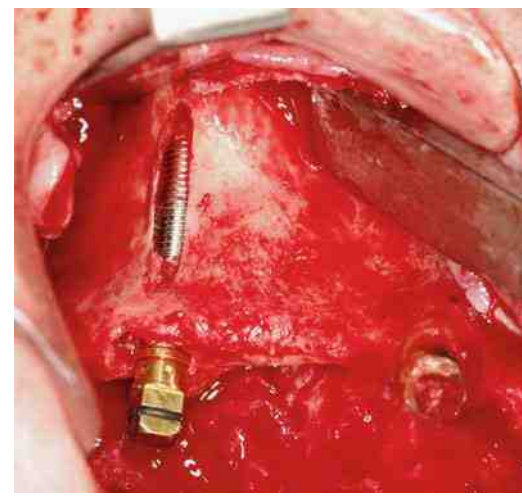

Fig. 9.9 Sinus slot technique for zygoma implant placement (Reproduced with permission from Chrcanovic and coll.)

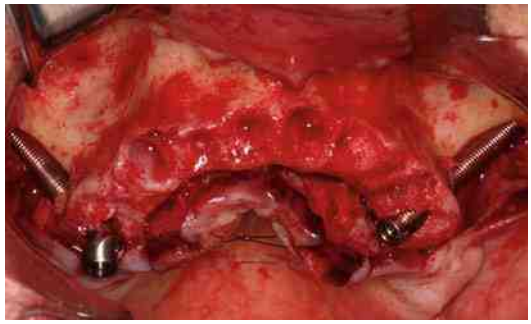

Fig. 9.10 Exteriorized approach for zygoma implant placement (Reproduced with permission from Chrcanovic and coll.)

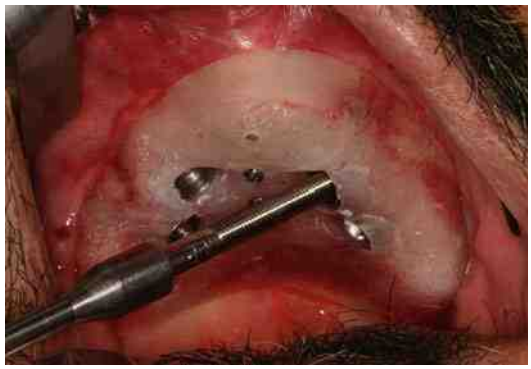

Fig. 9.11 Custom-made drilling for zygoma placement (Reproduced with permission from Chrcanovic and coll.)

use of an exteriorized approach; the contrary happens when no concavity is present, and the classical or slot techniques should be employed.

Regarding the custom-made drill guides and computer-aided surgery, their use still needs to be validated. Moreover, they're more expensive and limited to centers where the necessary equipment is available.

The most common complications as reported in the literature are sinusitis in up to 21 % of patients, implant failure in up to 11 % of patients, and perforation of the orbit in to 6 % of patients. Maxillary or zygomatic nerve deficits and intracranial penetration are also reported in the literature, but these serious complications are limited to single case reports [20].

Reported survival rates of zygoma implants are in the range of 95.6–100 %. The high survival rates are likely dependent by the fact that careful patient selection and skilled clinicians in specialized centers are involved in the placement of this kind of implants [21–23].

Wang and coll. [22] included three studies in their systematic review with a total of 196 implants placed in 49 patients; the reported weighted mean survival rate was 96.7 % (92.5–98.5 CI 95 %). Despite this, the study suggests the reliability of zygoma implants in full-mouth maxillary rehabilitation (Fig. 9.12); no RCTs are available, and further studies are needed to give strength to these results.

Zygomatic implants are very useful solutions in those cases in which other options are unfeasible, especially post-oncologic ablation patients and very severe atrophy of the upper jaw. The delicate structures involved in the placement procedures should be taken into account; therefore, placement of zygomatic implants should be limited to experienced surgeons, in adequate structures ready to face the possible complications which may occur.

9.1.5 The All-on-Four Concept

The All-on-Four™ is a prosthetic design concept (Nobel Biocare, Goteborg, Sweden) which employs four implants in the anterior jaw (maxilla or mandible), of which the central two are vertically placed, while the most distal are maximally angulated in order to minimize the cantilever length and support a full-arch, provisional, immediately placed fixed prosthesis (Fig. 9.13). No RCTs are available for evaluation of this prosthetic solution compared to other ones, but a systematic review [24] analyzed six prospective and retrospective studies for evaluation of effectiveness and long-term success of the All-on-Four protocol. The follow-up in the included studies ranged from 12 to 36 months. Studies reported success rates for the implants in the range of 98.6–99.1 % and for the prostheses from 99.9 to 100 %. Anyway, this high survival rates need to be taken cautiously. First, the majority of the studies included were conducted in Italy and Portugal by experienced clinicians that had a huge experience with this procedure, so it is difficult to understand if these excellent results may be replicated by the average practitioner in the everyday practice. Second, the lack of RCTs and

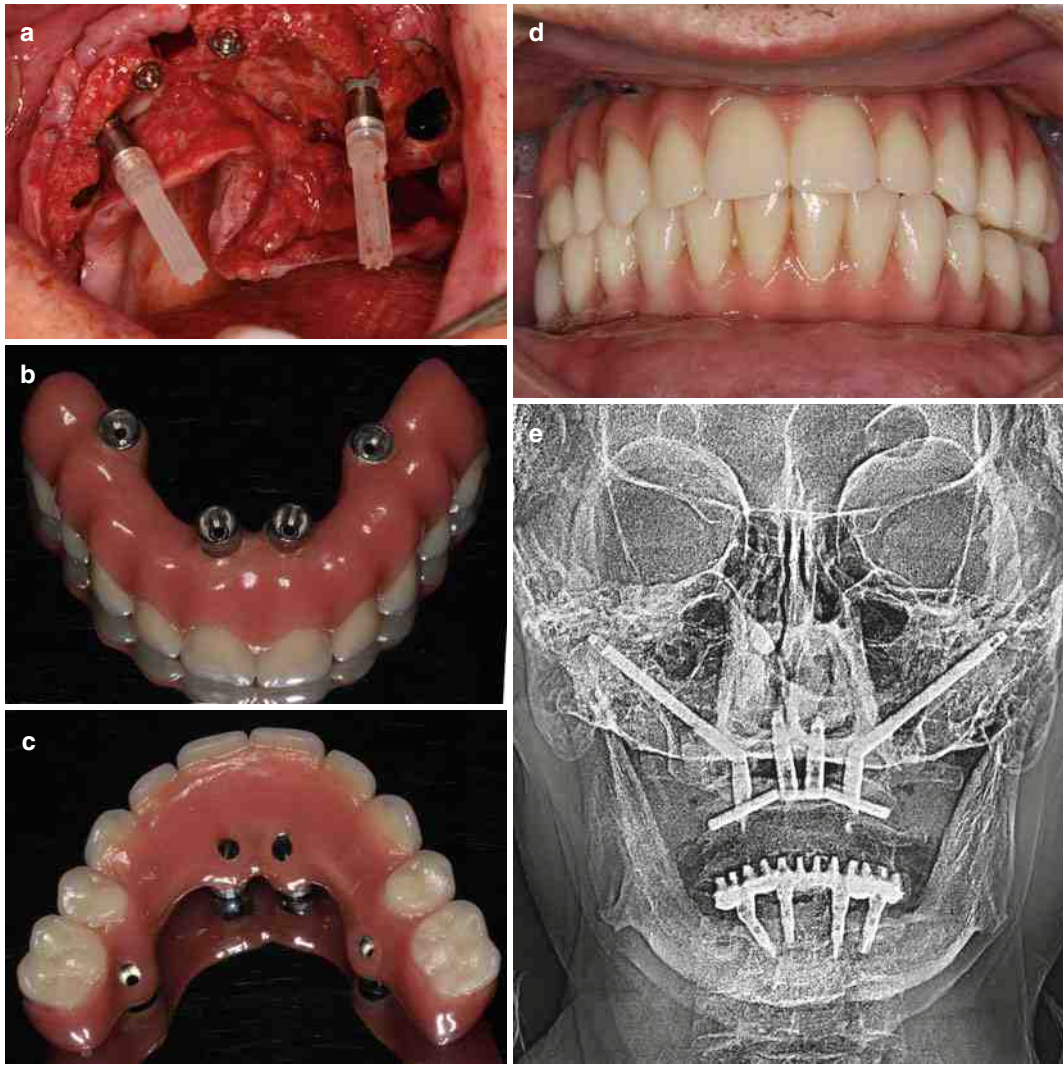

Fig. 9.12 (**a**–**e**) Zygomatic implant placement (**a**). Maxillary prosthesis (**b**, **c**). Delivery of the prosthesis and X-ray showing the correct placement of the implants up to the zygomatic bone (**d**, **e**)

the short follow-up periods does not allow to draw any certain conclusion. Undoubtedly, long-term studies with follow-ups of at least 5 years are necessary.

9.2 Optimal Number of Implants for Fixed Reconstructions

One of the questions that accompanied the dental implant practice since its beginning is about the optimal number of implants that guarantees the best clinical results.

Addressing this question, it is not an easy task; in the past, some clinicians advocated the option of one implant for every missing tooth, but clinical results have shown that this is not the case.

Nevertheless, there is still a lack of clarity when the issue of the *ideal number of implant* is analyzed.

Mericske-Stern and coll. [25] tried to find answers to the question reviewing the evidence of the past 30 years. The authors concluded that despite the lack of long-term studies and RCTs regarding the implant number and prosthetic

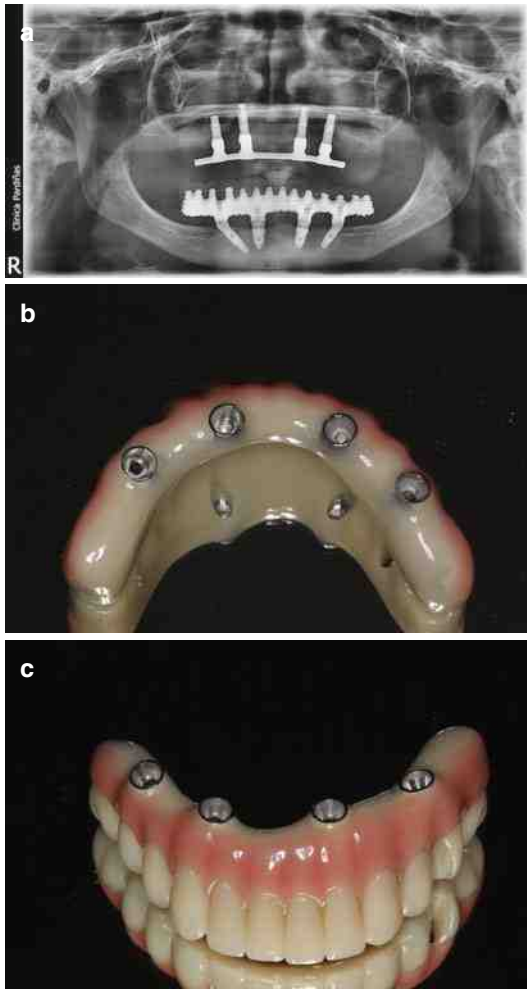

Fig. 9.13 (**a**–**c**) Example of a mandibular All-on-Four implant placement and restoration

design, consistent results are reported in the implant literature. In particular, high survival rates and relatively low risks of complications are achieved regardless of the number of implants used. The majority of articles to rehabilitate edentulous jaws report four to six implants; therefore, this seems a reasonable number for full-mouth rehabilitation with implants ≥10 mm long.

At the FOR Consensus Conference in 2014 [26], it was established that a sufficient number of implants for full-mouth restorations with fixed prostheses consisted of four implants in the mandible and six in the maxilla. Moreover, it was recalled that four implants of standard dimensions (≥10 mm long and ≥3.5 mm in diameter) can be considered a valid alternative in the maxilla.

Also Heidecke and colleague [27] assessed the 5-year survival ad complication rates of implant-supported fixed reconstructions in partially and totally edentulous patients in the attempt to establish the optimal number of implants according to a specific type of reconstruction (FDP or full arch). The results of the analysis were considered just extrapolation from studies performed for other kind of evaluation, given that no trial exists that specifically attempts to answer the original question.

Therefore, the authors concluded that four to six implants in the edentulous jaws are a good number for full-arch restorations, while for FDP the evidence remains unclear.

9.3 Implant Overdentures

It is common for edentulous patients wearing a maxillary or mandibular complete removable denture to suffer from insufficient stability or poor retention of the prostheses. This may have a huge detrimental impact on chewing abilities, phonation, esthetics, and quality of life as a whole.

Implant overdentures (OVD) aim at overcoming these problems conferring better retention, function, and phonetics.

OVD are defined as complete dentures partially supported by dental implants. Some authors have proposed the distinction between implant-*supported* and implant-*retained OVD*, the first referring to a prosthesis entirely supported by implants and the second instead retained by dental implants but finding its support on the mucosa as well [28].

Analysis of the literature allows to evaluate the various attachment systems and optimal number of implants which should ensure optimal survival and complication rates of the implants and the OVD prosthetic components.

Different attachment systems for mandibular and maxillary OVD exist.

Bar, *ball*, *magnets*, *and telescopic attachments* are the most commonly employed mechanisms of retention [29].

- A *bar* (Fig. 9.14) mechanism has the purpose of splinting the abutment teeth and at the same time support the prostheses.
- *Ball* (Fig. 9.15) attachments are the simplest type, constituted by a small ball on the implant which houses a corresponding space contained within the prostheses.
- *Telescopic* attachments (Fig. 9.16) are made of a primary coping attached to the implant which inserts in a secondary coping present within the prostheses.
- *Magnets* (Fig. 9.17) are composed of the rare Earth material neodymium-iron-boron (Nd-Fe-B) which is the most powerful magnet available or another rare material which is samarium-cobalt (Sm-Co).

In general, the selection of an attachment system has been dependent on the preferences of the clinician, but it should be important to understand if treatment outcome is in some way dependent by the type of attachment chosen.

Kim and coll. [30] systematically reviewed the publications on this topic; in their research, they included RCTs and prospective studies with follow-up in the range of 1–10 years. Survival rate of implants ranged from 97 % to 100 % with a mean survival of 98 %. Magnet attachments were most

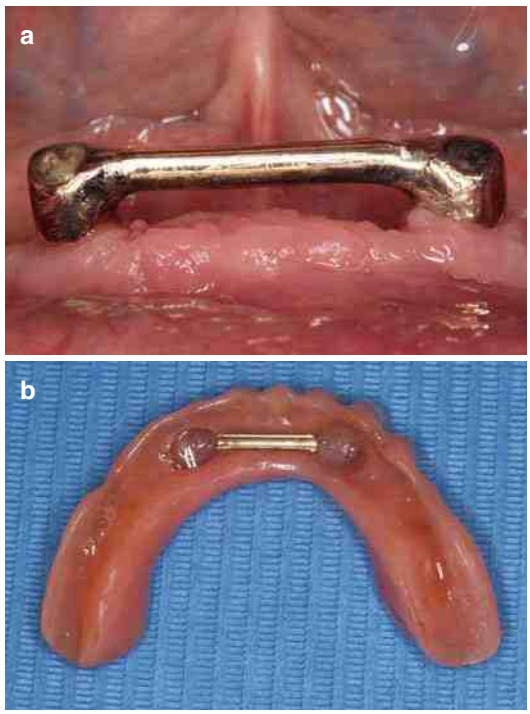

Fig. 9.14 (**a**, **b**) Example of bar attachment for a mandibular OVD

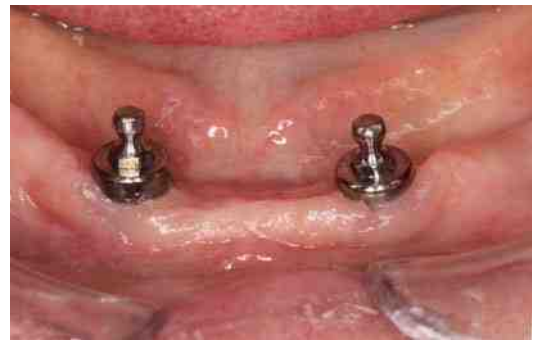

Fig. 9.15 Example of ball attachments

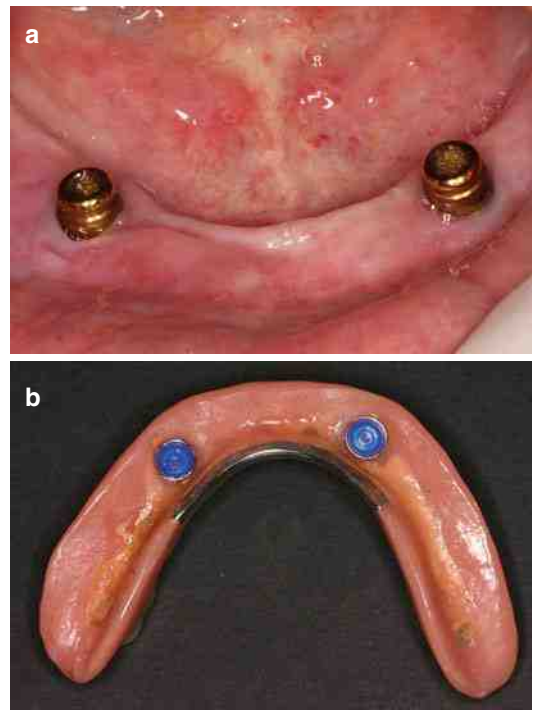

Fig. 9.16 (**a**, **b**) Example of telescopic attachments

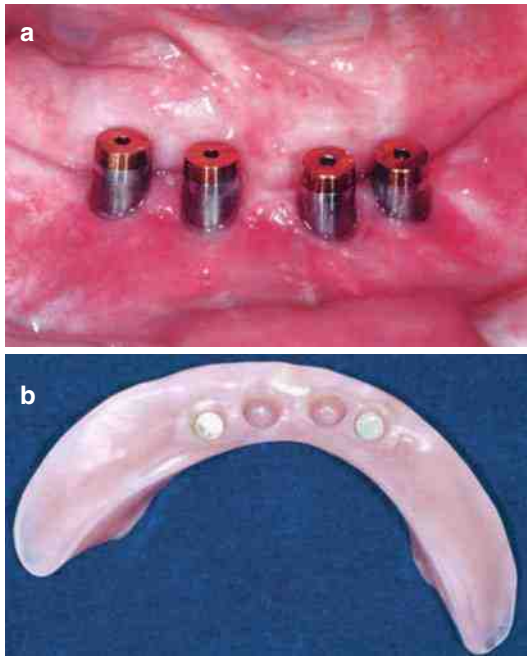

Fig. 9.17 (**a**, **b**) Example of magnetic attachments (Reproduced with permission from Chu and coll.)

commonly affected by complications due to wear and corrosion. These complications were more frequent with old magnetic materials such as AlNiCo, but with new materials such as Nd-Fe-B or Sm-Co, they can be potentially reduced.

Clip loosening in *bar* attachments and matrix loosening in *ball* attachments were the second most common reported complications.

Andreiotelli and coll. [28] evaluated RCTs and prospective studies with follow-up ≥5 years. The authors found that information regarding mandibular OVD was found more commonly than maxillary one. Results showed that implant survival was in the range of 93–100 % at 10 years and did not seem to depend by splinting or the number of implants employed. Implant survival was higher for the mandibular OVD compared the maxillary ones.

Prosthetic success ranged greatly and was not calculated cumulatively; therefore, a numerical synthesis between the various studies was not performed.

In order of frequency, the most common reported complications were loss of retention, need of rebasing/relining, attachment fracture, OVD fracture, opposing prosthesis fracture, acrylic resin fracture, abutment screw loosening, and implant fracture. Higher incidence of complications was observed for the maxillary OVD in respect to the mandible.

Although it was considered not feasible to perform an objective assessment of the retention systems, it was any way possible to observe that the majority of the studies outlined a substantial lack of difference in terms of implant survival between splinted and unsplinted OVD. Single attachments are less costly and easier to manufacture; therefore, it should be preferable to adopt them instead of a bar retaining system.

The ball retentions seem to show the highest retentive capacity. On the opposite side, magnets and bars tend to show a decrease of the retention capacity over time.

Also, it was observed that there seems to be no correlation between attachments and prosthetis, aside from bars with distal cantilever that show a higher degree of fractures.

Regarding the optimal number of implants for mandibular implant OVD, a systematic review of RCTs and prospective studies with a follow-up ranging from 1 to 10 years [31] draw the conclusion that the prognosis of OVD is excellent and implant survival rates were similar between the one, two, and four implant OVD designs; it was concluded that high survival rates can be obtained regardless of the number of implants inserted. Also, denture maintenance and patient satisfaction scores seemed to be not affected by this factor.

Raghoebar and coll. [32] specifically evaluated the ideal number of implants for the maxillary OVD. Considering that implant survival rates are generally lower than the mandibular ones, it is reasonable to assume that in order to prevent loss of the prostheses, a greater number of implants are required for maxillary OVD (Fig. 9.18).

In fact, the meta-analysis showed an event rate/year for implant loss of 0.019 in case of ≥6 splinted implants compared to 0.030 event rate/year for ≤4 splinted implants and 0.111 event rate/year for ≤4 unsplinted implants.

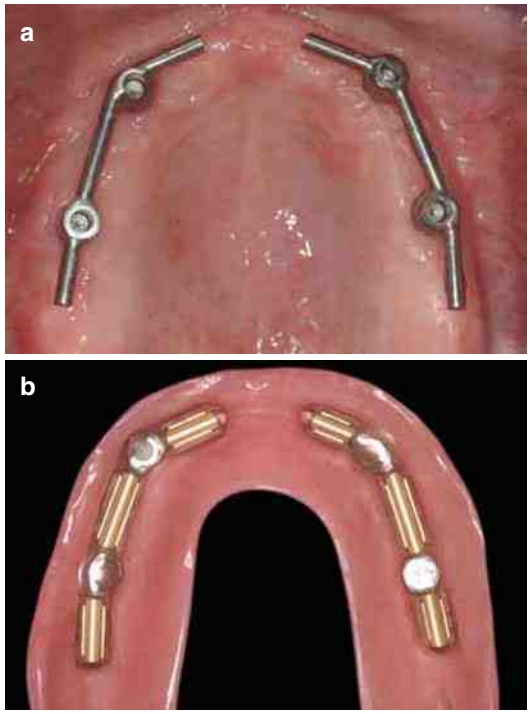

Fig. 9.18 (**a**, **b**) Example of maxillary overdenture. In these cases, implants connected with a bar seem to be more reliable than other prosthetic solutions (Reproduced with permission from Slot and coll.)

About prostheses loss, the event rate/year was of 0.005 in case of ≥6 splinted implants, 0.031 for ≤4 splinted implants, and 0.012 for ≤4 unsplinted implants. This figures led to the conclusion that implant-supported maxillary OVD should be ideally supported by six implants splinted between each other, the minimum number being four splinted implants. The worst outcomes were observed with ≤4 unsplinted implants (Tables 9.10 and 9.11).

Another similar systematic review, on studies with a mean observation period of 1 year [33], arrived at similar conclusions.

The survival rate of both prostheses and implants was >95 % for all the design configurations analyzed (six splinted implants, four splinted implants, four implants with bar attachments). Anyway, the best results were obtained with six splinted implants, followed by four splinted implants, the least successful being the four implant ball design. For this reason, it was concluded that four implants maxillary OVD need to be considered as a second-line treatment option, although good results can be obtained in any case.

The McGill consensus statement, published after the symposium held at McGill University in Montreal, recommended that the minimal acceptable treatment for the fully edentulous mandible is the two implant OVDs. This was not intended as the best treatment option but instead the minimally acceptable solution for patients that cannot undergo more extensive prosthetic and implant treatment [34].

This concept was widely validated by numerous RCTs. In a recent meta-analysis [35], the patient-assessed quality of life evaluated with a Visual Analogue Scale was considered to be higher in patients having an implant-supported OVD compared to conventional denture wearers.

Also the functional aspects, such as chewing ability and phonation, were notably improved with the adoption of an implant-supported OVD.

In light of this, it is possible to state that the McGill consensus statement in which two implant OVDs are the minimally acceptable treatment options for the fully edentulous patient should be fully incorporated in clinical practice at any level.

An aspect that merits consideration is the degree of MBL around implants retaining or supporting OVDs. When literature is systematically reviewed, attachment type and implant design do not seem to influence the MBL change [36] although the high heterogeneity of the studies reporting this value does not allow to draw strong conclusions at this regard.

Finally, maintenance of OVD is an aspect investigated by researchers in light of the fact that it reflects the chair time spent for this kind of treatment and has important economical repercussions. There is a general consensus in the literature that the highest frequency of reinterventions and readjustments is performed in the first year after loading. Loss of retention due to damage or wearing of the attachment system is the most common cause of reintervention. Also relining of the denture is a quite common

Table 9.10 Maxillary OVD treatment – overdenture survival

	Six implants and bar superstructure	Four implants and bar superstructure	Four implants not splinted
Slot and coll. [33] Survival rate per year (95 % CI)	98.1 % (96.4–99.0)	97.0 % (91.4–99.0)	89.0 % (96–97.4)
Raghoebar and coll. [32] Survival rate per year (95 % CI)	99.5 % (97.8–99.8)	96.9 % (92.4–98.7)	98.8 % (91.4–99.8)

Table 9.11 Overdenture complication reported rates

OVD complications	
Andreiotelli and coll. [28]	Loss of retention 30 %
	Needs of rebasing/relining 19 %
	Clip or attachment fracture 17 %
	OVD fracture 12 %
	Opposing prosthesis fracture 12 %
	Acrylic resin fracture 7 %
	Prosthesis screw loosening 7 %
	Abutment screw loosening 4 %
	Abutment screw fracture 2 %
	Implant fracture 1 %

necessity, in the range of 6–18 % according to various authors (Table 9.7).

In conclusion, implant-supported or retained OVD constitutes an excellent treatment option in edentulous denture wearers that for economical, surgical, or anatomical reasons cannot undergo extensive implant surgery for full-arch fixed dental prosthesis.

From a review of the literature, it emerges that the various attachment systems available are all reliable although a possible increase in complications can occur with magnets and ball attachments. The presence of a bar does not seem to confer appreciable improvements in clinical outcomes for the mandibular OVD, whereas in the maxilla, six implants connected by a bar constitute a safer option in terms of implant and prosthesis survival.

Finally, it was observed that mandibular OVD sustained by two implants gives excellent results and should be considered the treatment of choice for denture wearers. The choice of the attachment system does not influence the success and survival rates of implant and prostheses. Anyway, it seems that magnets are associated with an increase in complications such as loss of retention, especially at long term.

9.4 Dental Implant Impressions

An accurate impression is one of the fundamental steps in the success of the implant treatment. Accuracy of the impression has a direct role in the accuracy of the cast and the proper fit of the definitive prosthesis. Various materials and techniques have been employed in implant dentistry, and choosing between them can be a challenge for the practitioner [37].

First of all, the ideal impression material should possess some basic properties:

- *Accuracy* refers to the property of the material to reproduce the fine details in a precise way. An accurate material should be able to reproduce details with a limit of at least 25 μm.
- *Elastic recovery* means that, after induration, the material is deformed by the undercut areas in the mouth during removal, but then it recovers its original shape.
- *Hydrophilia* is another important property because it allows the material to flow even in the presence of saliva or blood. In fact, the more a material is hydrophilic, the more it can "spread" over a given surface.
- *Viscosity* refers to the ease of the material to flow readily. It is important for a given material to possess an equilibrium in viscosity such that it can be contained in the tray without flowing away but at the same time maintain a certain degree of flowability into the small anatomic details.

- *Workability* is the property of the material to be handled with ease for insertion in the mouth and at the same time possessing a setting time that allows impression taking without much discomfort for the patient.

Two materials, belonging to the elastomeric class, have emerged as possessing all the qualities to achieve excellent results in implant dentistry. These are the *polyethers* and the *addition silicones (polyvinylsiloxanes or PVS).*

Polyethers are available in low-, medium-, and heavy-body consistency.
PVS are available as extra low, low, low medium, heavy, and very heavy (putty).

Polyethers have shorter working times and are more hydrophilic compared to PVS, even if surfactants have been added to silicones in order to improve the wettability of these materials. On the other hand, PVS have the best elastic recovery. Both materials undergo shrinkage after polymerization in the order of −0.15–0.20 % after 24 h; this means that the models should be prepared as soon as possible if the maximum accuracy is desired.

Three methods are commonly employed in making implant impressions,

- *Dual-viscosity* technique, a low-consistency material is injected, usually through a syringe, on a higher viscosity material already present in the tray.
- *Monophase* technique, impression is taken with a single, medium-viscosity material.
- *Putty-wash* (Fig. 9.19) technique, a putty material is inserted in the tray, and a preliminary impression is taken. Then, in the created cavities, a low-consistency material is injected, and the preliminary reimpression is inserted.

Regarding the techniques of impression coping, it is possible to differentiate between *transfer (closed tray)* and *pickup (open-tray)* techniques.

In the *transfer* technique (Fig. 9.20), the impression copings remain in the mouth on

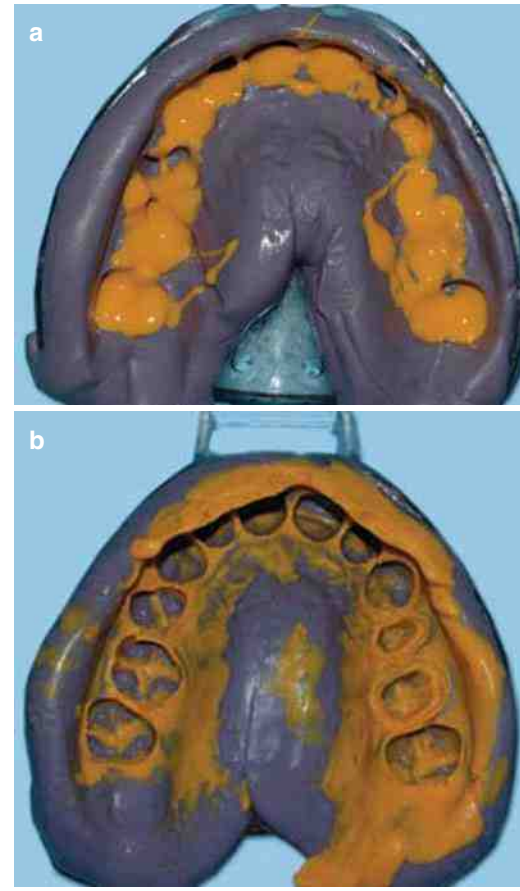

Fig. 9.19 (**a**, **b**) Putty-wash technique in which a putty material (the picture is *purple* in color) is inserted in the tray, and a first impression is taken. Then in the indentations left by the first impression, a low-consistency material (*yellow* in the picture) is injected, (**a**) and the final impression is taken (**b**)

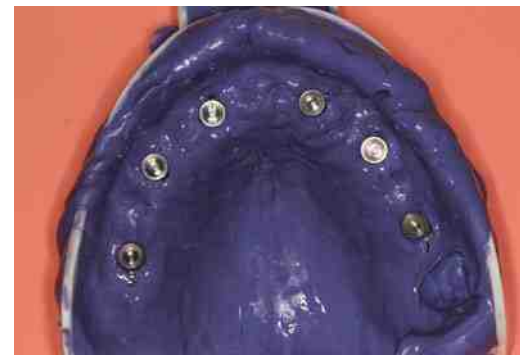

Fig. 9.20 *Transfer* (*closed tray*) technique performed with a *monophase* material (polyether)

removal of the set impression; their insertion occurs outside of the mouth on the indentations left on the impression.

In the *pickup* technique (Figs. 9.21, 9.22, and 9.23), the impression copings and the analogues are screwed to the implant; an open tray is used to take the impression. With the tray still in the mouth, the analogues are removed, and finally the coping-impression assembly is removed together; at the end, the analogues will be connected to the copings outside of the mouth and sent to the laboratory.

To ensure the maximal stability of all the components, there is the possibility to splint the copings together in the mouth with a scaffold formed of dental floss or orthodontic wire covered by a resin.

Finally, digital impressions have emerged as possible alternatives to the traditional techniques (Figs. 9.24 and 9.25).

9.4.1 Implant Impression Accuracy

Regarding the assessment of implant impression technique accuracy, the majority of the available studies comprise in vitro evaluations.

Linear distortion is the most common method used for the evaluation of impression accuracy, which is the assessment of the displacement on the x,y,z plane of the implant or abutment heads between each other after having established two reference points (such as the abutments themselves). Displacement is the most important factor determining the impression accuracy.

Angular distortion instead aims at evaluating the rotation of the implant head around the implant long axis and the translation of the head along a reference plane.

Due to the nature of the evaluations, only narrative reviews are available for assessment and comparison of various implant impression

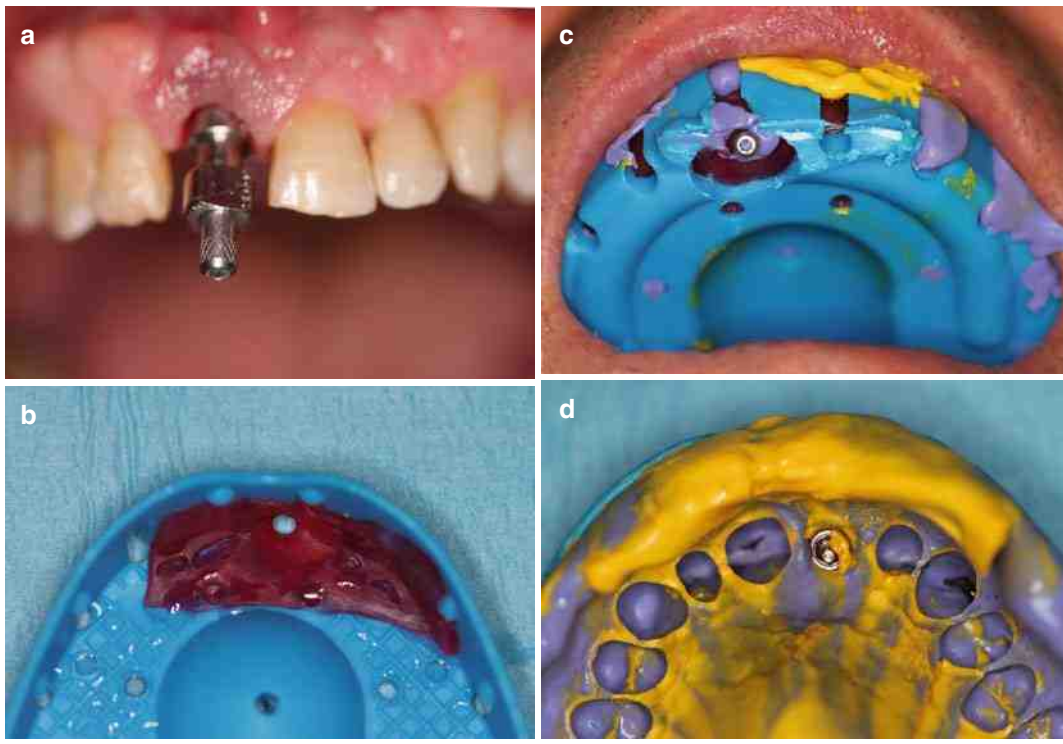

Fig. 9.21 (**a**–**d**) Pickup (open-tray) technique, the coping is screwed to the implant (**a**). An open tray is used to take the impression (**b**). With the tray still in the mouth, the analogues are removed (**c**), and the coping-impression assembly is finally removed from the mouth (**d**). Two materials (*dual-viscosity* method) of different consistency were used (PVS)

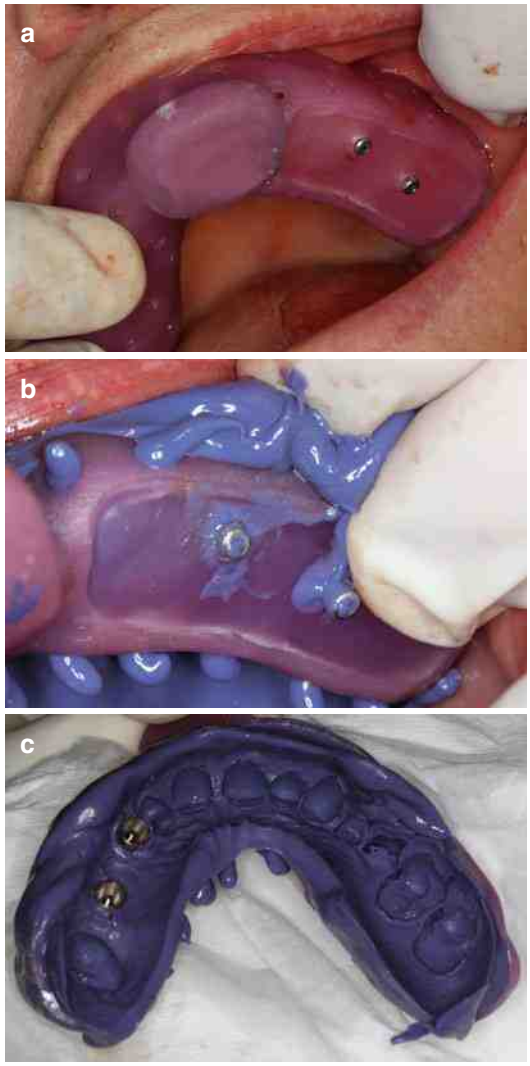

Fig. 9.22 (**a**–**c**) A *custom tray* can be used for the *pickup technique*; this ensures greater comfort for the clinician and greater ease in impression taking. In this case, a *monophase* material was used (polyether)

techniques [38–44]. Anyway, general conclusions can be drawn by analysis of the literature.

In a recent review [38], including only in vitro studies, accuracy comparison of implant impression techniques was performed. Regarding the *transfer* versus *pickup* technique, it was found that a large part of the studies showed more accurate impressions with the open techniques, especially in case of four or more implants.

The material evaluation evidenced that the most used and accurate material was the polyether, followed by PVS.

Splinting techniques were also analyzed. Acrylic resin with dental floss splinting was the most often used. Also, sectioning of the resin before complete polymerization seemed to prevent the detrimental shrinkage effect to occur. Regardless of this, splinting impression technique was the most accurate compared to non-splinting.

As expected, angulation of the implants presented the worst accuracy even if number of implants, adjacent teeth proximity, and implant height may also have an influence on accuracy.

Finally, regarding digital impression, unclear evidence emerged mainly due to the lack of studies. It was concluded that high-accuracy scanners and the usage of powder particles as a marker give the best results. It is obvious that a current trend exists of shifting toward digitalization of implant procedures, and digital impression improvements may potentially lead to elimination of multiple materials and clinical/laboratory steps, but more studies are needed to confirm their clinical validity in comparison to the traditional procedures.

In conclusion, it is possible to state that splinting seems to ensure a greater accuracy than non-splinting technique. Sectioning of the resin before full polymerization has been advocated to give the best results.

There is small difference between *pickup/open-tray* and *transfer* technique, even if it seems that *pickup* technique may guarantee a better accuracy in case of divergent and multiple implants.

Polyether and *PVS* show similar performances, but the first has been reported to be the most accurate.

Finally, insufficient data exists on digital impression techniques to draw definitive conclusions.

9.5 Esthetics in Prosthetic Implant Dentistry

Optimal esthetic results depend by numerous factors. Of course, the prosthesis itself plays a fundamental role on the esthetic outcomes. The perfect mimicry with the natural tissues depends

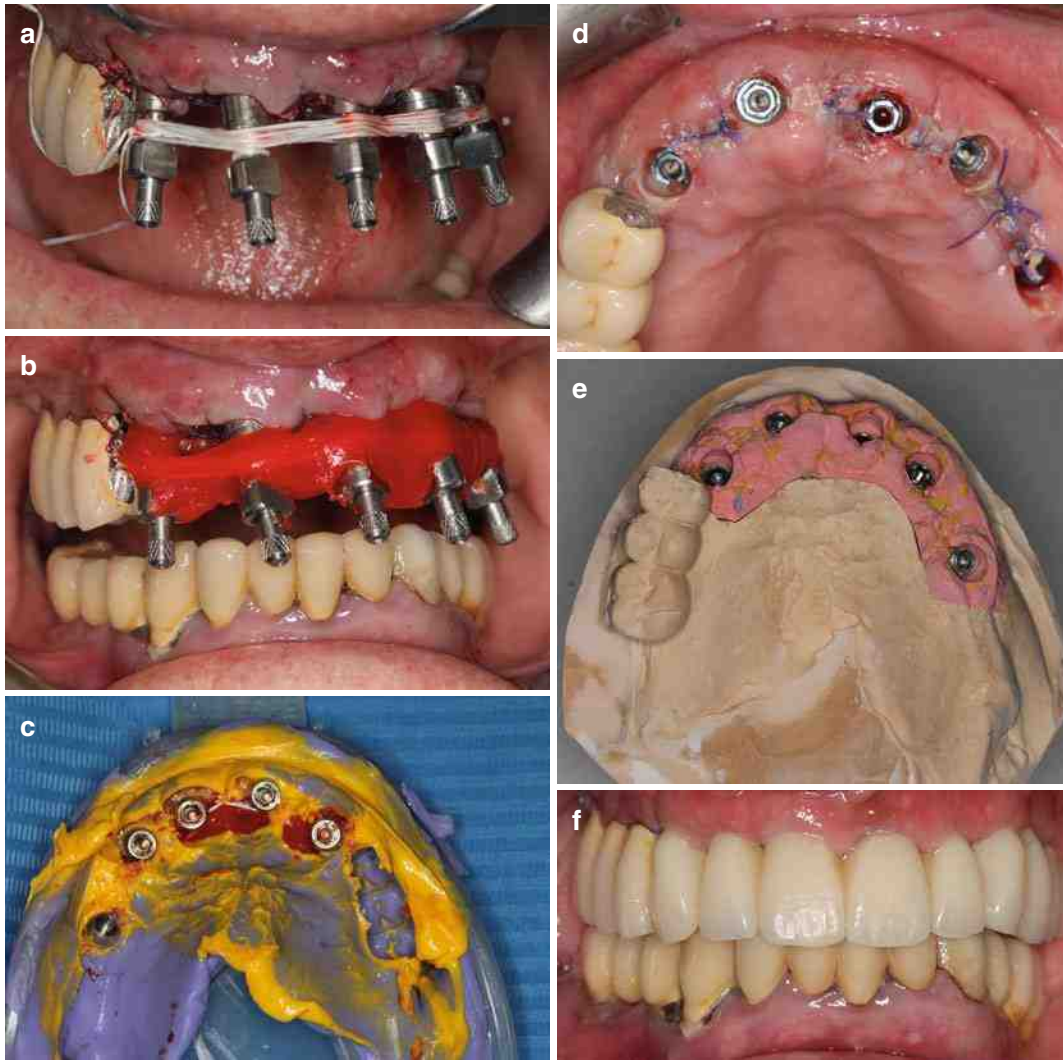

Fig. 9.23 (**a**–**f**) Splinting of the implants with resin at the moment of taking, the impression ensures the greatest precision due to the absence of micromovement at the moment of tray removal from the mouth. In this case, the scaffold for the resin was made with tooth floss (**a**, **b**); dual-viscosity materials (PVS) were used in an open-tray technique (**c**). Excellent reproduction of details for an immediate loading restoration (**d**–**f**)

upon the materials adopted and upon the perfect integrations of the implant and the prosthesis with the surrounding structures.

Other factors such as implant position, provisional restorations, and timing of loading may have a role in obtaining optimal esthetic results.

The review of Martin and coll. [45] addressed this topic, examining RCTs and prospective and case series studies published in the last decade.

Implants malpositioning seems to play a role in esthetic outcomes. In particular, an excessive buccal inclination of the implant increases the possibility to incur in mucosal recessions.

Adoption of a provisional to allow proper adaptation and evaluation of the tissues before temporary restorations was strongly recommended because it allows the possibility of planning the final restoration. Moreover, soft tissue

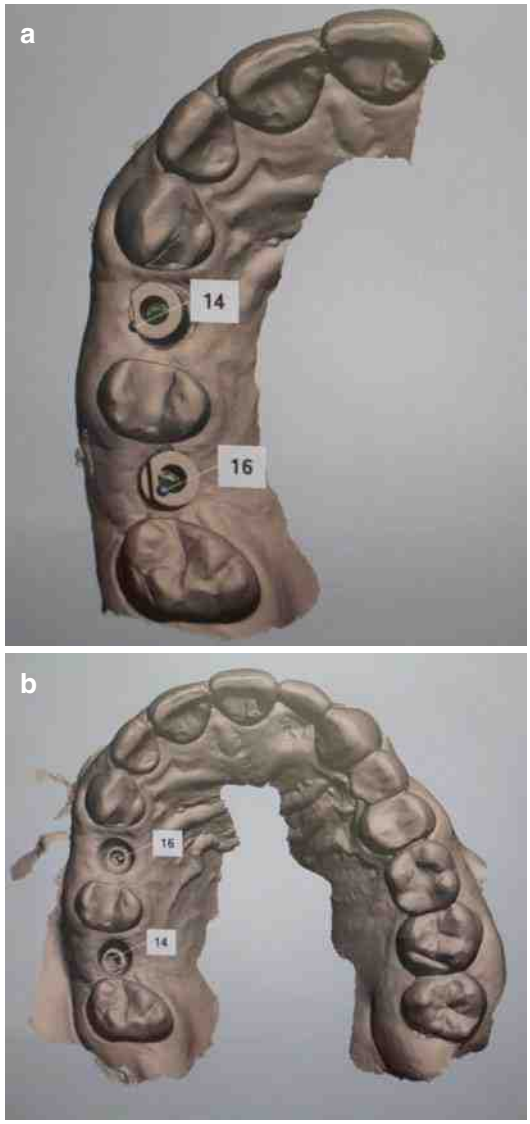

Fig. 9.24 (**a**, **b**) Virtual impression techniques allow a digital view and study of the case

maturation was considered an essential prerequisite for excellent results.

Regarding the retention system in relation to the esthetic outcomes, few studies available do not allow to propend to screw or cement retained.

The problem that emerged from this analysis is a general lack of RCTs having esthetics as the first aim of evaluation. PES/WES scores are not uniformly reported; the same is true for the papilla index and other standardized objective evaluation systems.

A true evidence-based comparison of esthetic outcomes in implant dentistry is impossible and this problem must be addressed in future studies.

9.5.1 Zirconia Versus Metal Ceramic

As already pointed out in the previous chapters, the use of zirconia has gained popularity due to its better esthetic mimicry with the natural dental tissues. The use of zirconia implant restorations is therefore aimed at improving the esthetic outcomes of the implant treatment in the cases in which the patient expects the best esthetic results.

The worries expressed for other applications of ceramics (see Chaps. 4 and 5) in implant dentistry persist even for the prostheses manufacturing. In particular, the theoretical reduced mechanical performances in posterior regions of the mouth.

When the literature is critically reviewed [46], it is found that implant-supported *single crowns* tend to show similar cumulative survival rates at 5 year (97.1 %) compared to the metal-ceramic restorations.

The studies used for comparison present the usual problem of limited number of patients and follow-up, but results are anyway encouraging.

Also, rates of complications associated with all-ceramic crowns were not different from the metal ceramic. Although it must be pointed out that these results can be different for FDP and full-arch restorations, because of their greater complexity.

Veneer chipping was considered to be the most common technical complication of all-ceramic single crowns.

In the same fashion, systematic reviews on zirconia FDPs [47, 48] showed excellent results at short-term clinical evaluation both in terms of survival than technical complications.

The encouraging results must be balanced by the recognition of the fact that well-designed RCTs are missing in the dental literature. Also, some of the available studies lack in reporting some

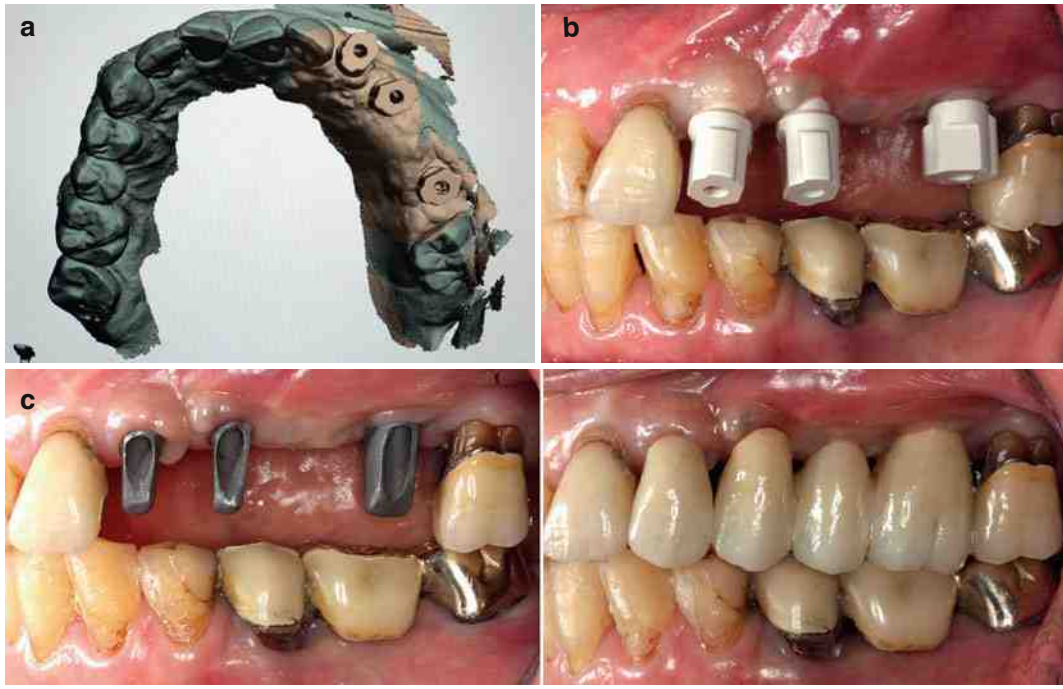

Fig. 9.25 (**a**–**c**) Example of digital impression taken with intraoral scan bodies and custom abutment fabrication (Reproduced with permission from Brandt and coll.)

important information such as the region of the mouth in which the restoration is placed, the type of restorations or the condition of the opposing dentition. At the current state, it is not possible to draw strong conclusions on zirconia restorations.

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Pre-Implant Reconstructive Surgery 10

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Abstract

The long-term predictability of dental implants is directly associated with the quality and quantity of the available bone for implant placement. Many times, clinicians have to face situations where implants cannot be placed in an ideal position. For different reasons, soft and hard tissues do not present an adequate volume that is required to achieve an ideal situation to ensure the survival, function, and aesthetics of our implants. To solve these problems, bone grafting procedures may be indicated in order to prepare the site in advance or sometimes at the time of implant surgery. When the alveolar ridges lack appropriate volume, reconstructive surgery is needed.

Several surgical techniques and bone grafting materials are available for that purpose. For that, the surgeon needs a critical evaluation of all these techniques and biomaterials to be able to select the most appropriate procedure and graft type.

The ultimate aim of the surgeon is to maximize success and minimize morbidity.

The use of bone grafts in the repair of defects in dentistry has a long history of success, primarily with the use of autogenous bone. There is an increase in the demand for reconstructive surgery and thus bone substitutes, principally due to the increase in life expectancy, changes in the lifestyles with expectation of a good life quality, and the wide acceptance of minimally invasive surgery.

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Bone graft is placed to sustain coagulum stabilization and reduces the risk of soft tissue collapse into bone defects. The graft would thus support the maturation and remodeling of the coagulum into an osseous tissue. Ideally, bone substitute materials should be biocompatible, not antigenic, sterilizable, sufficiently strong to maintain space, and easy to manipulate.

A great number of different treatment options have been proposed to achieve an adequate bone volume. Success rates of different bone grafting techniques are high and often have the same success rates as in native pristine bone. However, disadvantages such as morbidity, prolonged treatment times, increased costs, and technically demanding procedures that require an expert surgeon are associated with these techniques.

In this chapter, meta-analyses, systematic reviews, and clinical trials were the main source of data obtained to compare different therapeutic alternatives and materials. This evidence-based approach assures clinicians that their therapeutic decisions are supported by solid research that will help standardize implant protocols.

This chapter will summarize the most common reconstructive options and the different grafting materials available for bone augmentation, focusing on its indications, advantages, limitations, complications, and survival and success rates.

10.1 Introduction

Osseointegrated implant is a highly predictable method to restore an incomplete dentition and rehabilitate function, phonation, and aesthetics.

In the past, conventional removable dentures and/or fixed bridges over natural teeth were the only available prosthetic rehabilitations. Nowadays, implantology has introduced a new era of treatments.

Many times, clinicians have to face situations where implants cannot be placed in an ideal position. For different reasons (trauma, prolonged edentulism, congenital anomalies, periodontal disease, and infection), soft and hard tissues do not present an adequate volume that is required to achieve an ideal situation to ensure the survival, function, and aesthetics of our implants.

When a tooth is lost, the alveolar ridge resorbs in width and height very fast; it can reach as much as 50 % loss in width in the first 12 months, two-thirds of which occurs in the first 3 months [1].

To solve these problems, bone grafting procedures may be indicated in order to prepare the site in advance or sometimes at the time of implant surgery. The ideal and most appropriate approach is first to plan the prosthetic reconstruction and then place the implants in the optimal 3D position, evaluating the necessary bone to osseointegrate the implants [2]. A great number of different treatment options have been proposed to achieve an adequate bone volume and overcome these limitations.

However, this is not always possible due to different patient-related variables. These variables include patient expectations, finances, compliance, aesthetics, and medical history.

There are different important factors that must be known in advance in order to achieve a good prognosis of the procedure. These include soft tissue closure, vascularization, immobilization of the graft, space maintenance, absence of infection, type of defect, graft materials used, growth factors, etc. The clinician should analyze the planned recipient site for the keratinized gingiva, tissue thickness, high muscle attachments, frenum, and scarring, among others. Also, the bone augmentation technique employed to reconstruct different ridge defects depends on the horizontal and vertical extent of the defect.

Success rates of different bone grafting techniques are high and often have the same success rates as in native pristine bone. However, disadvantages such as morbidity, prolonged treatment times, increased costs, and technically demanding procedures that require an expert surgeon are associated with these techniques. Each treatment has its own indications and contraindications, as well as advantages and disadvantages.

Therefore, many clinicians and patients are willing to perform the easiest and less invasive procedure to solve their situation, avoiding graft surgery. In this sense, many other options are also available such as zygomatic implants, short implants, tilted implants, computerized implantology, etc., which also have their indications, limitations, and risks.

There are different reasons for the number of complications and failures experienced by the clinicians. One is that the total number of implants placed has increased during the last 10 years, and consequently a more number of dentists started to place implants and perform reconstructing procedures, often without the necessary academic background and training. Moreover, many practitioners currently receive their surgical training from continuing education courses, many times given by implant and material companies. These trainings usually lack of the sufficient clinical practice and enough patient follow-up that will enable the clinician to become familiar with intraoral surgical complications as well as postoperative and long-term complications.

Many courses and lectures often show high implant and grafting success and survival rates; although it may be true, this data should be analyzed with care as they may not have enough long-term basis, the inclusion and exclusion criteria may eliminate patients with high risk of complications, or the lecturers may have a great experience with a specific type of material or implant and will show their most successful cases.

Another reason is that nowadays due to patient expectations or clinician desires, more aggressive protocols such as extraction, grafting, and immediate implant placement with immediate loading are used. Also many times implants are placed in compromised sites where there is inadequate bone and soft tissue that requires augmentation procedures before implant placement.

Considerable controversy still exist regarding the choice of the most reliable technique and materials. However, the clinician should be aware that the most important thing and the end goal of treatment is to provide the patient a functional and aesthetic restoration in harmony with the natural dentition. The easiest procedure could be the first choice, provided it offers the same success rates as the more complex one, and the clinician has the required experience to perform it.

This chapter will summarize in an evidence-based approach the most common reconstructive options available, materials used, and their outcomes, focusing on its limitations, complications, and success rates (Fig. 10.1).

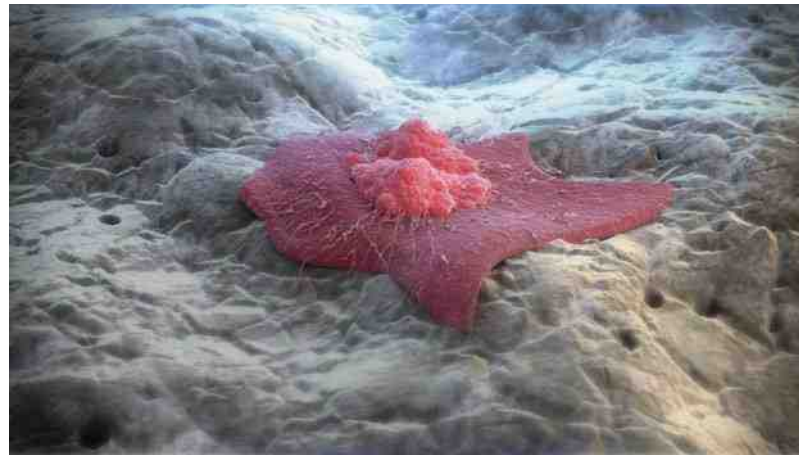

Fig. 10.1 3D image of an osteoblast over bone surface (Copyright © Dr. Pardiñas López)

10.2 General Review of the Literature

Implantology has become a main field in dentistry, but most of the research that flows into the clinician's office is sponsored by companies, which means that their studies are based on new products and technologies.

Many dentists still adopt a self-experience-based approach in their practices. Their decisions are mostly based on intuitive comparisons with other patients, making their accumulated knowledge and reliance on standard practices to be of great importance. As a result, many clinicians are slow and reticent to welcome a change.

Decision making in evidence-based implant dentistry involves diagnostic and therapeutic uncertainties, clinicians' heuristics and biases, patients' preferences and values, as well as cost considerations [3].

Information derived from clinical trials is considered more reliable than information based on intuition, authority, or custom. There is a hierarchy when considering the levels of evidence. Systematic reviews of randomized controlled trials are considered to be at the highest level, whereas expert opinion is considered the lowest level of evidence [3].

Several treatment choices are analyzed for different surgical situations as well as indications, advantages, complications, survival and success rates, and limitations.

It is important to differentiate between implant survival and implant success. Implant survival refers to implants still in function, but may be aesthetically compromised or may have periimplant bone resorption. Implant success should be evaluated as good function, good aesthetics, and absence of pathology. Most of the articles refer to success if the following criteria, previously defined by Albrektsson et al. [4] and adapted by Buser and coworkers [5] as well as Karoussis et al. [6], are fulfilled:

- Absence of persistent subjective complaints, such as pain, foreign body sensation, and/or dysphasia
- Absence of periimplant infection with suppuration
- Absence of mobility
- Absence of a continuous radiolucency around the implant
- Vertical bone loss less than 1.5 mm in the first year of function and less than 0.2 mm annually in subsequent years of function [7]. Although these criteria would need to be updated in the following years according to the new implant surfaces and designs.

In this chapter, meta-analyses, systematic reviews, and clinical trials were the main source of data obtained to compare different therapeutic alternatives and materials. This evidence-based approach assures clinicians that their therapeutic decisions are supported by solid research that will help standardize implant protocols.

Heterogeneity of studies is important in a meta-analysis or systematic review because data from multiple studies are pooled based on the assumption that studies are similar enough to be compared with confidence, and thus, the results may be more generalizable.

Studies evaluate different parameters which may have an impact on the final outcome of the treatment. These parameters include the initial clinical alveolar ridge situation (which traditionally has been classified as horizontal (class I), vertical (class II), or combined (class III) defects) [8, 9] (Fig. 10.2), patient-related factors (age, gender, smoking, medical history), implant characteristics (dimension, micro-/macrostructure, surgical technique, loading protocol), prosthetic characteristics (type and fixation, crown-implant ratio, occlusal situation), materials used, graft harvesting sites, and outcomes (success criteria, survival rates, follow-up time, complications).

Not all studies evaluate the same parameters, and not all parameters are defined the same way. There is a lack of comparative effective research to guide decision making in oral grafting surgery and no long-term investigation comparing all available treatment options could be identified.

It has been suggested that priority may be given to procedures that appear less invasive and carry a lower risk of complications [10].

This chapter will evaluate different preimplant surgery options and materials available to help

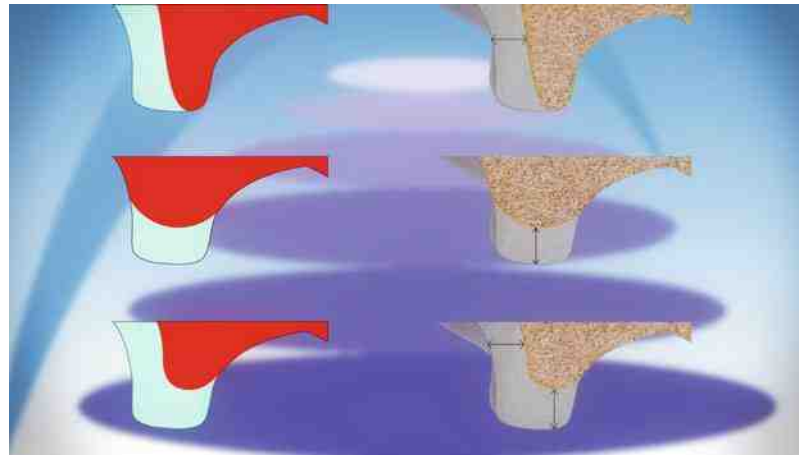

Fig. 10.2 Classification of alveolar ridges: class I, class II, class III (Copyright © Dr. Pardiñas López)

clinicians to make decisions based on the available scientific evidence literature.

10.3 Materials Used in Pre-Implant Surgery

10.3.1 Classification of Grafting Materials According to Their Origin

10.3.1.1 Autogenous Bone

The bone is transferred from one position to another within the same individual. Autogenous bone is the "gold standard" in bone grafting as it is osteogenic (has bone-forming cells [11]), osteoinductive (actively promotes bone formation [12, 13]), osteoconductive (facilitates the colonization and ingrowth of new bone cells and sprouting capillaries on its surface [14]), and osteotransductive (degradability to be replaced by new bone).

Extraoral and intraoral donor sites have been established as donor sites that will be compared afterward (Figs. 10.3 and 10.4).

10.3.1.2 Allografts

The bone is obtained from an individual and placed in another individual of the same species [15]. Two main types of allogeneic bone grafts are clinically used, freeze-dried bone allografts (FDBAs) and demineralized (decalcified) freeze-dried bone allografts (DFDBAs).

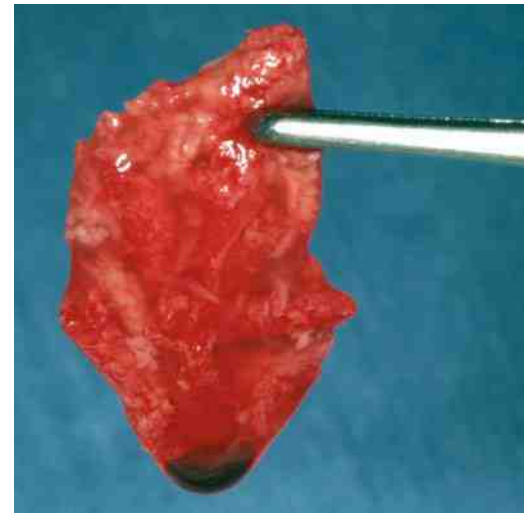

Fig. 10.3 Autogenous particulate bone mixed with PRGF

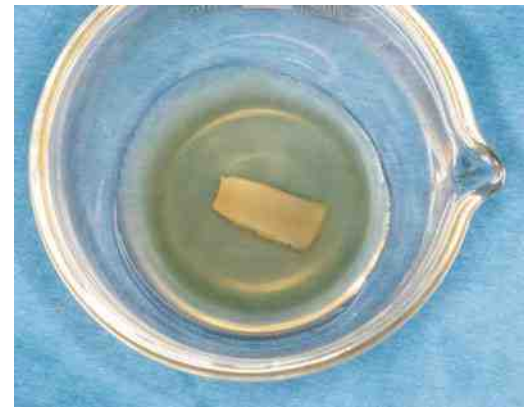

Fig. 10.4 Autogenous block graft

They are available in particulate, block, and injectable forms and are composed of cortical bone, cancellous bone, or a composite of both [16, 17].

The use of this source of bone substitute materials varies between countries. For example, it is the most frequently used as an alternative to autogenous bone in the USA [18]. The FDBA is both an osteoconductive and osteotransductive bone substitute material.

The acid (0.5–0.6 molar hydrochloric acid) demineralization of bone samples to obtain the DFDBA would preserve and expose bone morphogenetic proteins (osteoinductive proteins). Urist has been the first to describe the osteoinductivity of DFDBA [13]. However, the osteoinductivity of DFDBA shows great variation and is highly dependent on the manufacturing procedure [19, 20].

10.3.1.3 Xenografts

The bone is harvested from an individual and placed in another individual of different species. Three main sources could be identified: bovine, coral, and porcine. Bio-Oss (Osteohealth Co., Shirley, NY), Bio-Oss Collagen (Osteohealth Co., Shirley, NY), OsteoGraf/N (VeraMed Dental, LLC, Lakewood, CO), PepGen P-15 (Dentsply Friadent, Mannheim, Germany), and Endobon ® (Biomet 3i, Palm Beach Gardens, FL) are examples of commercially available bovine-derived bone substitute materials.

OsteoBiol® Gen-Os (Tecnoss Dental, Turin, Italy) is a hydrophilic porcine-derived bone substitute that contains both porous hydroxyapatite structure and collagen. Biocoral (Inoteb, Saint Connery, France) and porous fluorohydroxyapatite (FRIOS® Algipore®) (Friadent GmbH, Mannheim, Germany) are examples of commercially available products of coral and algae origin. The mineral composition of all these grafts is hydroxyapatite as shown in Fig. 10.5.

Deproteinized, anorganic bovine bone (Bio-Oss®, Geistlich Pharma AG, Wolhusen, Switzerland) is one of the most studied bone substitute materials [21]. Bio-Oss® is an anorganic bovine bone that is chemically and thermally treated to extract all organic components, maintaining the 3D structure of the bone [22].

There is evidence that Bio-Oss® undergoes resorption by giant multinucleated cells (like osteoclasts). However, the in vivo resorption of Bio-Oss® is very slow, which explains its presence in biopsies obtained after 10 years of placement [23, 24]. It is available in cancellous and cortical granules and blocks. A 10 % of highly purified porcine collagen is added to produce Bio-Oss® collagen (Fig. 10.6).

10.3.1.4 Alloplastic Materials

The use of synthetic biomaterials for bone grafting presents several advantages like unlimited quantity, avoidance of surgical morbidity associated with the harvesting of autogenous bone, and no risk of disease transmission [25].

Most alloplastic materials are composed of calcium and phosphate ions due to its chemical similarity to the mineral component of the bone [26]. The most common calcium phosphates that are commercially available are ceramic in nature (synthesized at high temperature) like hydroxyapatite (HA), tricalcium phosphate (TCP), and biphasic calcium phosphates (sintered HA and β-TCP) [27]. Synthetic, nonceramic resorbable hydroxyapatite materials are also available.

Calcium phosphates have the ability to promote bone growth and an appropriate three-dimensional geometry to promote cellular viability. β-tricalcium phosphate (β-TCP) is one of the most frequently used synthetic grafts in implant dentistry [28]. Tatum in 1986 was the first to successfully apply a bone substitute (tricalcium phosphate) for sinus floor augmentation [28].

Various randomized clinical trials have been conducted to study the efficiency of biphasic calcium phosphate (BCP) and beta-tricalcium phosphate (β-TCP) in bone regeneration. New bone formation with BCP ranged between 21 and 30 % after 5–6 months postoperatively [29–31]. In one study, new bone formation reached a value of 41 % after 8 months [32]. The β-TCP promotes 30–36 % of new bone formation after 6 months of sinus floor augmentation [33, 34]. Both bone substitutes are resorbable with a residual bone graft between 10 and 28 % for BCP and between 13.95 and 28.4 % for TCP [29–32].

Calcium sulfate has been used in craniofacial surgery for more than 100 years [27]. However,

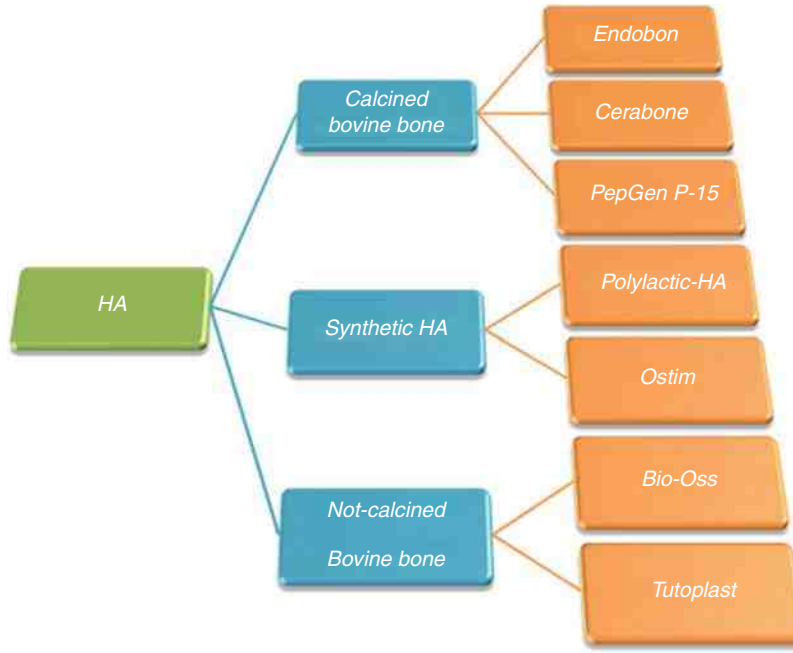

Fig. 10.5 Several sources (bovine, porcine, coral, and synthetic) are available for hydroxyapatite (*HA*) as grafting materials in oral and maxillofacial surgery

Fig. 10.6 Bio-Oss® with PRGF

calcium sulfate has a relatively high rate of degradation that may not be compatible with the rate of bone formation. It is completely resorbable in 5–7 weeks in vivo [35]. Calcium sulfate has been used as a bone substitute, a graft binder/extender, and a barrier in guided tissue regeneration [36].

Calcium sulfate is also used as a delivery vehicle for growth factors and antibiotics, although this application has not been thoroughly exploited in the clinical setting [36]. Osteoset® (Wright Medical Technology, Arlington, TN, USA) is an example of the use of calcium sulfate as a vehicle for the delivery of an antibiotic (tobramycin in the case of Osteoset) for the treatment of osteomyelitis. Calcium sulfate has never attracted the same degree of research interest as have other biomaterials. Recently, however, it has enjoyed a resurgence of sorts in the areas of periodontology, sinus augmentation, and orthopedic surgery [36].

Bioglass or bioactive glass is a calcium-substituted silicon dioxide. The bioactivity as property for bioglass refers to its ability to promote the precipitation of biological hydroxyapatite on its surface that would result in its bonding to the hosting bone. The leakage of sodium and potassium ions from the bioglass would result in the formation of a silica gel layer that would promote the precipitation of a hydroxyapatite layer on its surface [37]. It has been shown to experience severe resorption during the first 2 weeks after implantation; however, beyond this point, its resorption rate stabilizes [38].

The in vivo solubility of the biomaterial is proportional to the content of sodium oxide [37]. Successful outcomes in bone augmentation procedures and as filler for intra-bony defects have been reported [27]. However, its bone regeneration capacity has not been superior to calcium phosphate biomaterials [39].

10.3.2 Which Is the Best Bone Graft for Alveolar Bone Augmentation?

10.3.2.1 Alveolar Ridge Augmentation

In one systematic review, a mean implant survival rate of 98.6 ± 2.9 % for autogenous bone alone (healing period before implant placement 5.1 ± 1.4 months), 100 % for bone substitute material + autogenous bone (healing time before implant placement 5.25 ± 1.9 months), and 97.4 ± 2.5 % for bone substitute material alone (healing time before implant placement 4.7 ± 1.1 months) for a follow-up period of 30.6 ± 27.1 months has been reported. Implant success was indicated in five studies and ranged from 90.3 to 100 % [14].

Five studies (from 2000 to Jan 2014) that compared the clinical outcome of ridge augmentation procedure using bone substitute material or autogenous bone have been included in the meta-analysis. The meta-analysis has shown no statistically significant difference between both types of grafts. Three studies compared implant survival after ridge augmentation using bone substitute material + autogenous bone or autogenous bone alone. All these studies showed a survival rate of 100 % for both grafting materials [14] (Fig. 10.7).

When autogenous bone blocks (alone or in combination with membrane, grafting materials) have been utilized for horizontal bone augmentation, the mean gain in ridge width was reported to be 4.4 mm, the percentage of cases that had no additional grafting was 97.2 %, and the complication rate was 3.8 % [40]. When no autogenous block graft was used, the corresponding figures were 2.6 mm and 75.6 and 39.6 %. The survival of implants placed in augmented area with autogenous block from intraoral site ranged from 96.9 to 100 % [40]. The same RCT reported that augmented sites that were covered with nonresorbable membranes showed a mean gain in ridge width of 2.9 mm. When resorbable membranes were used, a mean gain in ridge width was 4.3 mm, and when no membrane was used, the results were 4.5 mm [40]. When the complication rate was calculated for studies with the use of nonresorbable membranes, resorbable membranes, or no membranes, the corresponding rates were 23.6, 18.9, and 9.4 % [40].

In a RCT, anorganic bovine bone with resorbable and nonresorbable membranes has been evaluated in horizontal ridge augmentation [40, 41]. The outcomes have indicated that both groups experience high frequencies of membrane exposures of 64 and 71 %, respectively [40, 41]. The most predictable horizontal bone augmentation seems to involve an autogenous block graft alone or in combination with a particulate bone graft of bone substitute material [40]. The best documented grafting protocol included intraorally harvested autogenous bone block alone or in combination with anorganic bovine bone and with or without coverage of barrier membrane [40].

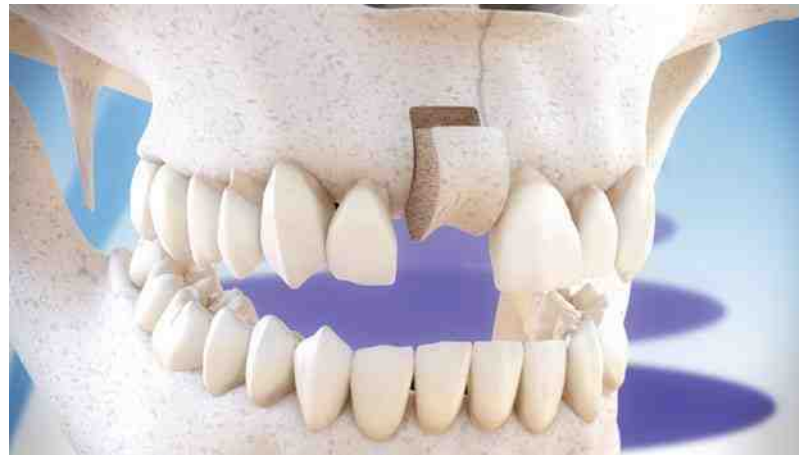

Fig. 10.7 3D image of a block graft placed in the anterior maxilla (Copyright © Dr. Pardiñas López)

In the same systematic review, regarding vertical bone augmentation, the use of autogenous block graft has resulted in a height gain of 3.7 mm, 83.1 % of the cases did not require second grafting and the complication rate was 29.8 % [40]. However, when particulate autograft or bone substitute material has been utilized, the corresponding figures were 3.6 mm, 67.4 and 21.0 % [40]. Comparing the data whether a membrane was used or not, the gain in ridge height was 3.5 mm vs. 4.2 mm, and the complication rate was 23.2 % vs. 25.3 % [40].

The most frequent grafting materials used were intraorally harvested autogenous block graft and autogenous particulate. The grafts were harvested from the mandibular chin or body/ascending ramus [40]. The use of block grafts seemed to yield more gain in ridge height and a greater reduction in the need of additional grafting procedures than the use of granular grafts. However, the rate of dehiscence seemed to increase with their use in comparison with horizontal bone augmentation [40].

10.3.2.2 Treatment of Fenestrations and Dehiscences: Guided Bone Regeneration

Autogenous and nonautogenous options are available. The source of autogenous particulate is the same as the one that has been discussed for block harvest. For small amounts of bone, local sites can be used, including the symphysis, ramus, and maxillary tuberosity. They have the advantage of a more rapid vascularization [42].

Nonautogenous bone substitutes, such as ABBM, may be also a valid alternative to autogenous bone (particularly when harvested from extraoral locations), since they are associated with less postoperative morbidity. They can also be used in combination with autogenous bone [42, 43].

The best documented augmentation protocols are anorganic bovine bone covered with a membrane, particulate autograft with or without a resorbable membrane [40].

Jensen et al. [40] in their systematic review found that the use of autogenous bone grafts, harvested intraorally, resulted in a defect fill of 83.8 %, 68.8 % of the cases showing a complete defect fill. Membrane or graft dehiscence was reported in 15.5 % of the cases. The use of anorganic bovine bone with or without membrane resulted in a mean defect fill of 88.9 % and a complete defect fill was achieved in 67.7 % of the cases. The rate of dehiscence was 12 %. Implant survival rates of 93–100 % have been reported.

Use of Membranes

Successful vertical and horizontal ridge augmentation with the GBR technique, using both resorbable and nonresorbable membranes, was shown in human studies [8, 44, 45].

Nonresorbable barriers are available as e-PTFE, titanium-reinforced e-PTFE, high-density PTFE, or titanium mesh [8].

e-PTFE is a synthetic polymer with a porous structure, which does not induce immunologic reactions and resists enzymatic degradation by host tissues and microbes. Titanium-reinforced e-PTFE membranes increase their mechanical stability and allow the membranes to be shaped [2]. However an increased rate of soft tissue complications after premature membrane exposure has been reported [2]. Once exposed to the oral cavity, the porous surface of e-PTFE membranes is soon colonized by bacteria, which can lead to infections and to the subsequent need for early membrane removal. This could interfere with bone regeneration. Another disadvantage of e-PTFE membranes is the need for a second surgery to remove the membrane [2] (Fig. 10.8).

Bioabsorbable membranes can be classified into natural or synthetic. Natural products are made of various types of collagen of animal origin, while synthetic ones are made of aliphatic polyesters (polylactic and polyglycolic acid polymers). The difference is their mode of resorption; collagen products undergo enzymatic degradation, whereas synthetic barriers are degraded by hydrolysis [8].

The main advantage of resorbable membranes is that a second procedure to remove the membrane is not needed; thus, patient morbidity is decreased. However, the difficulty of maintaining the barrier function for an appropriate length of time is considered a major disadvantage.

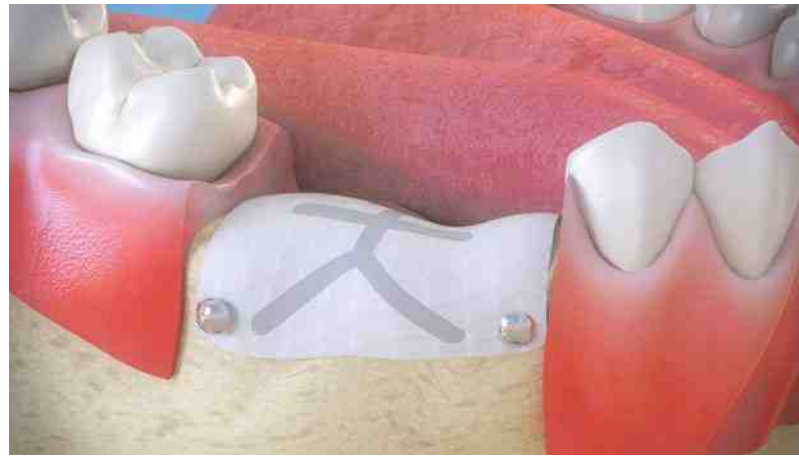

Fig. 10.8 3D image of a PTFE membrane placed over a defect and following the GBR principle (Copyright © Dr. Pardiñas López)

Depending on the material, the resorption process and length can vary [2]. Also, because of a lack of rigidity, in all but the smallest defects, most of these bioabsorbable membranes must be used in combination with a graft material for space maintenance in bone augmentation applications [8].

Some studies suggested that the volume of regenerated bone achieved was higher using nonresorbable membranes in comparison with resorbable membranes [8], although this did not affect the outcome of the treatment and implant survival rates.

In one RCT, regarding the use of nonresorbable membranes and resorbable membranes, the percentages of defect fill were 75.7 and 87 %; the percentages of cases with complete defect fill were 75.5 and 75.4 %; the rates of membrane/graft dehiscences were 26.3 and 14.5 %; and the implant survival rates were 92.9–100 % (median 96.5 %) with nonresorbable membranes and 94–100 % (median 95.4 %) with resorbable membranes [40].

Products that are available to stabilize membranes include nonresorbable mini-screws and bioabsorbable tacks made from polylactic acid [8].

The choice of membrane will depend on the required duration of membrane function for achieving the desired tissue regeneration (generally 6 months) [8]. In general, the criteria required to select appropriate barrier membranes for guided bone regeneration include biocompatibility, integration by the host tissue, cell occlusiveness, space-making ability, and adequate clinical manageability [2].

Addition of bone graft material to the GBR technique increases the amount of achievable vertical regeneration [8, 46].

10.3.2.3 Lateral Sinus Floor Augmentation

Histomorphometric Total Bone Volume

There are two systematic reviews that discussed the available scientific evidence regarding the histomorphometric parameter of total bone volume in maxillary sinuses augmented with different grafting materials [47, 48]. In the study by Handschel et al. [48], a meta-analysis has been performed for those studies that report sinus elevation with various grafting materials (autogenous bone, Bio-Oss® + autogenous bone, Bio-Oss®, and β-TCP). The study has demonstrated the presence of significantly higher mineralized bone during the early healing phase (the first 9 months after surgery) for autogenous bone compared to various bone substitutes.

However, the differences in the total bone volume between grafts disappeared over time, and after 9 months, no statistically significant differences were detected. Klijn et al. [47] have performed a meta-analysis of the total bone volume present in biopsies obtained from augmented maxillary sinus with autogenous bone. The study indicated that the bone harvested from an

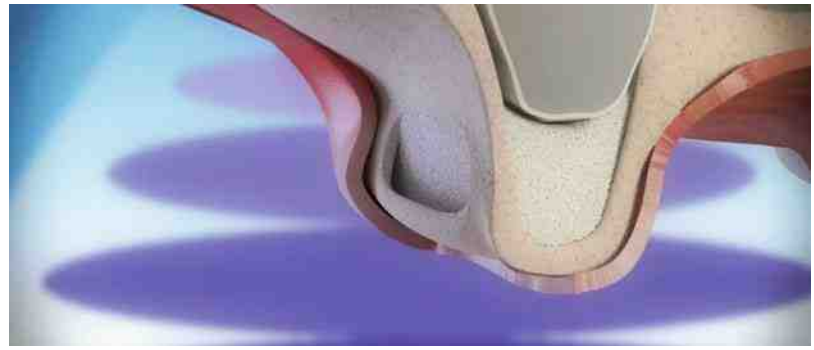

Fig. 10.9 3D image representing a grafted sinus with particulate xenograft (Copyright © Dr. Pardiñas López)

intraoral site would result in higher total bone volume than the bone harvested from the iliac crest [47].

In the systematic review by Pjetursson et al., it is suggested that maxillary sinuses grafted with autogenous bone may receive dental implants earlier than sinuses grafted with bone substitute materials [49] (Fig. 10.9).

Complications

Nkenke et al. demonstrated in their review that the partial or total graft loss related to the event of sinusitis is independent of the grafting materials used [50]. For that, the use of bone substitutes would not increase the risk of developing sinusitis and graft loss [14].

Implant Survival

Autogenous bone alone or autogenous bone mixed with bone substitute materials are the most common grafting materials used for sinus floor augmentation [40].

When autogenous bone block grafts from the iliac crest are applied, the overall implant survival rate has been reported from 61.2 to 94.4 % (median 84.9 %) after a period of function of up to 102 months [40] (Table 10.1). The use of particulate autologous bone grafts resulted in a survival rate with a range of 82.4–100 % up to 52 months of follow-up.

Implants placed into sinuses elevated with particulate autografts have shown higher survival rates than those placed in sinuses that had been augmented with block grafts [51, 52].

The relatively lower implant survival rates reported when autogenous bone blocks from the iliac crest were used can be explained due to the fact that most of the placed implants had a machined surface [51, 52].

The lateral and anterior wall of the maxillary sinus and maxillary tuberosity has also been employed as a donor site of autogenous bone but in particulate form [53]. The lateral wall of the maxillary sinus has also been used as a donor site for onlay bone graft to gain alveolar width [54].

The use of a mixture of a composite graft consisting of particulate and a bone substitute has also been evaluated, showing an implant survival rate ranging from 84.2 to 100 %. In one systematic review [40], allograft was added to autogenous bone in four studies that completed the inclusion criteria. All these studies have reported a 100 % survival rate up to 42 months. In another nine studies, autograft was mixed with DBBM. The implant survival rate ranged between 89 and 100 % (median 94.3 %) with a follow-up of 12–60 months after loading [40].

When comparing autogenous bone alone and bone substitute material mixed with autogenous bone, the meta-analysis results indicated the absence of statistically significant differences in implant survival between the two groups [14]. The meta-analysis showed trends toward a higher implant survival when using bone substitute materials compared to autogenous bone; however, the difference was not statistically significant [14].

When DBBM alone was used for maxillary sinus floor elevation, implant survival rates ranged from 85 to 100 % (median 95 %) [40]. When the xenograft was mixed with PRP/PRGF, the results ranged from 90 to 96 %. When using

Table 10.1 Sinus augmentation

Study	Technique/graft	Implant success (%)	Implant survival (%)	Implant survival (only rough implants) (%)	Time (months postloading)
[194] SR	Autogenous, xenograft, or alloplast		92/91.1		12–102
[49] SR	Lateral (material not specified)		90.1 (86.4–92.8)		36
[174] SR	Lateral (material not specified)		75.6–100		36–84
[148] SR/MA	Lateral (material not specified)		91.7–100		
[44] CIR	Autogenous		89		6–134
[52] SR	Autogenous		87.7		More than 12
[40] SR	Autogenous		94.2 (61.2–100)		Up to 60
[173] SR	Autogenous		92.4 (86.0–98.8)		More than 18
[14] SR/MA	Lateral, autogenous		97.4 ± 2.2		39.7 ± 34.6 (4–170)
[49] SR	Lateral, particulate autogenous		84.3 (52.5–95.6)	99.8 (98.7–100)	36
[40] SR	Particulate autogenous		97.1 (82.4–100)		12–54
[57] SR	Autogenous block/ immediate load		75.3–79		Up to 36
[57] SR	Autogenous block/delayed load		82.4–96		12–72
[49] SR	Lateral, autogenous block		80.1 (69.1–87.5)	96.3 (89.5–99.2)	36
[51] SR	Lateral, iliac block		83.3 (78.8 machined implants)	89.5	More than 12
[194] SR	Iliac		88		12–102
[40] SR	Iliac		84.9 (61.2–94.4)		58
[194] SR	Alloplastic/PRP		81/95.1		12–102
[44] CIR	Alloplast		98.4		6–134
[40] SR	Alloplast		96–100		Up to 36
[194] SR [44] CIR	Allograft		93.3		12–102
[40] SR	Xenograft		95 (85–100)		Up to 68
[194] SR [44] CIR	Xenograft/PRP		95.6/96		12–102
[171] RS	Lateral, xenograft + PRGF		90		85.87 ± 43.80
[14] SR/MA	Lateral, bone substitute		98.6 ± 2.6		39.7 ± 34.6 (4–170)
[173] SR	Bone substitute		97.2 (93.7–98.9)		More than 18
[52] SR	Bone substitute		95.98		More than 12
[49] SR	Lateral, bone substitute		92.5 (86.5–95.9)	96.7 (90.8–98.8)	36
[40] SR	Bone substitute		96.8 (82–100)	88.6–100	12–107
[51] SR	Lateral, particulate		92.3 (90 machined)	94.6	More than 12
[40] SR	Autogenous + allograft		100		42
[40] SR	Autogenous + xenograft		94.3 (89–100)		12–60
[14] SR/MA	Lateral, autogenous + substitute		88.6 ± 4.1		39.7 ± 34.6 (4–170)
[52] SR	Autogenous + combination		94.88		More than 12
[173] SR	Autogenous + combination		93.8 (84.2–96.8)		More than 18
[49] SR	Lateral, particulate combination		95.7 (93.6–97.1)	96.8 (94.7–98.0)	36

Table 10.1 (continued)

Study	Technique/graft	Implant success (%)	Implant survival (%)	Implant survival (only rough implants) (%)	Time (months postloading)
[40] SR	Autogenous/or with substitute		94.2 (61.2–100)	96–100	60
[96] SR [44] CIR		98.5 (74.7–100)	95 (60–100)		6–144
[40] SR	Allograft + xenograft		90.7 (82.1–96.8)		up to 107
[40] SR	Only coagulum		97.7–100		12–27.5
[44] CIR	Transalveolar	93.5–97.8	96.4 (94.9–100)		6–93
[40] SR	Transalveolar		96 (83–100)		Up to 64
[40] SR	Transalveolar, no material		96 (91.4–97.3)		Up to 25
[40] SR	Transalveolar, xenograft		99 (95–100)		12–45
[40] SR	Transalveolar, autogenous		94.8–97.8		Up to 54
[172] SR	Transalveolar	96	90.9 (88.6–100)		36 (6–42)
[51] SR	Transalveolar		93.5		More than 12
[195] SR	Transalveolar		92.8 (87.4–96.0)		36
[174] SR	Transalveolar		95.4–100		36

CIR clinical investigation review, *SR* systematic review, *MA* meta analysis, *RS* retrospective study

alloplastic materials after a period of function up to 134 months, the survival rate ranged from 81 to 100 % (median 93 %) (Table 10.1).

In different systematic reviews, it was reported that when only rough-surface implants were included, bone substitutes, a combination of autogenous bone and bone substitutes, and autogenous bone blocks all showed similar annual failure rates [49, 51, 55] (Table 10.2). The lowest annual failure rate of rough-surface implants was observed using autogenous particulate bone graft (Table 10.2).

When the overall machined implant survival rates were compared with rough-surface implant survival rates, the results were lower for machined than for rough-surface implants [40, 51, 52].

Consequently, the use of autogenous bone alone or in a combination with other bone substitutes would not affect implant survival. Klinge et al. in the consensus report on tissue augmentation and aesthetics have indicated that the evidence neither supports nor refutes the superiority of any specific graft material for sinus augmentation [56]. A Cochrane review has concluded that bone substitute materials may replace autografts in this indication [43]. Furthermore, Nkenke et al. concluded that graft resorption seems not to affect implant survival [50].

Table 10.2 Implant survivals according to implant surface

Study [49, 51]	Implant survivals (all types of implants) (%)	Implant survivals (excluding machined implants) (%)
Autogenous block alone	69.1–87.5	89.5–99.2
Autogenous particulate	82.4–100	98.7–100
Autogenous combined with bone substitute	84.2–100	94.7–100
Only bone substitute	82–100	88.6–100

For lateral sinus floor augmentation, the following grafting protocols may be considered well documented: autogenous particulate alone or in combination with either anorganic bovine bone or DFDBA, anorganic bovine bone alone or in combination with DFDBA, and an alloplastic HA alone [40].

Graft Stability

To overcome the inherent problem with resorption of an autogenous bone graft, it was suggested that particulate autogenous bone in a mixture with xenografts or alloplastic materials or bone substitutes alone may reduce the risk of bone

resorption and sinus re-pneumatization [44, 57]. The slow resorption capacity of the bone substitute can minimize the amount of resorption [57]. In one histological analysis of a sinus grafted with ABBM, particles were found surrounded by a new bone even 10 years after the grafting procedure, still showing osteoclastic activity [24] (Figs. 10.10, 10.11, and 10.12).

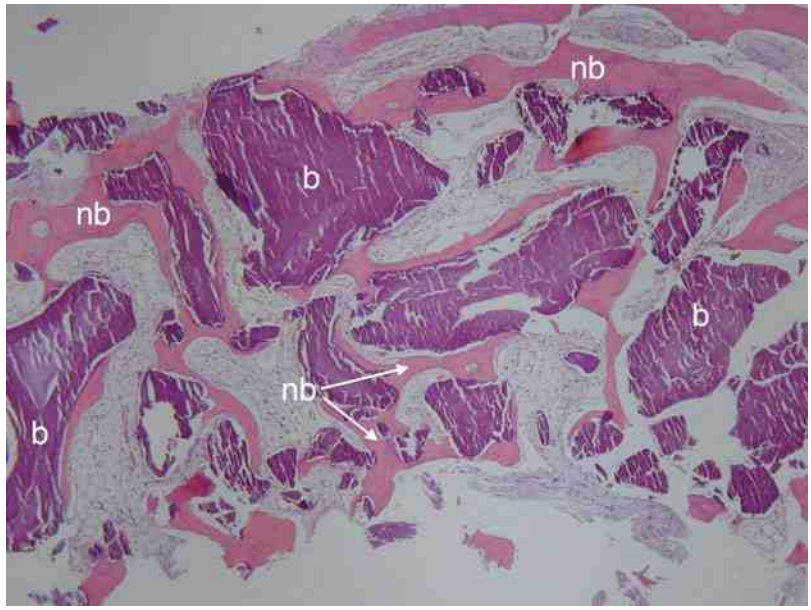

Fig. 10.10 Cross section of a core sample with ABBM and PRGF showing newly formed bone (*nb*) around particles of ABBM (*b*). Vital bone formation is apparent between the residual ABBM particles. (HE, 40×) (Reprinted from Pardiñas López et al. [24]. Copyright © 2015, with permission from Wolters Kluwer Health, Inc.)

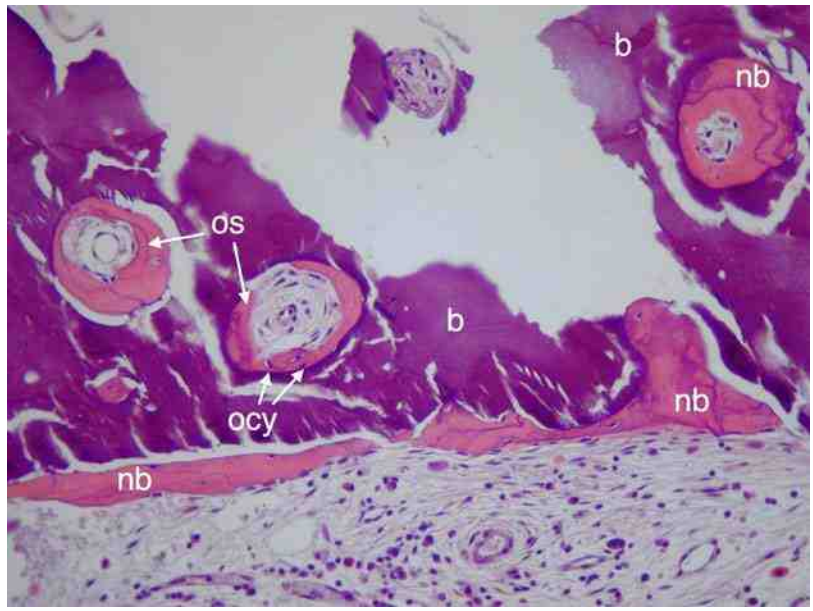

Fig. 10.11 High-power image showing immature, newly formed bone (*nb*) around particles of ABBM (*b*), along with osteoid (*os*). Note the osteocytes (*ocy*) inside the ABBM (*b*). (HE, 100×) (Reprinted from Pardiñas López et al. [24]. Copyright © 2015, with permission from Wolters Kluwer Health, Inc.)

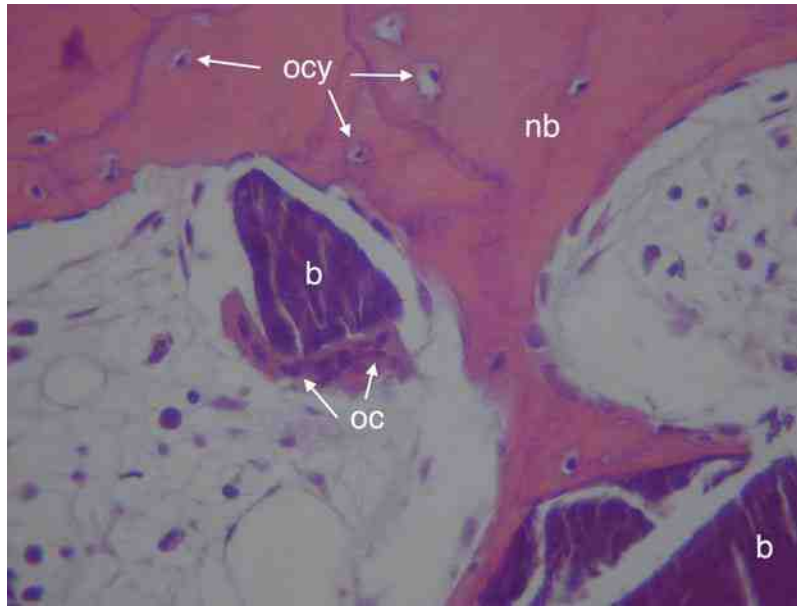

Fig. 10.12 High-power view of vital bone formation (*nb*) directly on the residual ABBM particles (*b*). Note the presence of osteoclast (*oc*) around ABBM. (HE, 400×) (Reprinted from Pardiñas López et al. [24]. Copyright © 2015, with permission from Wolters Kluwer Health, Inc.)

In a systematic review, volume changes of maxillary sinus augmentation using different bone substitutes were evaluated [58]. The study has included only those studies that report on volume changes using 3D imaging (like CT or CBCT). The analysis has been performed for only 12 articles that fulfill the inclusion criteria. Regarding autogenous bone, no statistically significant difference in average volume reduction was reported when comparing autogenous bone in either particulate or block form. The weighted average volume reduction was 48 ± 23 %. There was no statistically significant difference when autogenous block from the iliac crest was compared to allografts. A weighted average volume reduction of 30.3 % was calculated for allografts.

The use of bovine bone mineral showed a volume change of 15–20 % suggesting better volume stability over time compared to autogenous bone. The addition of particulate autogenous bone to bovine bone mineral in 70:30 and 80:20 resulted in volume reduction of 19 and 20 %, respectively, with no significant differences when compared to bovine bone mineral alone [58, 59].

The average volume reduction for allogeneic bone and for allogeneic bone + bovine mineral was 41 and 37 %, respectively [58, 60]. In one randomized clinical trial, the volume reduction after 6 months of sinus grafting with biphasic calcium phosphate (BCP) was 15.2 % [58, 61]. The study also found no significant effect on volume preservation by adding autogenous bone in 1:1 ratio to BCP graft [58, 61].

10.3.2.4 Extraction Socket Preservation

In the review by Horowitz et al. [62], it has been concluded that although extraction socket grafting has consistently demonstrated to reduce the alveolar ridge resorption, there is no superiority of one grafting material over the another. The biopsies of multiple studies that used mineralized grafting materials demonstrated the presence of 17–27 % of vital bone following 3–6 months of healing [62]. Nonmineralized products tend to demonstrate the presence of 28–53 % of vital bone [62]. However, there is a negative effect on alveolar ridge preservation for the use of collagen plug alone [63].

Fig. 10.13 3D image representing a socket preservation procedure using allograft material (Copyright © Dr. Pardiñas López)

In one review [64], the freeze-dried bone allograft performed best with a gain in height and concurrent loss in width of 1.2 mm. In one meta-analysis, the use of xenogeneic and allogeneic grafts has resulted in lesser height loss at the middle of the buccal wall when compared with the use of alloplastic grafts [65]. However, another review [66] has indicated that the scientific evidence did not provide clear guidelines with regard to the type of biomaterials to use for alveolar ridge preservation (Fig. 10.13).

10.3.3 The Use of Autologous Growth Factors and Bone Morphogenetic Proteins to Enhance the Regenerative Capacity of Bone Substitute Materials

The use of platelet-rich plasma would improve the handling and placement of particulate grafts providing stability and avoid the need for compaction [27]. A positive effect on soft tissue healing has been observed in most of the studies that were included in a systematic review on the use of platelet-rich plasma in extraction sockets [67].

A beneficial effect of plasma rich in growth factors on postoperative quality of life could be evidence, as a consequence of the enhanced soft tissue healing [67–71]. The use of plasma rich in growth factors has also been reported to reduce bleeding, edema, scarring, and pain levels [67, 71–74]. In the systematic review by Del Fabbro et al. [75], few clinically controlled studies are available on the effect of autologous growth factors (platelet concentrate) when combined with a bone graft for sinus augmentation. Even more, those few studies have significant heterogeneity [75].

Regarding implant survival, the authors concluded that no evident benefit of the use of platelet concentrates can be drawn from the included studies [75]. However, there is a suggestion that in critical clinical conditions, the addition of plasma rich in growth factors could be beneficial [75]. Regarding histomorphometric analysis of biopsies obtained from grafted maxillary sinuses, the review indicated the possible advantage of using platelet-derived growth factors during the early phases of healing (3–6 months) [75]. In a RCT, the addition of plasma rich in growth factors (Endoret (PRGF)) could enhance the bone formation supported by anorganic bovine bone with a slow healing dynamics [75–77].

Titanium grids have been used alone or with a graft material for the correction of height/width of the alveolar ridge. In the review by Ricci et al. [78], it has been shown that titanium grid exposure occurred in 22.78 % of patients. In a RCT, the effect of using plasma rich in growth factors (Endoret (PRGF)) on the outcomes of titanium mesh exposure has been evaluated [42]. While 28.5 % of the cases in the control group suffered from mesh exposure, no exposures were registered in the Endoret (PRGF) group. Radiographic analysis revealed that bone augmentation was higher in the Endoret (PRGF) group than in the control group.

Overall, 97.3 % of implants placed in the control group and 100 % of those placed in the Endoret (PRGF) group were successful during

2 years after placement [42]. The authors have suggested that the positive effect of Endoret (PRGF) on the Ti-Mesh technique could be related to its capacity to improve soft tissue healing, thereby protecting the mesh and graft material secured beneath the gingival tissues [42]. Plasma rich in growth factors employs fibrin scaffold and endogenous growth factors that orchestrate tissue healing to promote adequate tissue regeneration and to reduce tissue inflammation [79, 80]. These growth factors promote cellular growth, proliferation, and migration [79, 80] (Figs. 10.14 and 10.15).

10.3.4 Bone Morphogenetic Proteins (BMPs)

In a systematic review on the effect of using rhBMP-2 in maxillary sinus floor augmentation, only three human clinical articles were eligible for analysis [81]. Two of these studies were randomized clinical trials and one was a prospective study, evidencing the need for more randomized clinical trials with a long-term follow-up to provide evidence-based criteria for the use of rhBMP-2 for alveolar bone augmentation. The review has indicated that a higher level of initial bone gain and density was observed for the group of autogenous bone than for the group of rhBMP-2 [81]. Furthermore, higher cell activity, osteoid lines, and vascular richness have been observed in the rhBMP-2 groups [81].

A 1.50 mg/mL rhBMP-2/ACS has been compared to autogenous graft for maxillary sinus augmentation [82]. One hundred and sixty patients with less than 6 mm of residual bone height were treated. A significant amount of new bone was formed after 6 months postoperatively in each group. At 6 months after dental restoration, the induced bone in the rhBMP-2/ACS group was significantly denser than that in the bone graft group [82]. No significant differences were found histologically. The new bone was comparable to the native bone in terms of density and structure in both groups. 201 over a total of 251 implants placed in the bone graft group and 199 over a total of 241 implants placed in the rhBMP-2/ACS group were integrated and functional 6 months after loading. No adverse events were deemed related to the rhBMP-2/ACS treatment. However, when rhBMP-2 has been added to Bio-Oss (anorganic bovine bone), less bone formation has been observed [81, 83].

Moreover, no significant differences have been found when comparing autogenous bone and rhBMP-2/ACS after 6 months postsurgery (although initially higher bone gain was observed only subcrestally in the rhBMP-2 group) [84]. In another clinical study, guided bone regeneration with xenogeneic bovine bone and collagen membrane was performed with and without rhBMP-2 [85]. There were no significant differences between the groups after 3 and 5 years of evaluation [85]. In both groups, the implant survival and periimplant tissue stability were not affected by the use rhBMP-2 [85].

Fig. 10.14 PRGF mixed with ABBM

Fig. 10.15 Membrane of activated PRGF

Based on these data, a comprehensive assessment of the cost-effectiveness of using rhBMP-2 for alveolar bone augmentation should be performed.

10.4 Options for Preimplant Reconstructive Surgery

10.4.1 Ridge Augmentation

10.4.1.1 Block Grafts

Autogenous

Autogenous block grafts have been used for many years for ridge augmentation procedures for implant placement since it was first described by Branemark et al. [86].

Treatments with autogenous block grafts include different extraoral and intraoral harvest sites such as the iliac crest, calvarium, tibia, mandibular symphysis, and ramus, among others.

The election depends on the volume of graft required, the location of the recipient site, and the type of graft needed.

Intraoral

Symphysis

One study carried out by Pikos that reviewed more than 500 block grafts concluded that block grafts harvested from the symphysis show a predictable bone augmentation up to 6 mm in both horizontal and vertical aspects [87]. An average block size of 20.9 × 9.9 × 6.9 mm can be harvested [88], which means that up to a three-tooth edentulous site can be treated [87].

This type of graft is considered as corticocancellous with a density D-1 or D-2, with an average of 65 % of cortical bone and 35 % of cancellous bone [87, 89]. The corticocancellous nature of bone provides faster angiogenesis, achieving a more rapid integration and less potential resorption during healing [90, 91] (Fig. 10.16).

Ramus

The ramus block graft can be used for horizontal or vertical augmentation of 3–4 mm. An average block thickness of 2–4.5 mm can be harvested from the ramus, with a length enough to treat a defect involving a one- to four-tooth edentulous area [87, 92].

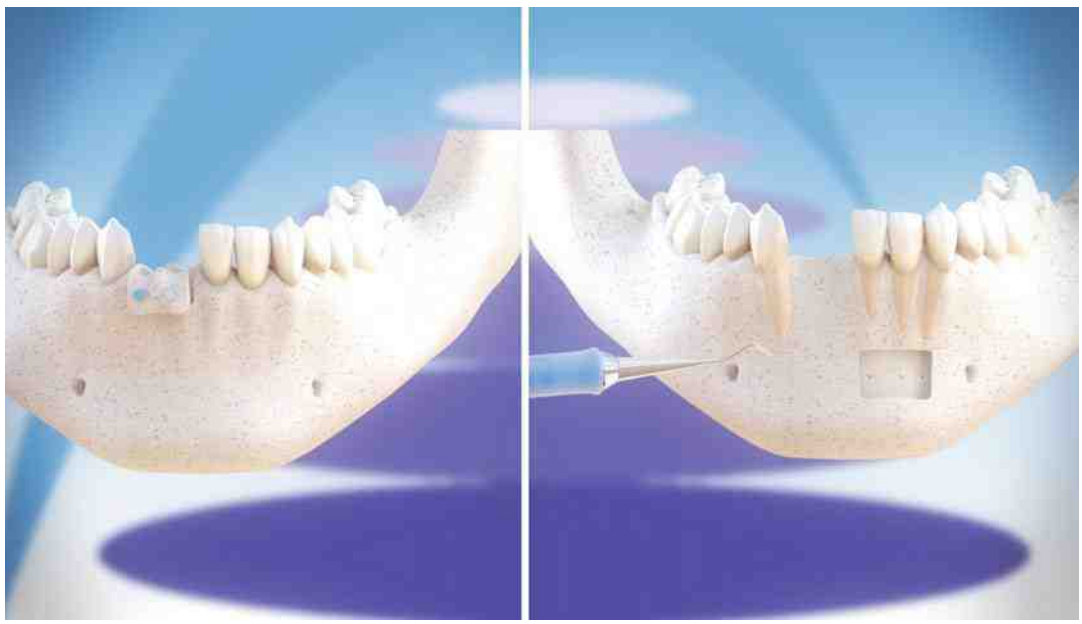

Fig. 10.16 3D image representing block graft harvested from the symphysis area (Copyright © Dr. Pardiñas López)

Fig. 10.17 3D image showing a block graft harvested from the ramus region (Copyright © Dr. Pardiñas López)

This type of graft has almost all cortical nature [89]. The cortical nature of bone exhibits less volume loss and maintains their volumes significantly better than cancellous bone [92, 93] (Fig. 10.17).

Bone blocks harvested from sites derived from intramembranous bone (intraoral) have been shown to revascularize faster and have less resorption than those from an endochondral (extraoral) source. This fact is related to a faster angiogenesis and greater inductive capacity, due to a higher concentration of bone morphogenetic proteins and growth factors [90, 94, 95].

Resorption

In the past, before the era of osseointegrated implants, the use of onlay bone grafts to reconstruct atrophic ridges was criticized because of the important resorption that they suffered.

Nevertheless, these drawbacks were mostly due to the use of removable dentures, which negatively affected the grafted jaws and also the nongrafted edentulous ridges.

The capacity of bone grafts to resist remodeling is variable, and results reported in the literature have a great variability. Different aspects can affect these results: differences in observation periods, type and site of reconstruction, timing of implant loading, use of provisional dentures on reconstructed sites, site of bone harvesting, type of implant, type of material, etc. Moreover, there is a paucity of information, as many studies only report implant survival rates and do not report changes in grafts [96].

Several studies have analyzed resorption rates of autogenous block grafts and most of them reported similar rates of resorption (Table 10.3).

Intraoral block graft resorption ranges from 0 to 42 % for vertical augmentation and from 9 to 24 % for horizontal augmentation, but can be excessive if graft dehiscence occurs [87, 97].

One study showed that the contraction in the horizontal bone augmentation with a bone block from the ramus of the mandible was from 4.6 ± 0.73 mm to 4.0 ± 0.77 mm [98]. Using the same graft source, other studies (using a CBCT scan) have reported a decrease in width from 6.1 ± 2.0 to 5.6 ± 2.1 mm of augmented alveolar ridges after 4 months of healing [99].

Vertical augmentation appears to be more problematic with both block and particulate grafts, with higher resorption rates than for horizontal augmentations [100–103].

One reason could be that the forces exerted on the graft when the soft tissue envelope expands vertically are higher than in horizontal augmentations [92].

Bone resorption is reported to be higher in the first year after the grafting procedure and in the first year postloading of implants [104]. Some studies have reported that resorption of the bone graft consolidates after implant placement. Furthermore, implant placement shortly after graft consolidation could have a stimulating effect on the bone, maintaining the graft volume and preventing further loss [96, 97]. Maintenance of the periimplant bone volume may also be due to occlusal stimuli to the implants [104, 105].

Wound dehiscence and/or infection is also related to partial or total loss of the graft, which in one study was reported in 3.3 and 1.4 % of the cases, respectively [44] (Fig. 10.18).

Use of Membranes

Membranes are often used in combination with block grafts and/or particulate graft materials to maximize the regenerative outcome and minimize graft resorption [8, 106, 107].

The use of membranes has shown a significant difference in width and height graft resorption, suffering less bone resorption in cases when a mem-

Table 10.3 Resorption rates of autogenous block grafts

Study	Resorption	Type of augmentation	Time (months)	Membrane	Comments	Mean gain (mm)
[87, 196–198] RS	0–20 %	Horizontal and vertical	5			3–7
[105] CS	17 %	Vertical	4–6	No	Block graft covered with particles of Bio-Oss	5.12
[103] PS	7.2 %	Horizontal	6	Collagen	Block graft covered with ABBM particles	4.7
[199] PS	18.3 %	Horizontal	6.3	No	Block graft alone	4.38
[200] PS	18.38 %	Horizontal	6	No	Ramus block with autogenous particles	–
[199] CS	9.3 %	Horizontal	5.5	No	Block graft covered with particles of Bio-Oss	4.46
[100] CS	23.5 %	Horizontal	5–6	No	Block alone	5
[100] CCT	32.5–42 %	Vertical	5–6	No	Block alone	2.2
[104] CCT	13.5 %	Vertical	4.6	Ti-Mesh	Block and autogenous particles	5
[104] CCT	34.5 %	Vertical	4.6	No	Block and autogenous particles	3.4
[133] PS	13.04 %	Vertical	4–5	No	Block and autogenous particles	4.6
[106] CS	23.7 %	Horizontal	6–8	PTFE		2.7
[99] CS	13.1 %	Horizontal	4	PRGF membrane	Ramus block and autogenous particles	3.1 ± 0.7
[40] SR		Horizontal	6.8		Autogenous intraoral block	4.3
[40] SR		Vertical	4.6	No	Autogenous intraoral block	4.5

PS prospective study, *SR* systematic review, *CS* clinical study, *RS* retrospective study, *CCT* controlled clinical trial

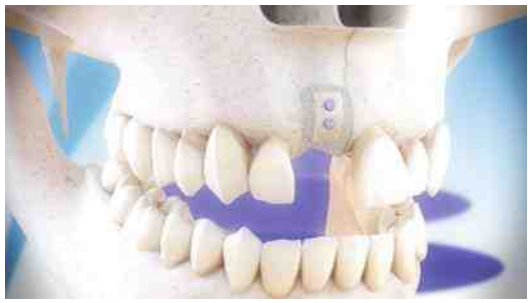

Fig. 10.18 3D image representing a block graft secured with screws in the anterior maxilla (Copyright © Dr. Pardiñas López)

brane was used than without membrane, 13.5 % vs. 34.5 %. However, this benefit was reduced when the membrane was exposed [104, 108].

Both nonresorbable and resorbable membranes reported good results, but the nonresorbable appears to have better results in terms of bone formation [40, 103].

One disadvantage is that resorbable membranes resorb relatively fast, so the block graft becomes unprotected. To avoid this, covering the block graft with ABBM particles will prevent surface resorption [103]. Regarding the disadvantages of the nonresorbable membranes, it makes more difficult the surgical technique (needs to be adapted and fixated to the underlying bone to prevent micromotion) and presents a higher risk of exposure which can lead to wound infection and complications [40, 106].

On the other hand, other authors only recommend the use of a membrane if a large quantity of particulate graft is used, as they report that no membrane is necessary for predictable block grafting [87] (Figs. 10.19, 10.20, 10.21, and 10.22).

Advantages, Disadvantages, and Complications

Different aspects have to be taken into account regarding the success rates of the different techniques.

The time of evaluation, the type of graft, the residual alveolar ridge present before surgery, the

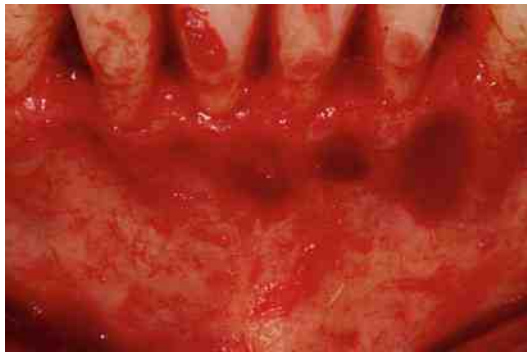

Fig. 10.19 Intraoral picture of the symphysis harvesting area

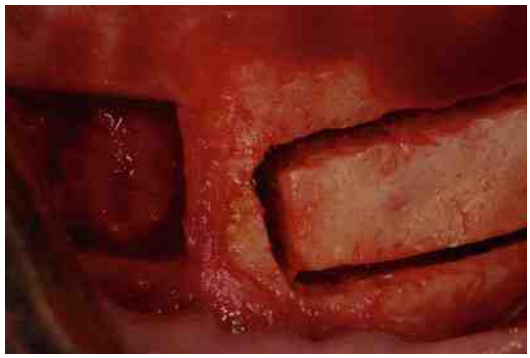

Fig. 10.20 Intraoral picture showing blocks harvested from the chin area

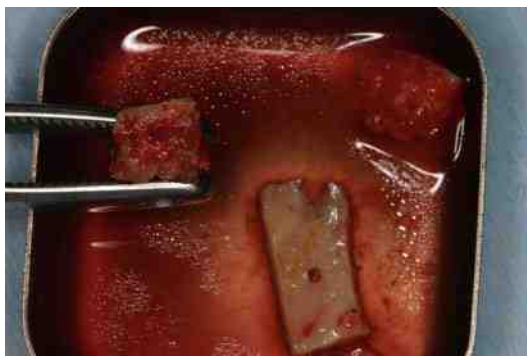

Fig. 10.21 Block graft harvested from the symphysis area

use of barrier membranes, the exposure of the membrane or graft, the tension-free closure, and the lag screw fixation, among others, can influence in the treatment results.

Autogenous block grafts have shown evidence of bone augmentation and high success rates. On the other hand, these techniques are associated with morbidity [92].

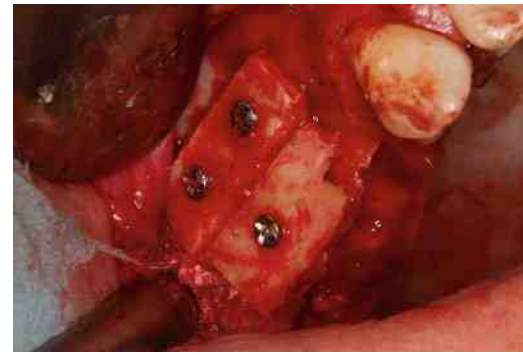

Fig. 10.22 Intraoral picture showing symphysis block grafts secured with screws in the posterior maxilla area

It is important to remark that there is heterogeneity in the literature in terms of what is considered a complication.

Complications must be differentiated in between donor sites and recipient sites. Many studies refer to complications only on the recipient site or only in the harvesting area; also other studies mix these complications. Although neural disturbances and graft exposure are the most important complications that must be taken into account, all complications should be considered as the final treatment will be affected by the whole range of procedures performed.

Complications have been reported up to 80 % in different studies. The most common surgical complications include neural disturbances. Temporary nerve disturbances involving the mental nerve have been reported as 10–80 % and 0–37.5 % when grafts were harvested from the mandibular ramus [97, 102, 108–110]. Permanent neural disturbances were reported to 0 % for ramus and 13 % for symphysis in one systematic review [96]. The most common postsurgical complications reported include mucosal dehiscences with or without exposure of the grafts or membranes, swelling, inflammation, and hematoma [92, 97, 102, 103, 108, 111] (Table 10.4).

Diabetes and smoking are common factors that were associated with a high rate of complications and graft failure in different studies [97, 102, 103].

Table 10.4 Complications intraoral grafts

Study	Graft	Complications (total)	Neural disturbances	Dehiscence or graft exposure	Type of augmentation	Total or partial graft loss
[103] CS	Intraoral origin	9.5 %				
[102] RS	Intraoral origin	28.1 %	3.1 %	12.5 %	Vertical 38.5 %, horizontal 29.1 %, mixed 32.4 % (of the total)	
[97] CS	Symphysis		9.6 %	10.7 %(in the donor area)		
[97] CS	Ramus	0 %	0 %	0 %		
[108] SR	Intraoral origin	43 %	14.3 % (5–33.3 %)	14.2 %	Vertical	10.7 %
[108] SR	Intraoral origin	10.6 %	0.62 %	7.5 %	Horizontal	2.5 %
[44] CIR	Ramus	0–5 %	0–5 %			
[44] CIR	Symphysis	10–50 %	10–50 %			
[133] PS	Ramus	50 %	37.5 %	12.5 % (in the recipient site)	Vertical	12.5 %
[128] RS	Ramus	27.8 % (5.6 % major, 22.2 % minor)				
[40] SR	Intraoral origin	3.9 %			Horizontal	
[40] SR	Intraoral origin	24.2 %			Vertical	
[96] SR	Symphysis	10–80 %	10–80 %			
[87] SR	Ramus		8 % (less than 1 permanent)			
[87] SR	Symphysis		53 (transient) less than 1 (permanent)			

CIR clinical investigation review, *PS* prospective study, *SR* systematic review, *CS* clinical study, *RS* retrospective study

Regarding the type of defect, vertical bone grafting is also associated with more complications rates than horizontal augmentations [102].

The mandibular ramus donor site results in fewer complications and morbidity and appears to have fewer difficulties in managing postoperative edema and pain in comparison with other donor sites [90, 97, 101].

Ramus graft has some advantages as compared to the chin area, the quality of bone is similar (mainly cortical), the amount of harvested bone may be higher, and the risk of neural disturbances is lower [44, 112]. However, surgical access in some patients is more difficult [97] (Figs. 10.23, 10.24, 10.25, and 10.26).

One important advantage of intraoral grafts is that the donor and recipient sites are in the same operating field, so surgical and anesthesia times are reduced as well as morbidity [92]. Also these grafts require a short healing period, in comparison to other techniques like GBR or particulate allografts or xenografts [97].

Fig. 10.23 Intraoral picture showing the harvesting area from the ramus

Moreover, fast osseointegration of the autogenous block grafts allows an early reentry for implant placement, often in 3–4 months, in comparison to the 6–8 months required for the particulate GBR techniques.

Cortical nature of the grafts results in optimal bone density for primary implant stability. Block

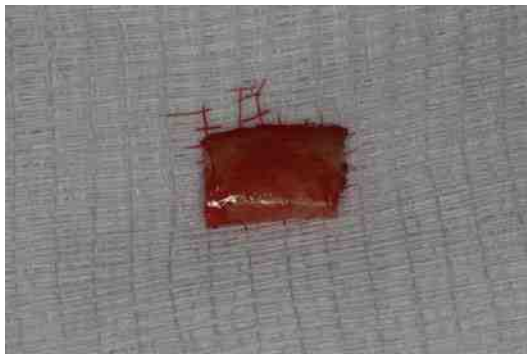

Fig. 10.24 Ramus block graft

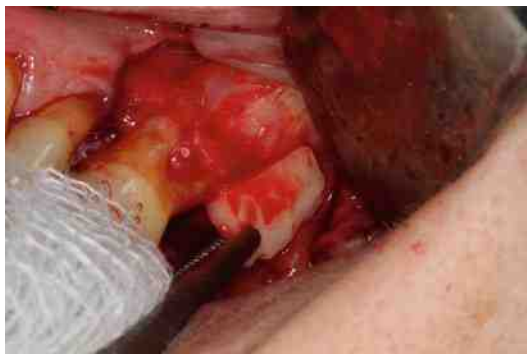

Fig. 10.25 Intraoral picture showing a ramus block graft placed in a maxillary defect

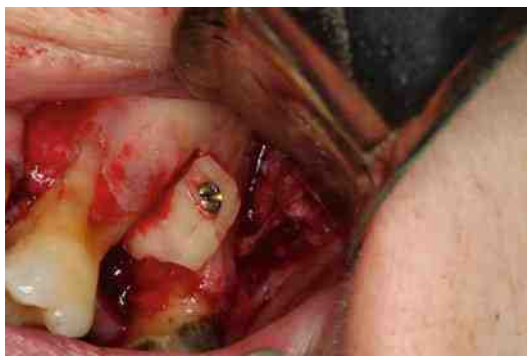

Fig. 10.26 Intraoral picture showing a ramus block graft secured in place with a screw

grafts are also good space maintainers during healing, preventing collapse and allowing the bone to form [90].

Success of the grafting procedure has been reported as 87.5 % [102], but the most relevant data is regarding implant success, which is the final goal of the treatment and will be discussed further on.

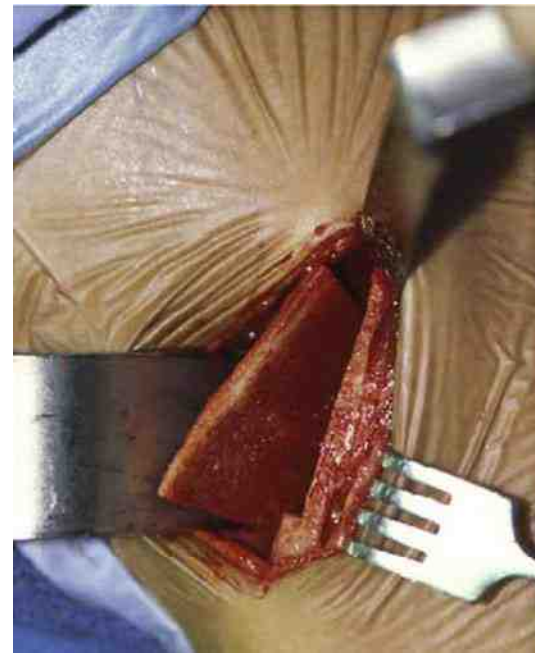

Fig. 10.27 Iliac harvesting site (Reprinted from Kademani and Keller [211]. Copyright (2006), with permission from Elsevier)

Extraoral

Distant site bone harvesting has been suggested as an indication when a large graft is needed. The iliac crest, calvarium, and tibia have been reported as reliable sources of grafts and are the most common extraoral harvest sites [113].

Ilium

The hip offers an area where large amounts of bone can be harvested, but these grafts usually have a thin cortical layer and a thick cancellous part [114].

However the main disadvantage is the morbidity associated with bone graft harvest (Figs. 10.27, 10.28, and 10.29).

The most frequently reported complications include temporary gait disturbance, paresthesia, infections, hematoma/seroma, fracture, scaring, and persistent pain [115–117].

The reported complication incidence is higher than with other donor sites, from 1 to 63.6 %,

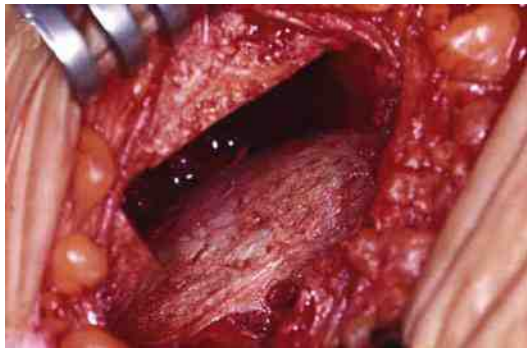

Fig. 10.28 Iliac harvesting site Reprinted from Kademani and Keller [211]. Copyright (2006), with permission from Elsevier)

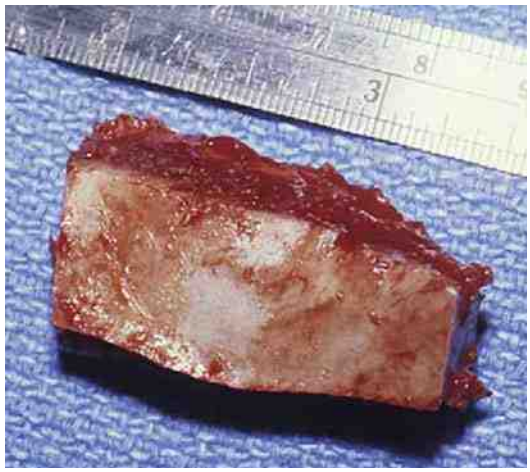

Fig. 10.29 Iliac block graft Reprinted from Kademani and Keller [211]. Copyright (2006), with permission from Elsevier)

and can be higher if postoperative pain/gait is considered.

Pain/gait disturbances were reported from 2 to 97 % of the cases [44]. This variability is also related with the personal resistance to pain, so it is important to note that complications should also be evaluated regarding patient feelings. A descriptive analysis of the visual analog scale (VAS) demonstrated that 70 % of the patients reported more severe pain from the harvest site than oral pain, 20 % reported more intense oral pain compared to hip pain, and 5 % reported that oral and hip pain were similar [116, 118].

The advantages of the iliac crest as a donor site are the simple accessibility and the potential abundant amount and quality of bone [118]. However, a second surgical site (donor site) is related with higher morbidity [118]. The mean hospital stay reported in the literature after an iliac crest bone harvest is 3–5 days [118, 119].

Resorption rates of the initial graft height 1–5 years postloading of implants have been reported in a range from 12 to 60 % [40, 44, 120].

Another study showed that at the 5-year examination, the mean bone resorption was 4.8 mm, although these results were attributed to the design of the 3.6-mm conical unthreaded part of the implant, which may produce more initial resorption [55]. Other authors reported a mean resorption of 2.75 mm [121] and 0.85 mm (range of 0–4.5 mm) [122] before implant placement.

When the resorption of iliac crest bone grafts used for vertical or horizontal onlay augmentation was compared between the maxilla and mandible, the resorption in the maxilla was significantly more pronounced after 2 years. After 6 years, 87 % of resorption was found in the mandible, while the grafts were completely resorbed in the maxilla [111].

Tibia

The tibia serves mainly as a source of cancellous bone and a small quantity of cortical bone [113].

When cancellous bone is needed, the tibia is one of the indicated harvest sites because it provides an abundant amount of bone with a low morbidity [123, 124].

Advantages include a low complication rate; a large quantity of cancellous bone can be harvested (1 × 2-cm block), and it is a technically simple and quick surgical procedure [116] (Figs. 10.30 and 10.31).

Although this procedure is relatively simple and safe, it also presents some complications. Reported complications include prolonged pain, gait disturbance, wound dehiscence, infection, scarring, hematoma, infection, paresthesia, and fracture, in a range of 1.4–5.5 % [116].

Calvarial

Calvarial grafts are usually harvested from the parietal bone, which has an average thickness of 7.45 mm [125] (Fig. 10.32).

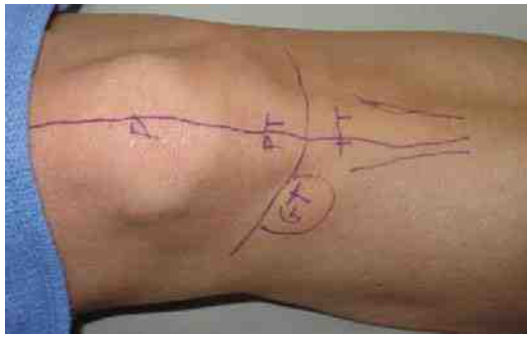

Fig. 10.30 Tibia harvesting site (Reprinted from Tiwana et al. [212]. Copyright (2006), with permission from Elsevier)

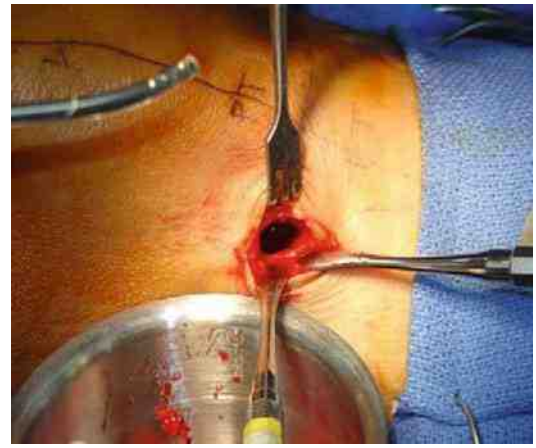

Fig. 10.31 Tibia harvesting site (Reprinted from Tiwana et al. [212]. Copyright (2006), with permission from Elsevier)

Large amounts of bone can be harvested from the skull with the advantage that the operative field is in proximity to the recipient site. The main advantage is the presence of a dense cortical structure that can better resist resorption [126] (Fig. 10.33).

On the other hand, this procedure usually requires general anesthesia in a hospital and requires a close postoperative care. Also minor and severe complications may occur, such as trepanation of the inner table, hemorrhage, superior sagittal sinus laceration, brain injury, air embolism, hematoma, infection, subgaleal seroma, meningitis, depression of the skull, altered sensation, and pain [127, 128].

Another point of interest is that the scar on the scalp can be visible and can also lead to localized alopecia [116].

Different studies reported a range of 0–57.7 % of both major and minor complications. Among which 0.4–4 % correspond to hematomas, 2 % to dura mater exposures, 2.3 % to alopecia, and 0–12 % to neurosurgical complications [128, 129].

Also another study reported an 82.1 % of cases in which skull depression could be observed [129]. A reconstruction by means of biomaterials is necessary to avoid this sequel.

These contrasts in complication rates may reflect differences in study designs and populations, harvesting techniques, and levels of surgical skill [128].

A close neurologic monitoring is required during the first 24 h postoperatively [129], and a mean of 5.1 days of hospital stay is reported in the literature [128].

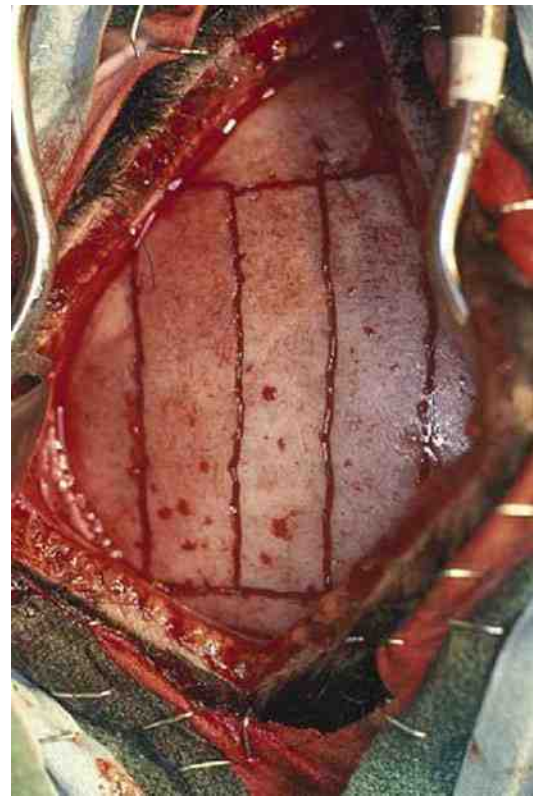

Fig. 10.32 Calvarial harvesting site (Reprinted from Ruiz et al. [213]. Copyright (2005), with permission from Elsevier)

Regarding graft resorption, most of the studies showed less resorption of calvarial grafts when compared to other donor sites. Two studies

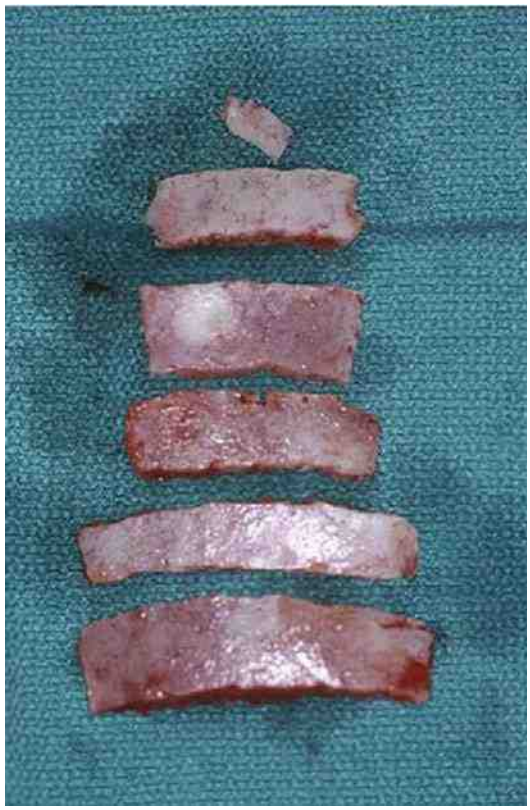

Fig. 10.33 Calvarial block grafts (Reprinted from Ruiz et al. [213]. Copyright (2005), with permission from Elsevier)

compared the resorption of calvarial grafts, ramus grafts, and iliac grafts. The resorption for calvarial grafts ranged from 0.18 mm ± 0.33 to 0.28 mm at the time of implant placement [122, 130], while at a mean follow-up of 19 months was 0.41 mm ± 0.67 mm [130]. Regarding ramus block grafts, the resorption was 0.42 ± 0.39 mm [130] and 0.35 mm (range of 0–1.25 mm) [122] at the time of implant placement and at a mean follow-up of 19 months was 0.52 ± 0.45 mm (range 0–1.75 mm) [130]. In the case of iliac grafts, the resorption was 0.85 mm (range of 0–4.5 mm) at the time of implant placement [122].

Some studies reported resorption rates of calvarial grafts ranging from 0 to 15 % of the initial graft height at a mean follow-up of 19.3 months (range 6–42 months) [44, 131]. However other authors reported that although at 10 months follow-up calvarial bone had significantly less resorption than iliac grafts, after 30 months the difference was no longer statistically significant [132].

Implant Placement

Implants placed in regenerated autogenous block grafts are predictable operations that have shown high survival and success rates [92].

Implant survival and periimplant bone levels have shown no significant differences between implants placed in block-grafted areas and implants placed in nongrafted native bone [133]. Implant survival and success rates have been reported in the literature in a mean range from 76.8 to 100 % for autogenous onlay bone grafts [44], although the majority of articles reported survival rates of more than 90 %.

Regarding the harvesting site, the least implant survival rates occurred in patients reconstructed with iliac grafts, followed by implants placed in calvarial grafts, and lastly for implants placed in areas grafted with intraoral grafts (Table 10.5).

Data were more insufficient in terms of success rates of implants according to well-defined criteria [96]. Also, a less number of implants were analyzed for success rates in comparison to the number of implants analyzed for survival rates.

Regarding intraoral harvesting sites, with no statistically significant differences between the ramus and symphysis, reported survival rates ranged from 92.3 to 100 %, while success rates ranged from 89.5 to 100 %. Implant survival rates placed in grafted areas with iliac bone grafts range from 60 to 100 %, and implant success rates vary from 72.8 to 95.6 % (Table 10.5). Implant survival rates placed in grafted areas with calvarial bone grafts range from 86 to 100 % and success rates range from 90.3 to 97.6 % (Table 10.5).

Survival rates of implants placed in grafted mandibles are reported to be better than in grafting maxillae (Table 10.6).

Time of Implant Placement

Many different characteristics and situations can influence the osseointegration of implants, such as waiting times for implant placement and

Table 10.5 Implant success and survivals when placed in grafted areas with autogenous bone

Autogenous	Study	Implant success (%)	Implant survival (%)	Time (months after prosthetic load)
Ramus	[44] CIR	95[a]	97.1 (93–100)	
	[133] PS	89.5	100	38
	[111] SR	93.5	100	33
	[96][a] SR	91.9–93	94.5	6–90
Symphysis	[44] CIR	90.7–100	97.1 (92.3–100)	
	[111] SR	95.5		23.3
	[96][a] SR	90.7–100	94.5 (92.3–100)	
Iliac	[131, 202] LTR		73.8	12–120
	[111] SR	76.4	93,1	33 ISuccess/60 ISurvival
	[194] SR		88	12–72
	[a][96] SR	83–95.6	82.5 (60–100)	6–90
	[55] PS	72.8–83.1	72.8–83.1	120
	[121] PCT	86.9	100	13–22
	[202] RS	83.1	91	120
Calvarial	[44][a] CIR	90.7–97.6	94.9 (86–100)	
	[96][a] SR	90.7–97.6	94 (86–100)	6–90
	[111] SR	90.3	99	33

CIR clinical investigation review, *PS* prospective study, *PCT* prospective controlled trial, *SR* systematic review, *LTR* long-term review

[a]*Success rates* only one-fourth of the total number of implants placed in the grafted jaws. Data were more insufficient in terms of success rates of implants according to well-defined criteria

loading, macro- and micro-implant geometry and materials, and quality of bone [44].

The level of evidence for implant survival and success rates is better for the delayed implant placement and may be preferable to simultaneous placement, although much controversy still exists [44, 105, 108, 134] (Table 10.6).

It has been suggested that immediate implant placement is exposed to some risks like wound dehiscence (which can expose the graft and lead to infection with the inherent risk of losing the graft partially or totally) and that immediate implants are placed into a non-vascular bone, which increases the risk of no osseointegration [44].

In addition, with the two-stage protocol, the operator can achieve prosthetically better implant placement and superior aesthetics [105].

Authors that rely on immediate implant placement suggest that resorption of the onlay graft is more pronounced after transplantation; therefore, immediate implant placement would shorten the waiting time before the prosthetic rehabilitation, thus preventing resorption [44].

Loading of Implants

The majority of studies suggest to wait similar times as to implants placed in native bone (3–6 months) [44], although there is also evidence that an early or immediate loading in grafted areas may have a stimulating effect on the bone and thus prevent bone resorption [96]. Research has shown that primary implant stability is crucial to the success of implant therapy and to determine the election of immediate or delayed loading.

How to Select the Donor Site of Autogenous Bone for Implant Site Preparation?

Based on the available scientific evidence, there are several factors that may help the surgeon to decide on the different donor sites of autogenous bone.

Due to the high heterogeneity of the studies available which analyze many different variables, it is very difficult to compare results of the different treatment options. General conclusions can be drawn but must be analyzed with care.

Table 10.6 Implant survivals and success when placed in grafted areas with autogenous bone

Study	Immediate implant placement	Delayed implant placement	Graft	Implant success (%)	Implant survival (%)	Time (months)	Area	Periimplant bone loss (mm)
[44] CIR	X		Autogenous block		79.3 (range 72.8–92.3)	6–120	Maxilla	
[44] CIR		x	Autogenous block		93.4 (range 80–100)	6–120	Maxilla	
[44] CIR	X		Autogenous block		92.7 (88.2–100)	6–120	Mandible	
[44] CIR		x	Autogenous block		100	6–120	Mandible	
[108] SR		x	Intraoral autogenous block	96.9–100	96.9–100	12–24	Horizontal augmentation	0.08 ± 0.9 to 0.20 ± 0.50
[108] SR	X		Intraoral autogenous block	89.9		12	Horizontal augmentation	0.69 ± 0.67
[108] SR		x	Intraoral autogenous block	89.5–91	95.6–100	12–38	Vertical augmentation	
[96] SR	X		Autogenous block		81.8 (range 72.8–92.3).	6–240	Maxilla	
[96] SR		x	Autogenous block		89.9 (range 80–100).	6–240	Maxilla	
[96] SR	X			83–100 (median 89),	91.1 (88.2–100)	6–240	Mandible	
[96] SR		x		83–100 (median 89),	100	6–240	Mandible	
[96] SR	x		Onlay iliac		95.6	12		
[96] SR	x		Onlay calvarial		100	12–36		
[203] RS	x		Intraoral autogenous	89.5	100	12		(0.69 ± 0.67)
[203] RS		x	Intraoral autogenous	96.9	96.9	12		0.20 ± 0.50
[202] RS			Intraoral autogenous		88	60		0–3.3
[40] SR			Intraoral autogenous block		96.9–100	12–60	Horizontal	
[40] SR			Intraoral autogenous block		96.9–98	22–24	Vertical	
[120] SR	x		Iliac	88.2		48	Mandible	
[120] SR	x		Iliac	72.8		120		
[120] SR	x		Iliac	83			Maxilla	

CIR clinical investigation review, *SR* systematic review, *RS* retrospective study

- *Graft volume*:
  Extraoral donor sites are usually selected when a large amount of bone is needed for jawbone reconstruction [54].

  However, reconstruction of alveolar bone for the placement of dental implants is usually localized to a small area and requires smaller amounts of bone which makes feasible the selection of an intraoral donor site [54]. A recent study in cadavers showed that grafts harvested from the symphysis had higher thickness than grafts harvested from the ramus [135]. Bone blocks retrieved from the symphysis could provide sufficient bone to achieve a horizontal augmentation of 4–6 mm [90, 136], whereas a block from the mandibular ramus provides sufficient bone to thicken the alveolar ridge by 3–4 mm [90].

- *Surgical morbidity*:
  Harvest of iliac crest bone is associated with the highest percentage of complications, followed by intraoral and calvarial grafts. Intraoral harvest site complications have been reported up to 80 % in different studies (Table 10.7). The most common surgical complications include neural disturbances. Temporary nerve disturbances and morbidity have been reported more in grafts harvested from the symphysis area than grafts harvested from the ramus area. Also regarding the type of defect, vertical bone grafting is associated with more complication rates than horizontal augmentations.

  Intraoral grafts have the advantage that donor and recipient sites are in the same operating field, so surgical and anesthesia times

Table 10.7 Complications of extraoral grafts

Study	Graft	Complications	Neural disturbances	Comments	Pain/gait
[115] LTR	Iliac	1–25 %			
[116] SR	Iliac	1–30 %	26.5 %		7.4–16.5 %[a]
[118] PS	Iliac	20 % (excluding pain)	5 %		65 % irregularities on gait and 25 % walking aid necessity
[44] CIR	Iliac				2 %
[117] RS	Iliac	1.88 % (not including pain as a complication)	0.8 %		100 % (within 15 days)
[119] SR	Iliac	19.37 % (10–39 %)		0.28 % dehiscence or graft exposure	7.75 % more than 6 months
[111] SR	Iliac	–			17–34 % (need for the use of crutches 37–50 %)
[128] RS	Iliac	63.6 %	23.44 %	7.3 % major, 56.4 % minor	35 %
[204] CIR	Iliac	17 % (excluding pain)			97.4 % at 1 month, 31.42 % at 6 months, 14.28 % at 1 year
[121] PCT	Iliac	30 %			
[116] SR	Calvarial	0.3 %	0.02 %		
[128] RS	Calvarial	57.7 %		19.2 % major, 38.5 % minor	
[129] RS	Calvarial	6.8 %	0–2 % (0–12 % in other studies)	86 % skull depression	
[44] CIR	Calvarial	0 %			

CIR clinical investigation review, *PS* prospective study, *PCT* prospective controlled trial, *SR* systematic review, *LTR* long-term review, *RS* retrospective study

[a]15.55 % reported some difficulty walking, 7.5 % with work activity, 15.4 % with recreation, 16.5 % with household chores, 11.8 % with sexual activity, and 7.4 % irritation from clothing

are reduced as well as morbidity, and mainly cortical bone can be harvested.

Main disadvantages of bone harvesting from extraoral areas include morbidity and hospitalization for general anesthesia and requires a longer surgical procedure [109, 137]. Studies have reported that the most frequent complaints of bone harvesting from the iliac crest were the temporary pain/gait disturbance [96]. Long-standing pain/gait disturbances were reported from 2 to 97 % in the literature. The surgical morbidity when calvarium was used was reported to be lower, from 0 to 57.7 %, although one study reported an 86 % of cases presenting skull depression (Table 10.7).

- *Promotion of new bone formation*:
  One meta-analysis was performed in relation to the total bone volume present in biopsies obtained from augmented maxillary sinus with autogenous bone [47]. The study indicated that bone harvested from an intraoral site would result in higher total bone volume than the bone graft from the iliac crest [47].

  Different studies reported that the mean gain at the time of implant placement (4–6 months after grafting) ranges from 2.2 to 7 mm for intraoral autogenous grafts (Table 10.3).
- *Stability of augmented bone*:
  The embryonic origin is different between the extraoral harvested bone (endochondral ossification) and the alveolar bone (intramembranous ossification) [138, 139]. This is a factor that could influence the success of bone augmentation surgery as intramembranous bone graft seems to maintain better its volume, whereas endochondral bone graft undergoes a variable degree of resorption over a variable period of time [94, 140, 141].

  Symphysis grafts have a corticocancellous nature, which provides faster angiogenesis, achieving a more rapid integration and less potential resorption during healing, while the ramus has almost all cortical nature which exhibits less volume loss and maintains its volume significantly better than cancellous bone.

  Intraoral block graft resorption ranges from 0 to 42.5 %, and vertical augmentation appears to show higher resorption rates than horizontal augmentations.

  The hip offers an area where large amounts of bone can be harvested, but it usually has a thin cortical layer and a thick cancellous part which is prone to more resorption. Initial resorption rates appear to be more significant in comparison with intraoral grafts. Also resorption is more pronounced in the maxilla than in the mandible.

  Large amounts of bone can be harvested from the skull with the advantage that the operative field is in proximity to the recipient site and that presents a dense cortical structure that can better resist resorption. It has been reported that calvarial grafts show less initial resorption when compared to other donor sites; however, at long-term follow-up, differences may not be significant [122]. Extraoral resorption rates of 0–15 % in calvarial grafts and up to 60 % in iliac bone grafts after the prostheses connection were documented with the use of extraoral autogenous block grafts [8, 126, 142].

  These data would indicate the importance of taking measures to compensate the loss in graft volume. Overaugmentation and the use of bone substitutes could be useful tools to compensate graft remodeling [99].

  Also, the use of membranes has shown less bone resorption in comparison to cases when a membrane was not used.
- *Healing*:
  If a bone block is needed, then it is highly recommended to use corticocancellous bone blocks [96]. Cancellous bone alone and particulate bone, if not associated with titanium mesh membranes or titanium-reinforced membranes, do not provide sufficient rigidity to withstand tensions from the overlying soft tissues or from the compression by provisional removable dentures and may undergo almost complete resorption [86, 96]. Wound dehiscence and/or infection is related to partial or total loss of the graft.

  Uneventful healing/consolidation of both intraoral and extraoral grafts could be expected [96]. One systematic review reported that wound dehiscence/infection occurred in 3.3 % of the cases of alveolar ridge augmentation, while total graft loss occurred in 1.4 % of the

cases, the majority being related to extensive reconstruction with iliac grafts [96].

Regarding the harvesting area, the least implant survival and success rates occurred in patients reconstructed with iliac grafts, followed by implants placed in calvarial grafts, and lastly for implants placed in intraoral grafts. Also implant survival rates placed in grafted mandibles are reported to be better than in grafting maxillae (Table 10.6).

The level of evidence for implant survival and success is better for the delayed implant placement and may be preferable to simultaneous placement, although much controversy still exists.

Allogeneic

Although for many clinicians, autogenous bone grafts (as block or particulate form) still remain the gold standard for ridge augmentation, donor site morbidity associated with block graft harvesting has changed directions to the use of allogenic materials.

Different studies demonstrated success with FDBA and DFDBA block graft material in horizontal ridge augmentation procedures [8].

The behavior of an allograft depends not only on the harvested bone but also on the method in which the harvested bone is prepared and also on the quality of the source.

Allograft bone grafts have the advantage of permitting the selection of blocks with a predefined configuration and corticocancellous composition [143]. Also, morbidity discomfort and operation time are reduced [144].

Clinical evidence for allogeneic block grafting is mainly limited to case series and reports, and many different aspects have to be taken into account like defect selection, treatment approaches, and follow-up period. Also many of the analyzed cases focused on anterior graft sites having little information in posterior alveolar ridge augmentation.

In terms of block graft failure rates, a range of 2–8.5 % was reported in one case series and a systematic review [144, 145].

Graft failures most often involved mandibular posterior defects (71 %), and as with autogenous onlay, graft wound dehiscence and membrane exposure appear to be the most common complications [143–145]. Sites yielded an average of 2–3.5-mm vertical gain and an average horizontal gain of 3.92–4.79 mm [143, 144].

In one study, only one of the 57 allogenic block grafts presented a resorption of 2.5 mm; none was observed in the others after 3–4 months after grafting. They remained stable after implant placement during the 26 months of follow-up [146].

In another study, allogeneic block graft resorption ranged from 10 ± 10 % to 52 ± 25.97 % at 6 months after grafting [144].

The studies examined reported evidence that successful alveolar ridge augmentation using allogeneic onlay grafts has a high (92.8–99 %) short-term (less than 5 years) implant success rates [143, 144]. Success rates in a range of 86.9–90.0 % have also been reported in another study [111].

The use of allogeneic bone block grafts represents a reliable alternative to autogenous block grafts for augmenting the atrophic maxilla. Furthermore, implants placed in areas grafted with allogeneic blocks can achieve similar implant survival rates as implants placed in areas grafted with autogenous block grafts. However, these conclusions should be interpreted with caution due to the limitation of studies [144].

10.4.1.2 Particulate Graft: Guided Bone Regeneration

The concept of guided bone regeneration (GBR) was first described in 1959 when cell-occlusive membranes were employed for spinal fusions [147]. This principle is based on that cells which first populate a wound area determine the type of tissue that ultimately occupies the original space.

This technique is used for space maintenance over a vertical or horizontal defect, enabling the ingrowth of osteogenic cells and preventing migration of undesired cells coming from the soft tissue. Therefore, osteogenesis can occur without the interference of other competing types of tissue cells [148–150] (Fig. 10.34).

Different space maintainers have been described, such as particulate grafts, block grafts, resorbable and nonresorbable membranes, and screws, among others.

Fig. 10.34 3D image representing the principles of guided bone regeneration. The membrane acts a barrier, enabling the ingrowth of osteogenic cells and preventing migration of undesired cells coming from the soft tissue (Copyright © Dr. Pardiñas López)

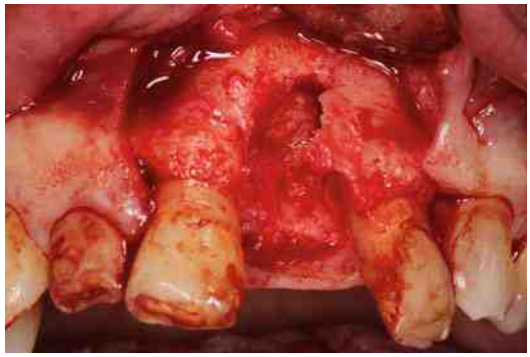

Fig. 10.35 Intraoral picture showing a bone defect in the maxilla

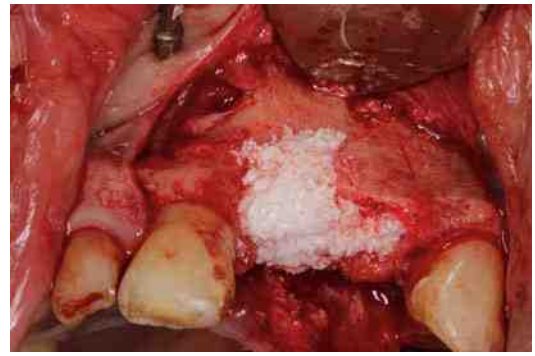

Fig. 10.36 Intraoral picture showing a bone defect filled with particulate xenograft

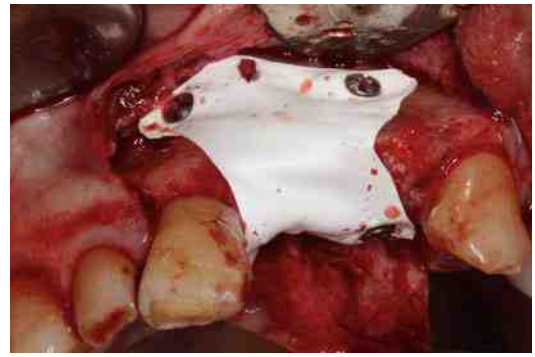

Fig. 10.37 Intraoral picture showing the bone defect covered with a nonresorbable membrane and secured with screws

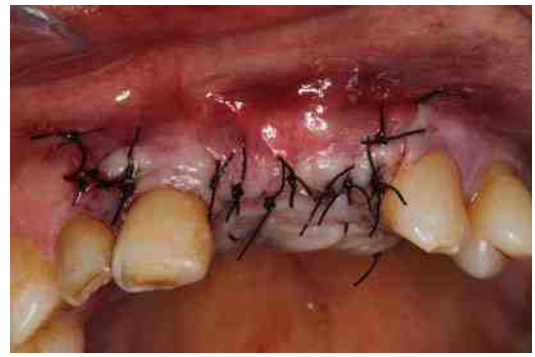

Fig. 10.38 Intraoral picture showing the grafted area sutured and completely covered by soft tissue

Guided bone regeneration (GBR) and guided tissue regeneration (GTR) are often used to describe the same procedure, which is inappropriate. GTR is referred to the regeneration of the periodontium, including the cementum, periodontal ligament, and alveolar bone, whereas GBR refers to the promotion of bone formation alone. GBR and GTR are based on the same principles [2, 8].

Studies reported a mean augmentation from 2 to 4.5 mm for horizontal augmentations and from 2 to 7 mm for vertical augmentations [8, 44, 45] (Figs. 10.35, 10.36, 10.37, and 10.38).

Implant Survival/Success

It has been documented that guided bone regeneration is a successful method for augmenting the bone in situations where there is inadequate bone volume for the placement of endosseous dental implants [151, 152].

Studies reported implant survival rates in a range of 76.8–100 %, while success rates ranged from 61.5 to 100 % in a period of 6–133 months. Most of them showed survival/success rates higher than 90 %, which is comparable to

implants placed in native bone [44, 153]. However bone resorption was more pronounced in sites with GBR treatment [154]. No differences were found regarding vertical or horizontal augmentation, while procedures in the maxilla tend to have lower implant survival rates than those performed in the mandible (Table 10.8).

The type of graft material (or without material) and the use of resorbable or nonresorbable membranes (including titanium meshes) do not seem to affect the clinical survival/success of the implants (Table 10.8). However, this conclusion must be analyzed with care; no conclusive recommendations can be given to clinicians as it is difficult to correlate the survival/success rate of implants to the type of grafting materials used in association with membranes, because of the wide range of different materials used, the wide range of initial defects, and the paucity of comparative, controlled, split-mouth studies comparing different grafting materials and different membranes [44].

Also, the time of implant placement (staged versus simultaneous) does not seem to affect the survival/success of the treatment [7], so no indications regarding the choice of simultaneous vs. delayed implant placement have yet been defined [44], although some authors reported that a staged approach may have a lower risk for crestal bone loss as compared with a simultaneous approach, but not affecting the treatment final outcome [44].

Resorption

Different studies report a range of 0.3–2.9-mm resorption in a mean of 65 months of follow-up (Table 10.8).

It was demonstrated that the initial bone gain undergoes contraction over time (40 % of the initial bone gain) [44].

The greatest amount of bone loss is reported to be within the first year after loading and thereafter seems to remain stable [7].

Cancellous bone alone and particulate bone, if not associated with membranes of titanium meshes, may not provide sufficient rigidity to support tension from the overlying soft tissues or from the compression by provisional removable dentures and may suffer from partial or total resorption [96].

Complications, Advantages, and Disadvantages

This technique can be applied to extraction socket defects, localized defects, horizontal and vertical ridge augmentation, and correction of dehiscence and fenestration defects around implants [8, 155].

Like the nonresorbable membranes, bioabsorbable membranes can experience premature soft tissue dehiscences and exposures.

Communication with the oral cavity accelerates their resorption rate and contamination of the regenerated bone matrix [8, 156], augmenting the chances of partial or total loss of the graft.

Although collagen barriers offer improved soft tissue response, they have less ability to maintain an adequate defect space than a nonresorbable one, which is more rigid [8]. Following this reason, when a particulate graft is selected for vertical augmentation, a rigid membrane may be used to protect the graft [156].

Failures are mainly reported to be related to premature membrane exposure. Rates of exposure have been reported up to 50 %, particularly when large vertical augmentations are performed, and can lead to infection and eventually partial or total loss of the regenerated bone [8, 156, 157].

One study showed that in 16 % of the cases where GBR was performed using resorbable membranes and in 24 % of cases where nonresorbable membranes were used, membrane exposure was present at the time of suture removal, and 44 % of the nonresorbable had to be removed prematurely [8].

10.4.2 Alveolar Split Osteotomy

Alveolar split osteotomy can be used to widen a horizontally narrow mandibular ridge. It is classically admitted that there must be at least 2–3 mm of crestal bone width and a certain amount of cancellous bone present to perform it [8, 113, 158, 159].

The procedure consists in splitting the alveolar bone longitudinally provoking a greenstick fracture, using chisels, osteotomes, or piezosurgical devices. With the use of sequentially expanding osteotomes, the bone can be forced

Table 10.8 Guided bone regeneration

Study	Grafting material	Success	Resorption	Implant success	Implant survival	Time (months)	Bone gain
[7] RM	Autogenous/allograft		0.64 ± −0.22 mm	97.5 % (all failures in maxilla)		74	
[194] SR	All				95.5 %	12–72	
[194] SR	Xenograft				96.2 % (93.4–99 %)	12–72	
[44] CIR	Horizontal GBR (all materials, not specified)	67–100 %	1–2.9 mm	86–98.3 %	98 % (range 76.8–100 %)	6–133	2–4.5 mm
[44] CIR	Vertical GBR (all materials, not specified)	67–100 %	1–2.9 mm	92.6 % range (61.5–97.5 %)	99.3 % range (99–100 %)	6–133	2–7 mm
[44] CIR	All with resorbable membrane			91 %	95–100 %	6–133	
[44] CIR	All with nonresorbable membrane			61.5–100 %	92–100 %	6–133	
[205] PS	Autograft, allograft, both or none with just membrane		2.03 ± 0.5 mm		96.1 %	60	
[162] PSR	Autogenous or PTFE (Polytetrafluoroethylene) membrane alone		0.3 ± 0.8 mm		76.8–83.8 % (maxilla-mandible)	60	
[162] PSR	Autogenous or xenograft	87–95 %			84.1–100 %	22.4–60	
[112] SR	Not specified				95.8 % ± 5.3 %	56.5 ± 25.5	
[154] PS	ABBM and resorbable membrane		1.83 mm		95.4 %	60	
[154] PS	ABBM and nonresorbable membrane		2.21 mm		92.6 %	60	

CIR clinical investigation review, *PS* prospective study, *SR* systematic review, *RM* randomized multicenter, *PSR* prospective systematic review

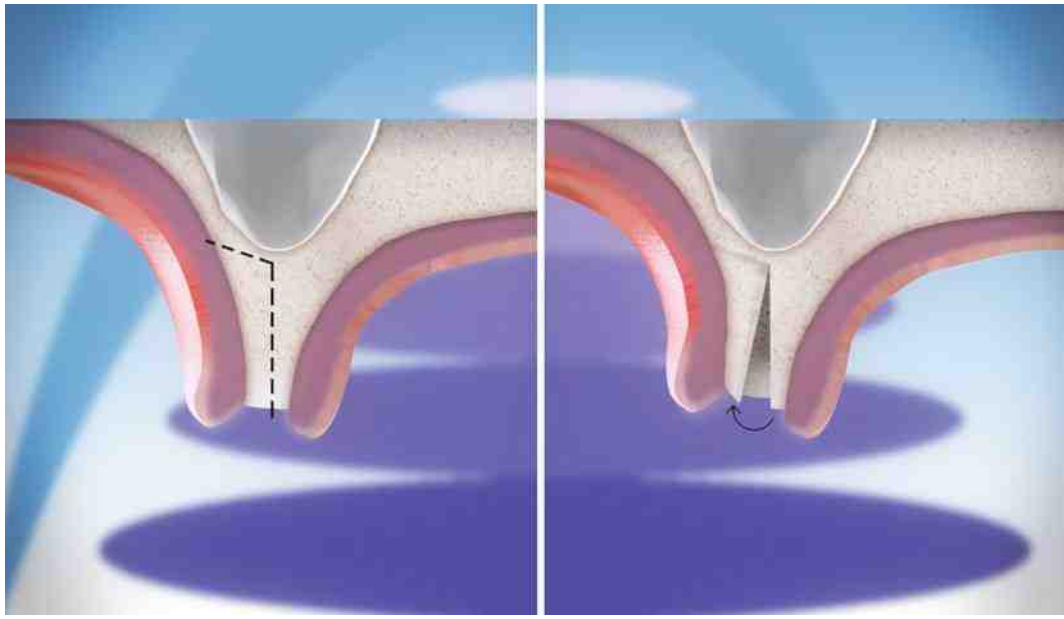

Fig. 10.39 3D image representing the alveolar split technique (Copyright © Dr. Pardiñas López)

Table 10.9 Alveolar split osteotomy

Study	Success of procedure	Resorption	Implant success	Implant survival	Time (months)
[96] SR [44] CIR	98–100 %		86.2–97.5 %	91–97.3 %	6–93
[162] PSR	87.5–97.8 %			86–100 %	12–60
[167] CIR		1.77 ± 1.1 mm		100 %[a]	52.4
[161] RS	93.5 %	0.69 mm (first year and an annual 0.06 mm) after loading, 1.61 mm vertical between postoperation and loading	93.2 %	100 %	6–96
[194] SR				97.4 %	6–144
[166] PS				97 %	27 (0–93)

CIR clinical investigation review, *PS* prospective study, *SR* systematic review, *PSR* prospective systematic review, *RS* retrospective study

[a]Achievement of primary stability of the implant was impossible at six sites; these were recorded as failures

buccally with the possibility of interposition (inlay) bone grafts or simultaneous implants to keep the segments separated and to shorten the treatment time, reducing morbidity and costs [8, 113, 158, 160] (Fig. 10.39).

The gap created by sagittal osteotomy/expansion follows a spontaneous ossification with a mechanism similar to that occurring in fractures.

Success rates of the surgical procedure ranged from 87.5 to 100 % in the studies analyzed. Fracture of the buccal plate during the ridge expansion is reported to be the most common complication, from 4 to 22 % [96, 161–164] (Table 10.9).

The limitations of this technique are the presence of highly compact bone and the lack of a cancellous bone layer between the two cortical plates [159].

Implant Placement

In the studies reviewed, survival rates of implants ranged from 86 to 100 % in a 6–144-month period, which is consistent with placement in native bone. Implant success rates ranged from

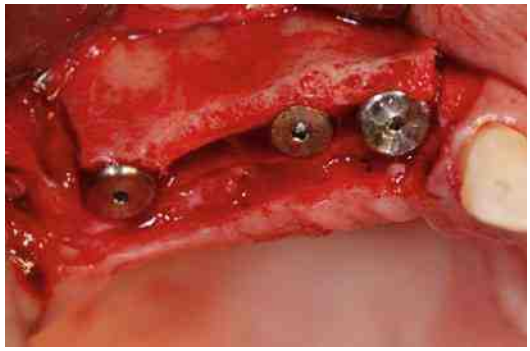

Fig. 10.40 Intraoral picture showing alveolar ridge splitting with implants placed (Reprinted from Gonzalez-Garcıa and Monje [214]. Copyright (2010), with permission from Elsevier)

Fig. 10.41 Intraoral picture showing alveolar ridge splitting with implants placed and space filled with particulate bone graft (Reprinted from Gonzalez-Garcıa and Monje [214]. Copyright (2010), with permission from Elsevier)

86.2 to 97.5 % [90, 165, 166]. However, the few available homogenous data shows that a slightly more marginal bone loss can be expected compared with implants placed in intact bone [159].

The primary advantages of the ridge split technique using particulate graft, block graft, or GBR are that treatment time and morbidity are reduced, resulting from avoiding the necessity to obtain a graft from a separate donor site [8] (Figs. 10.40 and 10.41).

Resorption

In different studies, the mean ridge width augmentation was 3.5 ± 0.93 mm–4.03 ± 0.67 mm [167, 168]. The mean vertical bone loss was

Fig. 10.42 3D image representing the distraction osteogenesis technique and the distractor device (Copyright © Dr. Pardiñas López)

1.77 + −1.1 mm (ranging from 0.35 to 4.35 mm) in a mean time of 52.4 months [167].

In one retrospective study, the mean marginal bone loss during the first year was reported as 0.69–0.43 mm followed by an annual loss of 0.065 mm in the following years. 1.61 mm of vertical bone loss between postoperation and loading was also reported [161].

10.4.3 Distraction Osteogenesis

Distraction osteogenesis relies on the longstanding biologic principle that a new bone fills in the gap defect created when two pieces of bone are separated slowly under tension. Distraction of the segment can be achieved in a vertical and/or a horizontal direction. The process involves cutting an osteotomy in the alveolar ridge. Then an appliance is screwed directly into the bone segments. The classic basic principles suggest an initial latency period of 5–7 days; the appliance is gradually activated to separate the bony segments at approximately 1 mm per day. The gradual tension placed on the distracting bony interface produces continuous bone formation, and the adjacent tissue expands and adapts to this gradual tension (histogenesis). A consolidation phase is needed for 3–4 months in order to allow bone regeneration. The distraction appliance is then removed, and implants are usually placed at the time of distractor removal [8] (Fig. 10.42).

Table 10.10 Distraction osteogenesis

Study	Success of the procedure	Resorption	Implant success	Implant survival	Time (months)	Gain
[96] SR			94.2 %	95.9 % (88–100 %)	6–72	
[194] SR				94.7 %	12–72	
[111] PS		0.3 mm (before implant placement) 1.3 mm (after 4 years)	94.7 %	100 %	41.3	5.3 mm (range 2–8 mm)
[44] CIR	98.4 % (96.7–100 %)		94.2 %	97 % (90.4–100 %)	6–60	3–15 mm
[169] SR				96.5 % ± 4.5 %	20 ± 22	
[206] SR			+90 %		More than 48	
[207] MPS			94.2 %	100 %	34 (15–55)	9.9 mm (4–15 mm)
[165] SR				90.4 %	36	6.5 mm (3–15 mm)

CIR clinical investigation review, *PS* prospective study, *SR* systematic review, *MPS* multicenter prospective study

The mean bone gain reported ranges from 3 to 15 mm, and the overall success rate of the procedure is reported to be in a range from 96.7 to 100 % [44, 96] (Table 10.10).

Implant survival rates reported ranges from 88 to 100 % after a period between 6 and 72 months after prosthetic rehabilitation, which are similar to implants placed in native bone [96, 133, 165]. The cumulative success rate of implants was reported as more than 90 % (Table 10.10). Data on implant success in distracted bone at 3–5 years postloading showed favorable results compared to other grafting approaches [165, 169] (Figs. 10.43, 10.44, 10.45, 10.46, and 10.47).

Bone resorption before implant placement was reported as 0.3 mm and 1.3 + −0.4 mm after 4 years postloading [133].

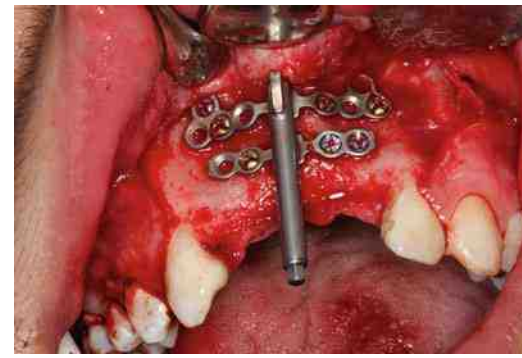

Fig. 10.43 Intraoral picture showing a distractor device placed in the anterior maxillary ridge (Courtesy of Dr. Cristina Garcías)

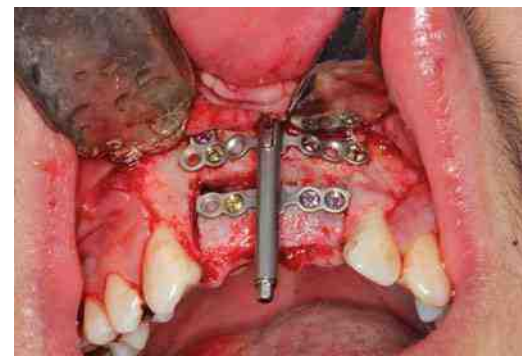

Fig. 10.44 Intraoral picture showing an activated distractor device placed in the anterior maxillary ridge with the osteotomy performed (Courtesy of Dr. Cristina Garcías)

Advantages, Disadvantages, and Complications

This technique presents a low postoperative morbidity because there is no need of bone harvesting. Another advantage is that the soft tissues overlying the distracted area also grow. Moreover, there is a low risk of infection of the surgical site.

However, this procedure has some limitations, bone gain may not be well controlled and an adequate thickness has to be present. Also, making a provisional prosthesis while the device is in use is very difficult or impossible, and after removing

the device, patients cannot wear any removable provisional prostheses for 2 months [133]. A second surgery is also needed to remove the distractor [112]. Other disadvantages include the need for daily activation, compromised speech, eating, and appearance.

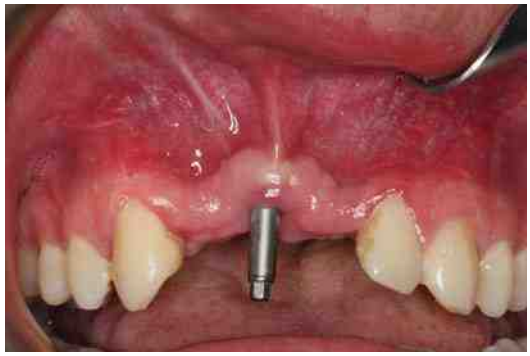

Fig. 10.45 Intraoral picture showing the intraoral device placed in the anterior maxilla and the soft tissue covering it (Courtesy of Dr. Cristina Garcías)

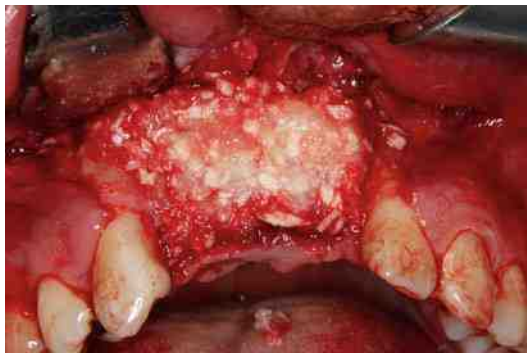

Fig. 10.46 Intraoral picture showing the distraction following after the distractor device was removed. Particulate graft was placed over the defect to augment the ridge horizontally (Courtesy of Dr. Cristina Garcías)

Smaller ridge defects of one or two teeth in width were associated with higher rates of complications in different studies when treated with the distraction technique; for this reason, it is recommended for an edentulous ridge span of at least three missing teeth [8, 169].

Complications include fracture of the moveable segment, increase in patient discomfort during activation of the device, damage to basal bone (2.7 %), incorrect direction of the distraction leading to excessive bone on the lingual aspect (8.3–35.4 %), resorption of the moveable segment (7.7 %), inadequate bone formation (2, 2 %), fracture of the distraction device (1.6 %), and transient paresthesia in the innervation area of the mandibular nerve (1.6 %). Total failure of the procedure was reported in only 1.1 % of the cases [96, 112, 165].

Histologic results seem to demonstrate that distraction osteogenesis allows formation of adequate quality and quantity of bone tissue, which can provide primary stability of implants and favorably withstand the biomechanical demands of loaded implants.

Survival and success rates of implants placed in distracted areas are consistent with those reported in the literature for implants placed in native intact bone [96].

The majority of authors reported some relapse of initial bone gain before implant placement,

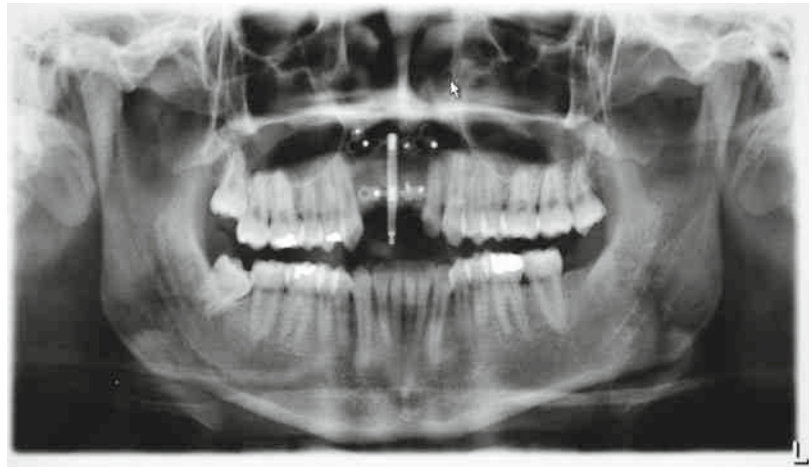

Fig. 10.47 Panoramic x-ray showing the distractor device placed in the anterior maxilla (Courtesy of Dr. Cristina Garcías)

Table 10.11 Le Fort I osteotomy and inlay bone grafts

Study	Graft	Success of the procedure	Resorption	Implant success	Implant survival	Time (months)	Stage
[44] CIR	LeFort (with inlay iliac)	95.8 %		82.9–91 %	87.7 % (67–95 %)	6–140	
[44] CIR	Inlay mandible (from iliac)	98 %	10–15 % at the time of implant placement	95 %	90–95 %	12–84	
[57] SR	LeFort				89 % (60–96.1 %)	12–108	
[96] SR	LeFort	99.5 %		82.9–91 %	88.5 % (range 79–95 %)		One
[96] SR	LeFort	99.5 %		82.9–91 %	90.9 % (range 66.7–95 %)		Two
[121] PCT	Inlay			90 %	100 %	18 (17–22)	

CIR clinical investigation review, *PCT* prospective controlled trial, *SR* systematic review

due to marginal bone loss of the most coronal part of the distracted segment. Therefore, an overcorrection was suggested. However, crestal bone changes around implants after the start of prosthetic loading seem to be similar to those occurring in cases of implants placed in native nonreconstructed bones [96].

10.4.4 Interpositional Bone Grafts: LeFort I Osteotomy and Inlay Bone Grafts

Interpositional bone grafts (also known as sandwich grafts) are mainly performed for reconstructing vertical defects. The osteotomized bone segment is secured in its final position.

Big differences exist between augmenting the mandible or maxilla with interpositional grafts (inlay) and performing a LeFort I osteotomy in the maxilla.

10.4.4.1 LeFort I

The overall complication rate of this surgical procedure was reported to be 3.1 % (range of 0–10 %). The most common complications include wound dehiscences (3–4 %), postoperative sinusitis (3 %), partial graft loss (3 %), and midpalatal fracture (2 %) [96].

Reported success rates of the grafting procedure range from 95.8 to 99.5 % [96].

Different studies reported implant survival rates in a range from 60 to 96.1 % (Table 10.11). Also more implants were lost when placed at the same time of the osteotomy (6.96 %) than when placed in two stages (4.62 %) [96]. Few publications reported implant success rates according to well-defined criteria in a range of 82.9–91 % [96]. Implant survival rates, although lower, can be compared with those of implants placed in native maxillary bone.

None of the publications reviewed proposed immediate loading of implants placed in the reconstructed maxillae [96].

The analysis of the available publications demonstrated an average poor methodological quality with regard to the completeness of follow-up and success criteria of implants. Despite these limits, some conclusions can be drawn.

LeFort I osteotomy in association with interpositional bone grafts and immediate or delayed implant placement is a reliable and demanding procedure that should be limited to severe maxillary atrophy cases which are associated with an unfavorable intermaxillary relationship. In these cases, onlay grafting, although it could create an adequate scenario for implant placement, may not be enough to achieve a correct intermaxillary relationship [44, 57, 96] (Figs. 10.48 and 10.49).

10.4.4.2 Inlay

When compared with the onlay technique, the inlay technique is associated with lower bone resorption values (10.2–14.2 % at 4 months postsurgery) [121] and produces more predictable outcomes, but requires an experienced surgeon.

However, once implant placement is performed, the outcomes are similar for both graft procedures (Fig. 10.50) (Table 10.12).

The most common reported complications include dehiscences (10–20 %) and neural disturbances in cases of posterior mandible. Up to 40 % of the patients reported altered sensation in the lip during the first weeks after surgery [121].

For inlay grafting in the mandible, the overall survival rate of implants ranged from 90 to 95 %, while the success rate of implants (95 %) was reported only in one article [44].

The inlay technique provides superior bone graft incorporation than the onlay method by assuring blood supply by the cranially displaced segment [121] (Fig. 10.51).

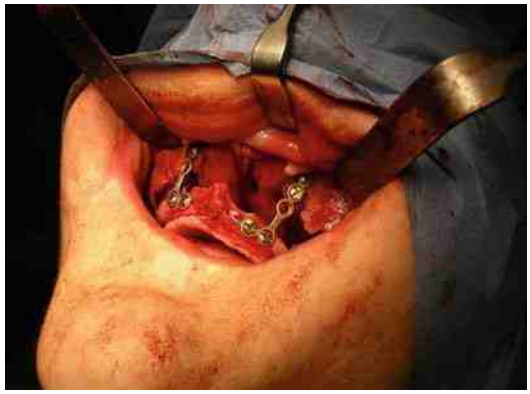

Fig. 10.48 Intraoral picture showing a LeFort I osteotomy (Reprinted from van der Mark et al. [215]. Copyright (2011), with permission from Elsevier)

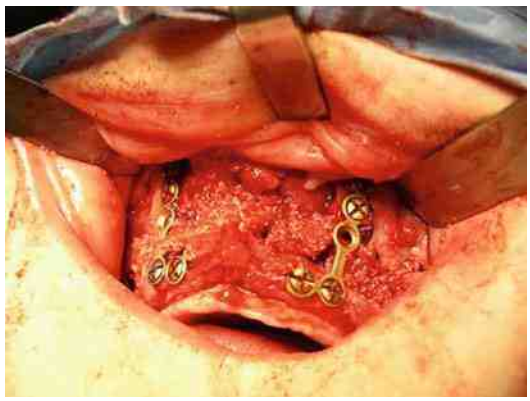

Fig. 10.49 Intraoral picture showing a LeFort I osteotomy with inlay particulate graft placed (Reprinted from van der Mark et al. [215]. Copyright (2011), with permission from Elsevier)

10.4.5 Sinus Augmentation Procedures

The edentulous posterior maxilla is often a challenging site for implant placement because of

Fig. 10.50 3D image representing a vertical osteotomy in the mandible with an interpositional inlay graft (Copyright © Dr. Pardiñas López)

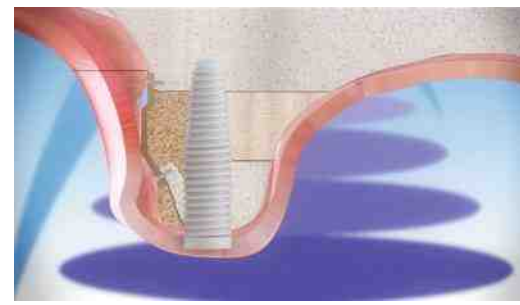

Fig. 10.51 3D image representing a vertical osteotomy with an inlay particulate graft secured in placed by mean of titanium plates and immediate implant placement (Copyright © Dr. Pardiñas López)

Table 10.12 Onlay versus inlay technique

[121]	Vertical bone gain	Resorption of the graft	Periimplant bone resorption	Implant survival	Implant success
Inlay	4.1 mm (2.7–6.3 mm) at time of implant placement	0.5 mm (0.10–2.9 mm) at 4 months post graft	0.9 mm (0.3–1.8 mm) at 18 months (range 17–22)	100 %	90 %
Onlay	4 mm (2–4.9 mm) at time of implant placement	2.7 mm (1.3–4.7 mm) at 4 months post graft	0.85 mm (0.2–2.8 mm) at 17.5 months (range 13–22)	100 %	86.9 %

atrophy of the alveolar ridge, poor bone quality, and increased pneumatization of the maxillary sinus [24].

The maxillary sinus augmentation procedure, initially published by Boyne and James [170] and described by Tatum [28], was introduced to restore this anatomic deficiency, placing graft material between the sinus membrane and the residual alveolar ridge. Since then, sinus augmentation procedure has been shown to be a predictable technique to increase available bone height in deficient posterior maxillary ridges prior to implant placement. Various approaches have been proposed in order to achieve the necessary bone dimensions for the insertion of implants in the atrophic posterior maxilla [24, 171].

The lateral wall sinus augmentation approach is considered as one of the most versatile preprosthetic surgical techniques. Recent systematic literature reviews have demonstrated that the sinus augmentation procedure is well documented with an overall implant survival rate well beyond 90 %. Evidence-based reviews have reported positive outcomes using different graft materials for maxillary sinus augmentation, such as autogenous bone, allografts, xenograft, alloplasts, and combinations of these graft materials [24, 171] (Figs. 10.52, 10.53, 10.54, and 10.55).

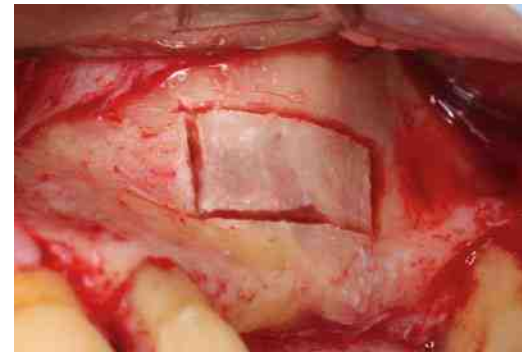

Fig. 10.52 Intraoral picture showing the lateral wall osteotomy performed with a piezoelectric unit

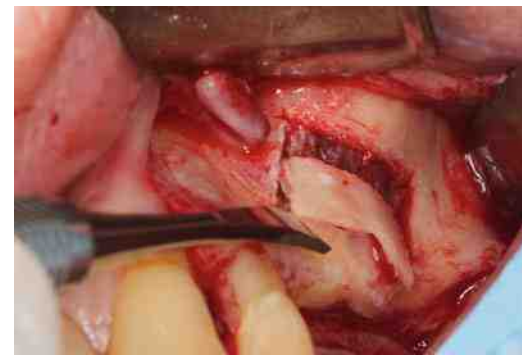

Fig. 10.53 Intraoral picture showing the lateral wall osteotomy

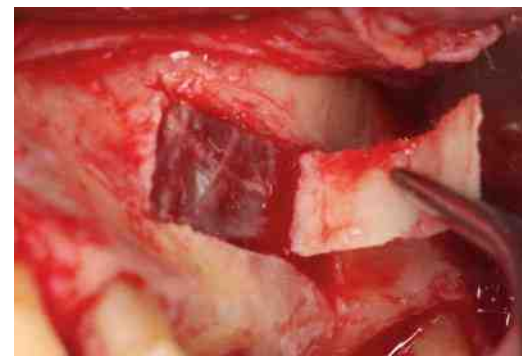

Fig. 10.54 Intraoral picture showing the lateral wall osteotomy

10.4.5.1 Lateral Approach

It is important to mention that results of the analyzed studies must be reviewed with caution, as many variables influence the outcomes, such as type of implant (machined vs. rough), residual crestal bone, immediate vs. delayed, use of membranes, and type of grafting material.

Overall, survival rates of implants were reported in a range from 52.5 to 100 % in the analyzed studies, with the majority of articles reporting values higher than 90 %, which is comparable and even higher to implants placed in native bone in the posterior maxilla with poor quality of bone, but adequate quantity for implant placement [172, 173]. Success rates of implants according to well-defined criteria range from 74.7 to 100 % [96], although few studies reported information on this (Fig. 10.56).

The most statistically significative parameters related to implant survival are the preoperative residual crestal bone, the implant surface (machined or rough), and the use of block grafts.

Regarding the type of material, no statistical differences were found between different bone grafts in implant survival rates except block

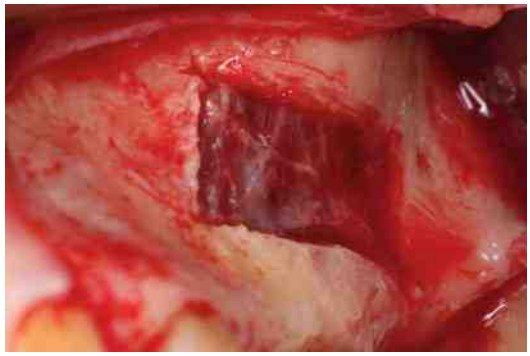

Fig. 10.55 Intraoral picture showing the lateral wall osteotomy without the lateral bone block. Branches of the posterior superior alveolar artery can be observed in contact to the Schneiderian membrane

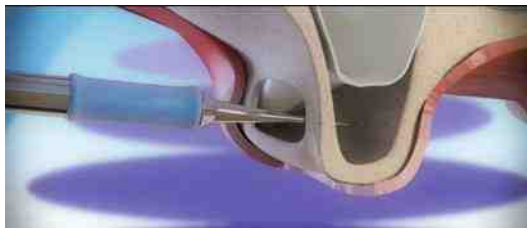

Fig. 10.56 3D image representing the elevation of the Schneiderian membrane through a lateral approach (Copyright © Dr. Pardiñas López)

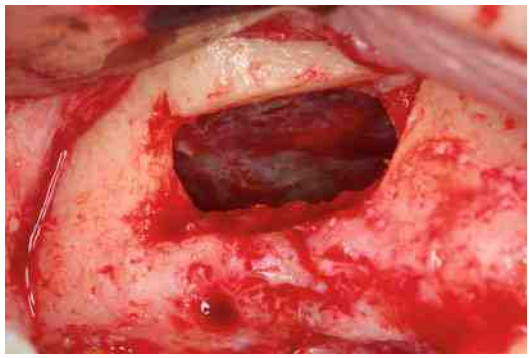

Fig. 10.57 Intraoral picture showing the lateral wall osteotomy

grafts. Block grafts seem to reduce the survival rate of implants compared to particulate autografts, although resorption is higher in autologous particles than in block particles (Table 10.1). But again, comparison of survival rates is difficult because of the many variables existing [52] (Figs. 10.57, 10.58, 10.59, and 10.60).

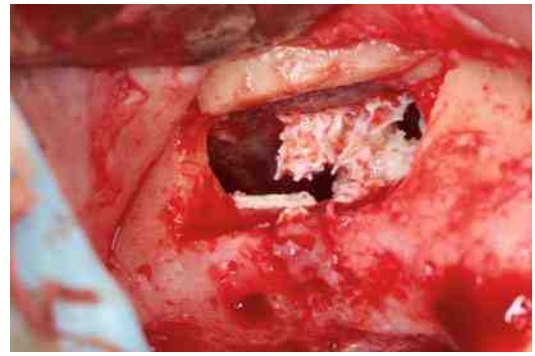

Fig. 10.58 Intraoral picture showing the lateral wall osteotomy with ABBM particle graft

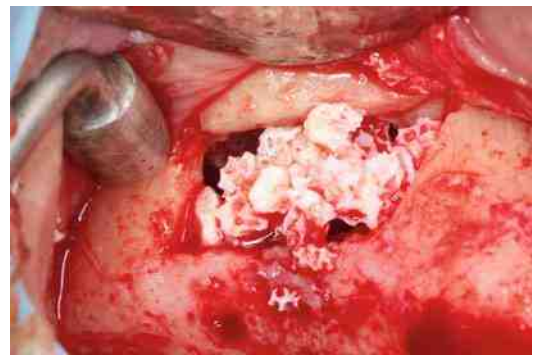

Fig. 10.59 Intraoral picture showing the lateral wall osteotomy with ABBM particle graft filling the sinus

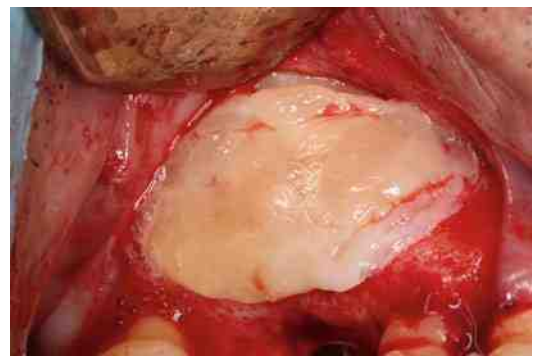

Fig. 10.60 Intraoral picture showing the lateral wall osteotomy covered by a PRGF membrane

In one meta-analysis of the volume changes after maxillary sinus augmentation, the weighted mean average resorption was 48 ± 23 % when calculated for controlled studies, and a wide variation in graft resorption was observed between individuals [58].

As far as the timing of implant placement is concerned, different studies show no statistically significant difference in the survival rate of implants placed in simultaneously or delayed. Rates were reported to be 61.2 % to 100 % (mean 95 %) for the simultaneous implants and 72.7–100 % (mean 93.7 %) in the case of a staged approach (Table 10.1) [49]. However another study reported that delayed implant placement had a 2–3-fold higher hazard risk of implant failure in comparison with simultaneous implant placement (HR = 2.37, 95 % CI 1.02–5.50) [171].

Moreover, some authors demonstrated that the survival of implants placed at the time of sinus augmentation using the lateral window approach is increased with crestal ridge heights >3 mm [8, 44, 96, 174]. In one study, a 55 % reduction in hazard risk of failure was observed comparing 3–4- to <3-mm residual crest and an 86 % reduction comparing ≥5- to <3-mm residual crest [171].

Although it is impossible to determine a clear indication, the majority of authors agree in suggesting immediate implant placement when the residual alveolar bone presents adequate quality and quantity to allow primary stability of implants [96] (Figs. 10.61 and 10.62).

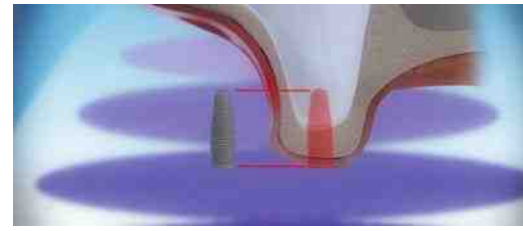

Fig. 10.61 3D image representing a pneumatized maxillary sinus without enough height to place an implant (Copyright © Dr. Pardiñas López)

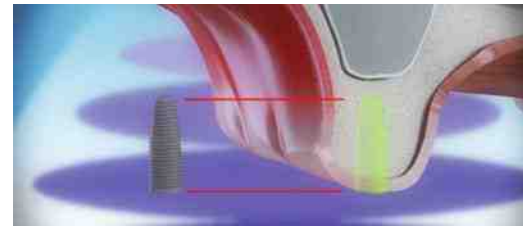

Fig. 10.62 3D image representing a graft maxillary sinus and the augmented bone needed for a proper implant insertion (Copyright © Dr. Pardiñas López)

Immediate Loading

Immediate loading in the posterior maxilla following sinus augmentation procedure is particularly controversial. Few studies have been published on immediate loading in the posterior maxilla, due to the low bone density, reduced bone volumes, and risk for low primary stability [171, 175]. However, some authors have suggested that immediate loading is applicable for implants placed in previously augmented sites with high implant survival rates (100 % in 13–24 months of postloading follow-up) [171, 176, 177]. They suggest that early functional loading could positively influence the rapidity of bone mineralization also during the early modeling phase of new bone formation [177].

However, another study reported a reduced implant survival with the immediate loaded implants. Implants that were immediately loaded had a 4–6-fold higher hazard risk of implant failure than those with delayed loading [171] (Fig. 10.63).

Use of Membranes

The placement of resorbable or nonresorbable barrier membranes over the lateral sinus window and graft material is reported to have a positive effect in terms of implant survival and new bone formation [8, 96] (Fig. 10.64).

Different studies reported implant survival rates ranging from 93.1 to 100 % when membranes were used and a survival of 78.1–96.3 % when no membrane was used [40, 49, 51]. However, it was shown in a systematic review that when smooth implants and iliac blocks were not considered (which reduce implant survival rates), the survival rates with and without the use of a barrier membrane were almost identical [40]. When the percentage of vital bone was analyzed, one study showed that results were higher when a membrane was placed over the window [51]. However, one meta-analysis indicated that there was no evidence whether the

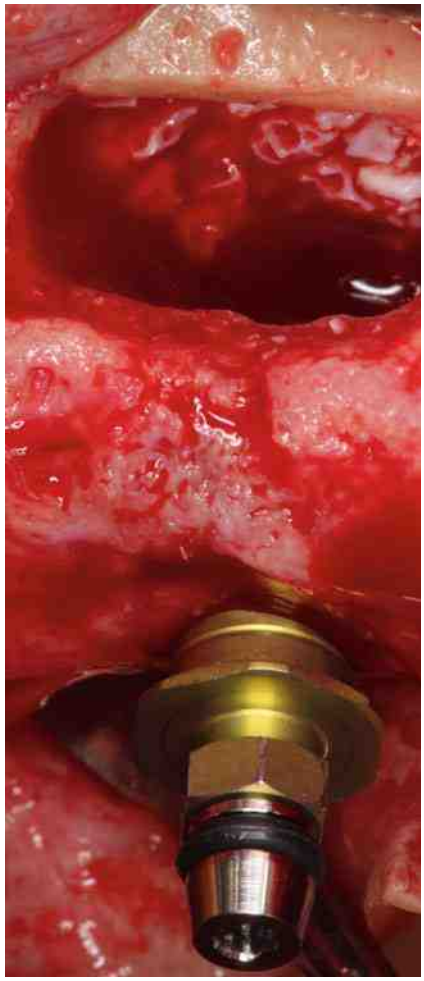

Fig. 10.63 Intraoral picture of a grafted sinus through a lateral wall approach with an immediate implant placed

Fig. 10.64 3D image representing a grafted maxillary sinus and a resorbable membrane that is going to be placed over the lateral wall osteotomy (Copyright © Dr. Pardiñas López)

use of a resorbable membrane over the lateral window would have a positive or negative effect on the amount of total bone volume [47] (Fig. 10.65).

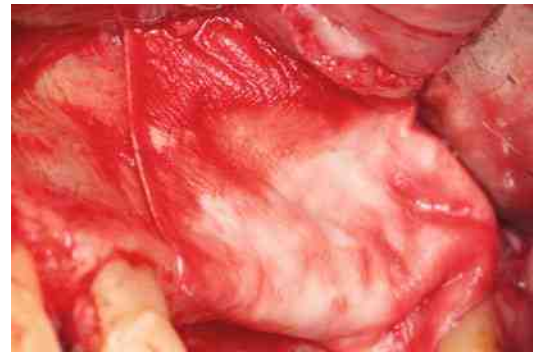

Fig. 10.65 Intraoral picture of a resorbable membrane placed over a lateral wall osteotomy

Table 10.13 Schneiderian membrane perforation

Study	Perforation %
[208]	11
[49]	19.5
[96]	10 (range 4.8–58)
[44]	10 (range 4.8–40)
[188]	25.7
[186]	19.5–41
[182]	37
[180]	44
[181]	25
[14]	19.2 ± 10.8
[171]	5.3
[209]	8.6
[210]	59.8

Advantages, Disadvantages, and Complications

Although the sinus augmentation surgery is a predictable treatment, it also carries some risks.

Complications include infection, bleeding, cyst formation, membrane perforations, ridge resorption, sinusitis, and wound dehiscence, among others [8].

The most frequent reported intraoperative complication is Schneiderian membrane perforation, which is reported to be in a range of 4.8–58 % (Table 10.13) (Fig. 10.66).

Controversy exists regarding the implant success rate and perforation of the Schneiderian membrane. Some studies suggest a lower success rate (70 % perforated vs. 100 % nonperforated) when the membrane is perforated (and repaired) [178, 179]. However, other studies show no statistically significant differences in

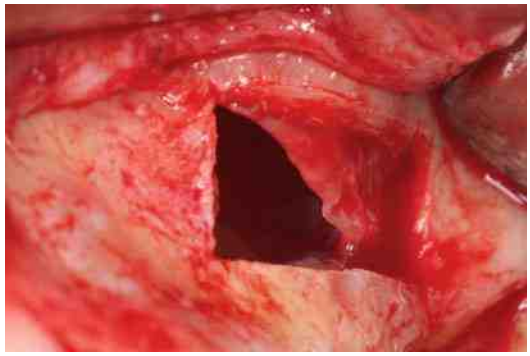

Fig. 10.66 Intraoral picture of a perforation of the Schneiderian membrane

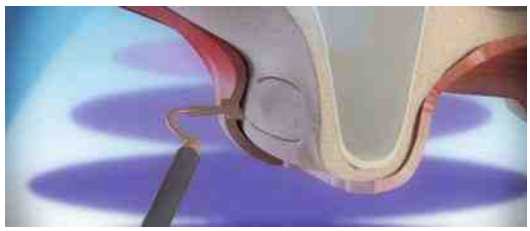

Fig. 10.67 3D image representing a lateral wall osteotomy using a piezoelectric unit (Copyright © Dr. Pardiñas López)

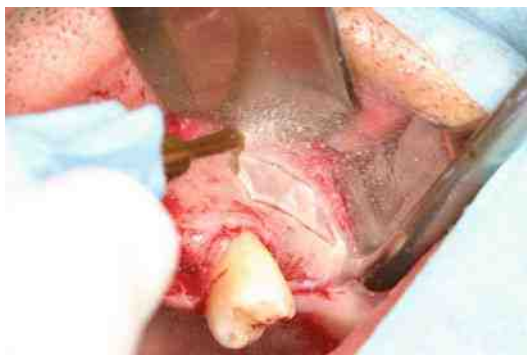

Fig. 10.68 Intraoral picture of a lateral wall osteotomy using a piezoelectric unit

implant survival in the nonperforated versus perforated sinus [180–182].

When a piezoelectric surgical device is used, the incidence of perforation is reported to be lower, 3.6–17.5 % [183–185] (Figs. 10.67, 10.68, and 10.69).

Another important intraoperative complication that can occur is an excessive bleeding due to the trauma to the intraosseous branches of

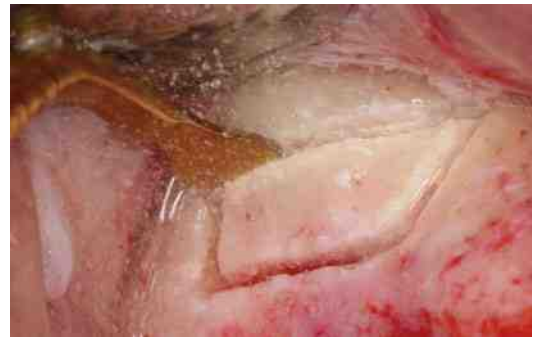

Fig. 10.69 Intraoral picture of a lateral wall osteotomy using a piezoelectric unit

the posterior superior alveolar artery, which can be occasionally encountered during the lateral window procedure in 2 % of the cases [186]. To prevent this, preoperative CT scan evaluations to detect the path of the artery should be performed [187].

The most common reported postoperative complications are sinusitis (2.5 %, ranging from 0 to 27 %) [44, 96, 180] and wound infection (2.9 %, ranging from 0 to 7.4 %) [40, 49, 181], followed by exposures and total or partial loss of the graft (less than 1.9 %) [44, 49, 96, 188].

Also some studies suggest that a history of sinusitis may be related to higher complication rates [171, 188].

The type of graft (particulate vs. block) is suggested to be related as more prone to total or partial loss of the graft, which is considered a postoperative complication [40, 51, 96, 173].

10.4.5.2 Transalveolar

Implant survival rates are reported in a range from 83 to 100 % with the majority of articles reporting values higher than 92 % (Table 10.1), while success rates are reported to be 93.5–97.8 % after a mean of 36 months after prosthetic loading (range 6–93 months) (Table 10.1) (Fig. 10.70).

The survival rate of implants placed in conjunction with the augmentation procedure is reported to show no statistical differences in comparison to implants placed in a staged approach [44].

Also the available data did not demonstrate significant differences in survival rates of implants according to different grafting materials [44].

Maxillary sinus floor elevation using the transalveolar approach may be a valid and less invasive supplement to the lateral window technique. A prerequisite for using this technique is that primary implant stability can be achieved [40].

One systematic review showed that implant survival rates were more than 96 and 85.7 % with pretreatment bone heights of ≥5 mm and 3 to 4 mm, respectively [172].

The average measured bone gain was 2.9–3.25 mm (range 2–7 mm) [172].

Membrane perforations are reported to be low, and most of them occurred when the membrane was lifted more than 5 mm [172]. Some authors recommend an endoscopic control when the sinus membrane is lifted >3 mm [172].

Sinus grafting is now considered a safe and well-documented procedure to prepare an environment in which dental implants may have an excellent prognosis [52]. Different sinus elevation techniques do not seem to affect the implant success rates [172].

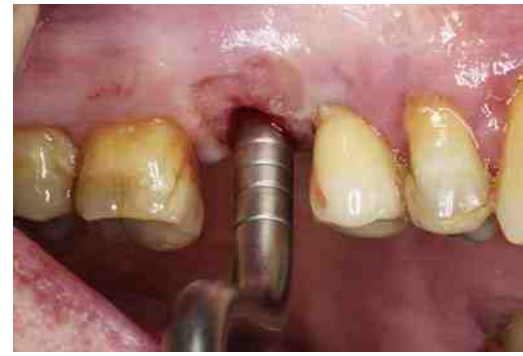

Fig. 10.70 Intraoral picture showing an osteotome used for performing a transalveolar sinus lift (Reprinted from Patel et al. [216]. Copyright (2015), with permission from Elsevier)

Fig. 10.71 3D image representing a socket preservation technique using particulate bone graft (Copyright © Dr. Pardiñas López)

Fig. 10.72 3D image representing a socket preservation technique using particulate bone graft and a resorbable membrane (Copyright © Dr. Pardiñas López)

10.4.6 Socket Preservation

Preclinical and clinical studies have demonstrated that after a tooth extraction, the socket and alveolar ridge suffer a physiological healing process that results in a reduction of its dimension [65], as previously described in Chap. 4.

Therefore, socket preservation techniques have been proposed with the objective of maintaining the hard and soft tissue dimensions after a tooth is extracted, which is particularly important in cases of anterior aesthetic and posterior implant placement, in order to have the best bone and soft tissue availability for achieving a successful final treatment [65, 66, 189] (Fig. 10.71).

If a tooth is nonrestorable and extraction is needed, simultaneous preservation of the socket using different bone materials can help in the maintenance of alveolar height and width [190].

It is evident that, regardless of the surgical procedures and biomaterials used, socket preservation techniques minimized the amount of postextraction bone loss [62, 66, 191] (Fig. 10.72).

Some studies reported an implant survival rate ranging from 90.3 to 100 % after 6–144 months, which is consistent with implant survival rates placed in native bone [192] (Table 10.14). There is no evidence to support the fact that implant placement survival is increased following socket preservation procedures in comparison with unassisted socket healing. The survival, success,

Table 10.14 Socket preservation

Study	Resorption	Implant success (%)	Implant survival (%)	Time (months)
[194] SR			90.3	6–144
[192] SR			98.4 (97.3–99)	Mean 25
[192] SR			97.5 (95.2–98.8)	48
[193] SR		95.2–100	95–100	12
[66] SR	−2.48 to + 1.3 mm (vertical), +3.25 to −2.50 (horizontal)			3
[191] SR	−0.58 (−4.76 to +1.30) (vertical), −0.36 (−3.48 to +3.27) (horizontal)			

SR systematic review

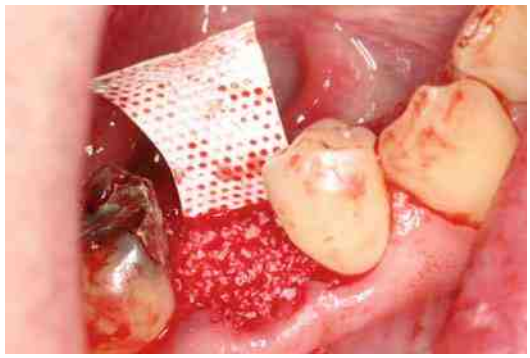

Fig. 10.73 Intraoral picture showing a socket preservation technique using particulate allograft and a nonresorbable membrane

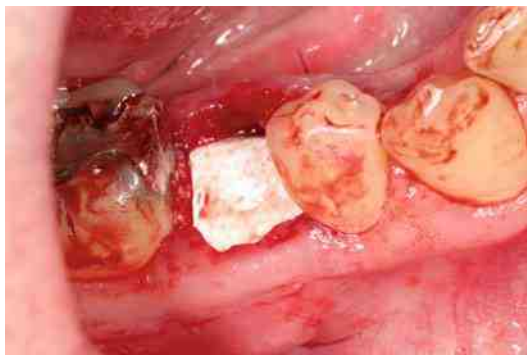

Fig. 10.74 Intraoral picture showing a socket preservation technique using particulate allograft and a nonresorbable membrane

and marginal bone levels of implants placed in alveolar ridges following socket preservation procedures are comparable to that of implants placed in untreated sockets [193]. Therefore, the positive influence of the socket preservation therapy may be attributed more to achieving enhanced

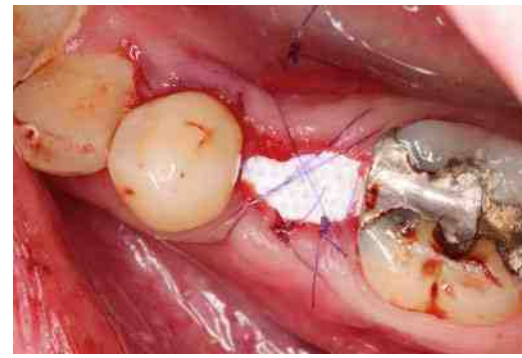

Fig. 10.75 Intraoral picture showing a socket preservation technique using particulate allograft and a nonresorbable membrane

restorative and aesthetic outcomes, as well as better maintenance of healthy periimplant soft tissues [66].

Different studies showed that immediate implant placement had a failure rate of less than 5 %, which is comparable to delayed placement [8]. However, one systematic review suggested that the insertion of dental implants in fresh extraction sockets affects the implant failure rates (4.75 % in fresh socket and 1.59 % in healed sockets) [189].

Also, the immediate placement of implants into fresh extraction sockets in conjunction with bone augmentation has shown comparable success to that observed in delayed implant placement [8].

No high-level evidence was found in the literature regarding contraindications specific for ridge preservation and if socket preservation requires primary closure [62, 63] (Figs. 10.73, 10.74, 10.75, 10.76, 10.77, 10.78, 10.79, and 10.80).

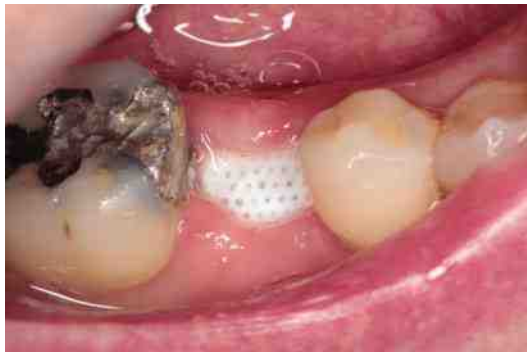

Fig. 10.76 Intraoral picture showing the healing of a preserved socket after 2 weeks

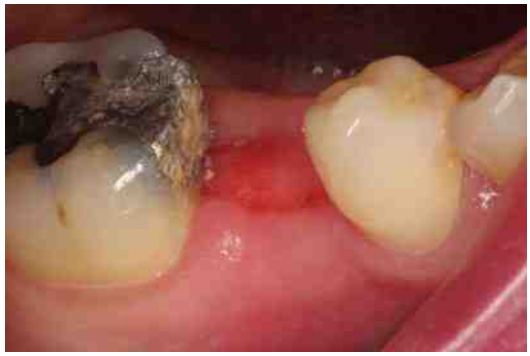

Fig. 10.77 Intraoral picture showing the healing of a preserved socket 1 week after membrane removal

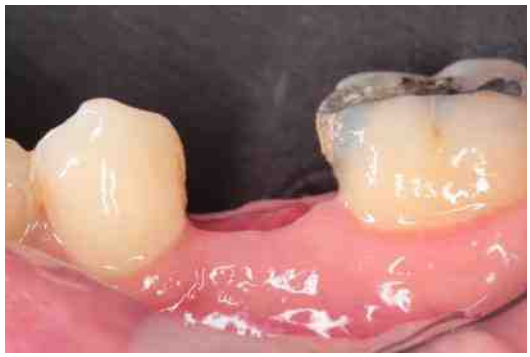

Fig. 10.78 Intraoral picture showing the healing of a preserved socket 1 week after membrane removal

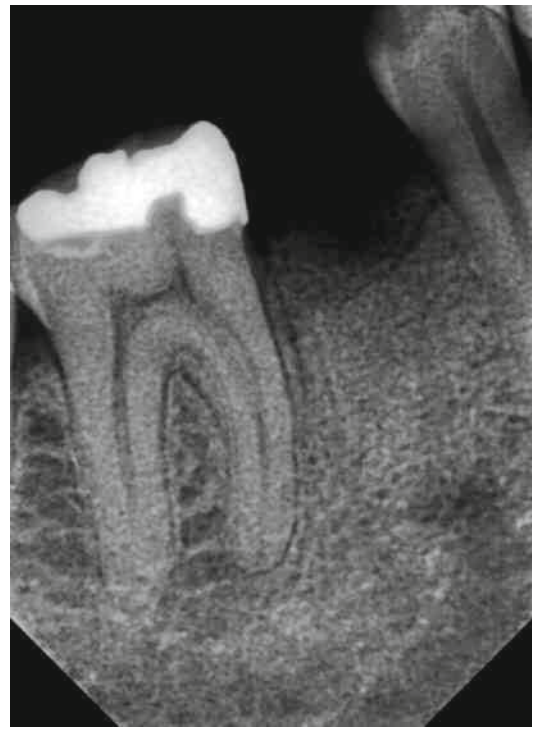

Fig. 10.79 Periapical radiograph taken immediately after socket preservation procedure

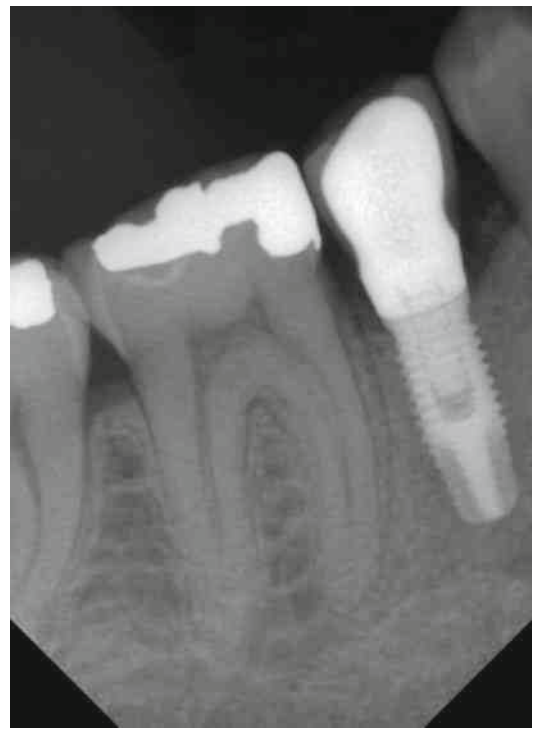

Fig. 10.80 Periapical radiograph taken immediately after implant loading after 5 months

Conclusion table (only including systematic reviews, retrospective studies, prospective studies, randomized studies, and meta-analysis)

Type of treatment	Implant survival rate mean/range	Implant success rate[a]	Bone gain (mm) (at 6 months in autogenous)	Graft resorption	Complications (%)
Autogenous onlay bone graft Ramus Chin Iliac Calvarial	91.5 (60–100) 97.9 (93–100) 95.8 (92.3–100) 85.5 (60–100) 95.9 (86–100)	90.3 (72.8–100)[a] 92.5 (89.5–95) 95.4 (90.7–100) 83 (72.8–95.6) 93.3 (90.3–97.6)[a]	---------- ---------- Horizontal and vertical 4.4 ---------- ---------- ---------- ----------	0–60 % 0–42 % 0–42 % 12–60 % 0–15 %	24+ 10.6 (0–37.5) 32 (10–80) 21.8 (1–63.6)[b] 16.2 (0–57.7)[c]
Allograft block	92.8–99	86.9–90.0	2–3.5 vertical 3.92–4.79 horizontal	10 ± 10 % to 52 ± 25.97 % (6 months)	2–8.5
Guided bone regeneration	93.7 (76.8–100)	87.5 (61.5–100)	5.12 (2–7)	1.82 mm (0.3–2.9 mm)	Up to 50 exposure
Alveolar split	96 (86–100)	92.3 (86.2–97.5)	3.5–4.03	0.35 to 4.7 mm	Up to 22
Distraction osteogenesis	96.4 (88–100)	93.5 (90–94.7)	7.9 (2–15)	1.3 mm (4 years)	1.6–35.4
LeFort I	89 (60–96.1)	82.9–91	–	–	3.1 (0–10)
Inlay	95 (90–100)	90–95	4.1 (2.7–6.3)	10–15 %	10–40[d]
Sinus lift	92.6 (52.5–100)[e]	92.4 (74.7–100)	–	–	4.5–58 (perforation) 0–27 (others)
Socket preservation	96.2 (90.3–100)	95.2–100	–	−0.6 mm (−4.76 to +1.30 vertical) +0.39 mm (−3.48 to +3.27) horizontal	–

These percentages should be evaluated with caution because some publications in which different donor sites were used did not separate implant failures according to donor site distribution. Also these percentages represent a mean of the data extracted from the studies reviewed

[a]Limited number compared with survivals

[b]Mean 35 % including pain (up to >90 % if pain persisting more than 1 month is included)

[c]Up to 86 % if skull depression is considered. No differences between materials, mandible or maxilla, and membrane/no membrane. Big ranging on follow-up from minimum of 6 months

[d]Up to 40 % in cases of posterior mandible neural disturbances

[e]No difference between graft type, implant surface, lateral, or osteotome technique

Conclusions

Many techniques exist for effective bone augmentation. The approach largely is dependent on the extent of the defect and specific procedures to be performed for the implant reconstruction. It is most appropriate to use an evidenced-based approach when a treatment plan is being developed for bone augmentation cases [8]. The capacity of bone grafts to restore original bone volume varies, and the results reported in the literature are contradictory due to differences in observation periods, type and site of reconstruction, timing of implant loading, and, last but not least, site of bone harvesting [133].

A second concern is the adequate adaptation, stabilization, and vascularization of the bone graft, which are critical for graft success [133].

In this chapter, when analyzing the effect of bone grafting materials, specific commercially

available bone substitutes have not been assessed. The clinician should be critical and evaluate the available studies in the scientific literature regarding the effectiveness of the product that he/she would use. Doing that, the clinician should ask for randomized clinical trials.

Oversized grafts should be harvested to maintain enough graft volume after the initial resorption phase. If autogenous bone grafts are used, it is highly suggested to use corticocancellous bone blocks. Cancellous bone alone or particulate bone, if not associated with membranes of titanium meshes, does not provide sufficient rigidity to withstand tension from the overlying soft tissues or from the compression by provisional removable dentures and may undergo partial or complete resorption [44].

More surgical challenges arise from vertical augmentations, which can be particularly difficult to reconstruct due to soft tissue collapse over the graft if the space is not maintained; thus, short implants may be a feasible option [108, 113].

Although autogenous bone has been considered the gold standard in the past, more recent studies have shown that vertical and horizontal augmentation can be successfully performed with allogeneic and xenogeneic grafts when properly protected with the appropriate membrane. In this sense, by eliminating the need for a second surgical site to harvest the graft, the morbidy is significantly reduced. Extraoral harvesting sites are related with an increased morbidity and prolonged treatment times in comparison to intraoral harvesting sites [201]. Moreover, the use of growth factors can enhance the success of grafts and provide a faster soft tissue healing [113].

Survival and success rates of implants placed in horizontally and vertically resorbed edentulous ridges reconstructed with block bone grafts are similar to those of implants placed in native bone, in grafted sockets, in distracted sites, in grafted sinus, or with guided bone regeneration [108].

Other surgical options such as LeFort I osteotomy with interpositional bone grafts and microvascular free flaps present even more morbidity and should be limited to extreme atrophy or severe intermaxillary discrepancy not susceptible to be treated with onlay grafts [44].

In conclusion, the clinician should have the enough knowledge and evidence-based data in order to choose the most appropriate technique and materials. The practitioner should also have the capacity to analyze the patient needs and expectations and be aware of his/her skill limitations, being able to develop a comprehensive treatment plan in order to provide the patient with the most proper solution.

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Peri-implantitis

11

Oreste Iocca and Giuseppe Bianco

Abstract

Peri-implant inflammatory conditions are not unfrequent in the implant population. Clinicians should be aware of the definition and diagnostic criteria of mucositis and peri-implantitis in order to adopt prompt interventions in order to save the implant.

The etiology of peri-implant diseases has many aspects in common with periodontitis, although some etiologic aspects are peculiar to the first one. Microbiological factors, inflammation, smoking, diabetes, and genetic factors are all considered risk factors for the development of mucositis and peri-implantitis.

The term cement-related peri-implant disease has been coined by some authors, referring to the peri-implant pathology arising around cement-retained implant restorations. It is possible that cement remnants have a role in the incidence of many cases of peri-implantitis.

Diagnosis of mucositis and peri-implantitis relies on clinical and radiological signs.

The management of mucositis is always nonsurgical. The treatment of peri-implantitis can involve nonsurgical or surgical options. Comparison of various treatment modalities is not easy mainly due to the lack of direct treatment comparisons. The use of network meta-analysis as a statistical tool for indirect treatment comparison may help to understand which are the best treatments available.

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11.1 Peri-implantitis

11.1.1 Definition and Epidemiology of Peri-implant Disease

Peri-implant inflammatory conditions, according to the seventh European Workshop on Periodontology [1], can be subdivided in this way:

Mucositis: An inflammatory reaction to the peri-implant plaque, characterized by bleeding on probing but without signs of peri-implant bone loss

Peri-implantitis: Inflammation extending to the supporting peri-implant tissues and characterized by clinical and radiographical signs of bone loss

Patient-based prevalence of these two conditions was analyzed by Derks and Tomasi [2]; in their study, an assessment of the literature was performed extracting data from cross-sectional studies and one RCT.

The prevalence of mucositis reported in the meta-analysis as *weighted mean value* was 42.9 % (95 % CI 32–54); the prevalence of peri-implantitis was 21.7 %(95 % CI 14–30).

Extent and severity of the conditions were poorly or inconsistently reported; therefore, the figures should be interpreted with some caution, but they can be considered a good approximation of the actual prevalence.

Atieh et al. [3] in a similar analysis estimated the prevalence of mucositis to be 63.4 % (95 % CI 59.8–67.1) and prevalence of peri-implantitis to be 18.8 % (95 % CI 16.8–20.8). When a subgroup analysis was performed, patients with a history of periodontitis were found to have an incidence of peri-implantitis of 21.1 % (95 % CI 14.5–27.8).

It is worth mentioning that not all the studies adhere to the above-defined diagnostic criteria of mucositis and peri-implantitis [4].

Mucositis has been diagnosed with just the presence of blood on probing (which is the European Workshop Criteria for diagnosis), but different studies considered for diagnosis probing depth values and gingival index scores.

Peri-implantitis diagnostic criteria also suffer of some heterogeneity in the literature. Variable probing depths have been proposed as a threshold to make diagnosis, ranging from at least 4 mm in some study to 6 mm in others. Moreover, the majority of the studies consider radiographic evaluation indispensable in order to make a definitive diagnosis of peri-implantitis, but in some other studies, this is not considered important.

Given this relative heterogeneity, it is possible that what is considered mucositis in one study may reenter in the classification of peri-implantitis in one other. Also, the small samples, the variation in follow-up time, and selection of patients in the various studies are all factors that may lead to incorrect estimation of the true prevalence of peri-implant disease.

Anyway, clinicians should be aware that these are problems commonly occurring in the implant practice. A focus on prevention with careful case selection and patient education is of the utmost importance in order to avoid their occurrence (Fig. 11.1). Once peri-implantitis becomes manifested, knowledge of possible therapy option and prognosis should lead to an appropriate treatment plan.

11.1.2 Etiology of Peri-implant Disease

11.1.2.1 Microbiological Factors

It has been considered reasonable that the peri-implant disease share similarities with periodontal pathology. Periodontitis, like peri-implantitis, is a multifactorial disease characterized by an imbalance in the equilibrium between the oral microflora and the host immunity system, which ultimately results in a destructive inflammatory process.

The microenvironment in the periodontal/peri-implant sulcus favors the selection of specific bacterial colonies that are considered key pathogens in triggering the inflammatory reaction leading to pathology (Fig. 11.2) [5].

In the first month after implant placement, colonization of the subgingival environment by the different species is similar to that of a natural tooth, i.e., Gram-positive cocci and bacilli.

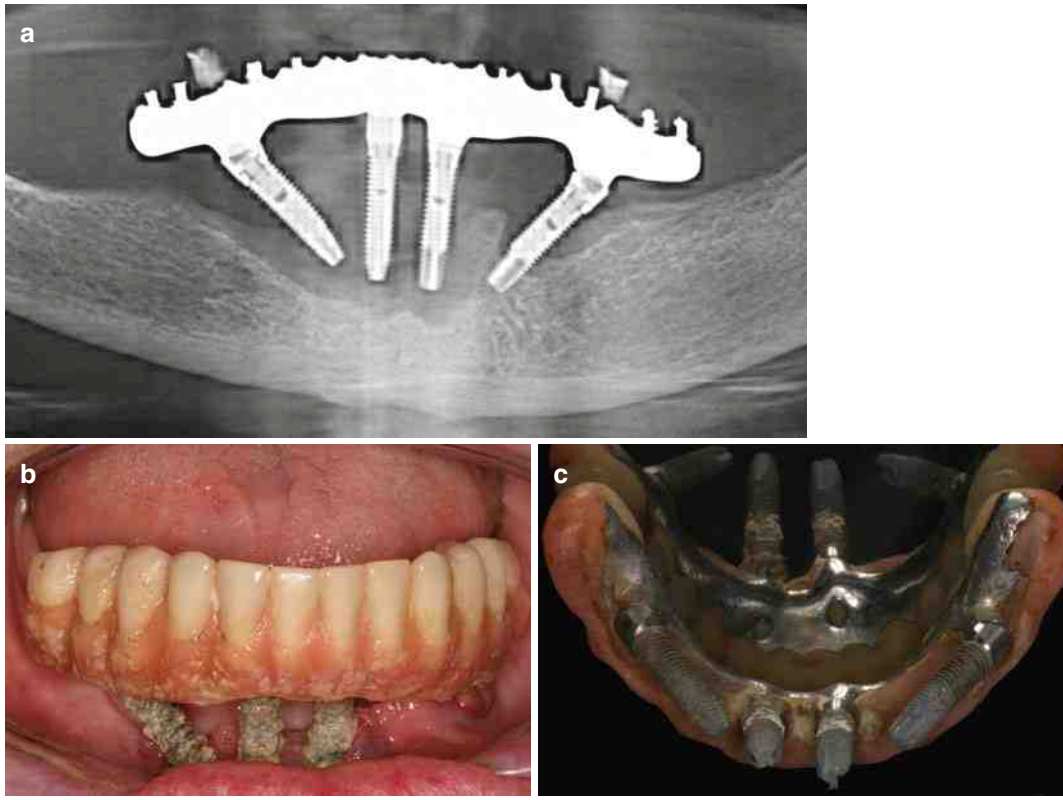

Fig. 11.1 (**a–c**) Peri-implantitis affecting the mandibular implants, implant removal is necessary in this case. Calculus is evident around the implants and prosthesis

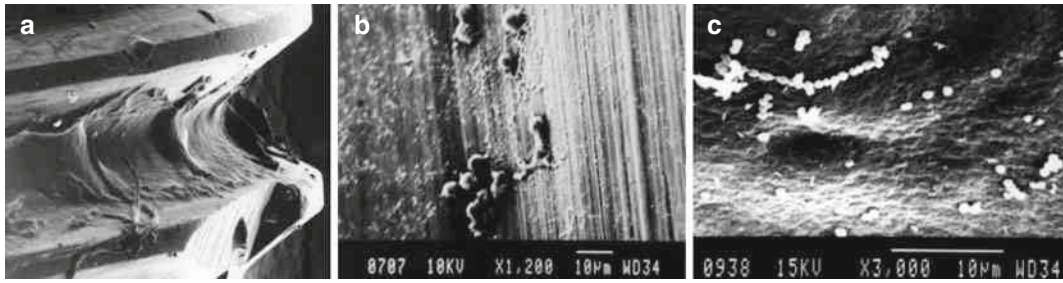

Fig. 11.2 Bacteria proliferating on a contaminated implant surface at various degree of magnification (**a–c**) (Reproduced with permission from Mouhyi et al.)

Switching to a more characteristic periodontitis-associated microflora has been found in case of peri-implantitis as well. In particular, specific Gram-negative anaerobic bacteria have been ascertained in many studies, using sequences of the 16S rRNA gene for identification of bacterial species. The species common to periodontitis and peri-implantitis include *Aggregatibacter actinomycetemcomitans (AA), Porphyromonas gingivalis (Pg), Tannerella forsythia (Tf)*, *Prevotella nigrescens (Pn), Prevotella intermedia (Pi), Treponema denticola (Td), and Fusobacterium nucleatum (Fn).*

Some authors suggest the presence of different bacterial species than those traditionally associated with periodontitis [6]. In detail,

Staphylococcus aureus has been suggested to have particular affinity for titanium and was frequently found in deep peri-implant pockets, together with *Pseudomonas aeruginosa* and *Bacteroides spp*.

de Waal et al. [7] reviewed the reporting of the microbiota around implants in *fully* and *partially edentulous* patients in order to find any difference between the two conditions. In the majority of the analyzed studies, it was found that in *partially edentulous* patients, a potentially more pathogenic peri-implant microflora was harbored compared to the *fully edentulous*. This is reasonable if we consider that some bacterial species found their ideal habitat only around a tooth.

In both fully and partially dentate patients, it was found that AA, Pg, and Tf were detected much more frequently around implants affected by peri-implantitis.

The potential of using specific bacterial markers as a tool in evaluating the prognosis of peri-implantitis remains controversial. Firstly, because the presence of the putative periodontal pathogens is considered to be an eliciting factor in peri-implantitis pathogenesis, but it is not the only factor. In consequence, the detection of these bacteria, by itself, cannot indicate the future loss or failure of dental implants. Various sampling and analysis methods are available (PCR, culture, DNA, and RNA analysis), but it is not clear which one may have a role in clinical practice.

11.1.2.2 Inflammation

Host response is considered another key element in the pathogenesis of peri-implant disease. The inflammatory reaction elicited by the biofilm has been studied in many animal and human studies. The major way by which the immune system reacts to microbial pathogens is with the accumulation of leukocytes, plasma proteins, and fluid from the vascular tissue [8].

Cytokines are key molecules in the orchestration and clinical manifestations of inflammation. The major pro-inflammatory cytokines are tumor necrosis factor (TNF), interleukin-1 (IL-1), and interleukin-6 (IL-6).

IL-1α and *IL-1β* isoforms have been strongly associated with osteoclast activation and downregulation of type 1 collagen in bone, thus contributing to the characteristic bone resorption of conclamated peri-implantitis. Immunohistochemical studies have evidenced an increased staining of IL-1α in peri-implantitis tissue specimens, whereas in periodontitis, TNF-α was more prevalent.

Different cell types are involved in the inflammatory reaction; *dendritic cells* play an important role in recognition of the resident flora and moderation in the mounting of the immune response. When dendritic cell homeostasis is disrupted, they present the antigens to B and T cells. In addition to dendritic cells, macrophages and B-lymphocytes perform important antigen-presenting function which can sustain T-cell activation and further production of cytokines.

Different classes of T cells are involved in peri-implant inflammation, CD4+ or T-helper, CD8+ or cytotoxic T cells, regulatory T cell, and γδ; each one has some specific and some overlapping function. Moreover, natural killer (NK) cells, macrophages, and neutrophils play an important role in tissue destruction.

As the inflammation is not properly regulated in periodontitis and peri-implantitis, the tissue destruction phase is mediated mainly by neutrophils and macrophages. Metalloproteinases are collagenases that have the physiological function of "creating space" for cells directed to the site of insult. But when inflammation does not resolve, these molecules will end to pathologically destroy the peri-implant tissues. Bone cells are then involved in this phase, in particular osteoclasts and osteoblasts. RANK-ligand, a member of the TNF superfamily produced by the osteoblasts, binds to osteoprotegerin (OPG) on the surface of the osteoclasts which are in this way activated and start the bone resorption process.

Complex interconnection between all these factors are in play during the course of peri-implantitis, and the role of each one is a matter of research [9]. What is clear is that in susceptible individuals, excessive cytokines and metalloproteinases lead to a damage extended to soft and hard tissues. Failure of resolving the inflammatory response is characterized by a chronicization

of these processes. Finally, a vicious circle ensues, in which healing processes are accompanied by chronic inflammation and formation of granulation tissue that creates an ideal environment for the same bacteria that started the process. At the end, as the destruction progresses and peri-implant pockets deepen, a more anaerobic environment develops favoring again the harboring of the periodontal/peri-implant pathogens.

Role of Inflammatory Markers in Clinical Practice

It has been suggested that cytokine analysis in the peri-implant crevicular fluid (PICF) may serve as a marker in order to identify peri-implantitis in latent, early, or conclamated state [10].

IL-1β and *TNF-α* have been proposed as suitable biochemical markers because of their elevated concentration in PICF of affected sites.

A systematic review and meta-analysis attempted to answer if PICF may have a role in the diagnosis of peri-implantitis (Table 11.1) [11]. Cross-sectional and interventional studies were included; the most studied cytokine were *IL-1β* followed by *TNF-α*, IL10, and IL-8.

The authors evidenced a huge variability in the techniques used for PICF collection and in general a great heterogeneity between the studies. That being said, evaluation of cytokine levels in healthy subjects versus subjects affected by mucositis/peri-implantitis, expressed as mean difference of *IL-1β* and *TNF-α*, was performed. The results are shown in the table.

A significant increase in *IL-1β* release in mucositis/peri-implantitis patients was evidenced compared to the healthy. The same was confirmed for *TNF-α* levels.

These results led to the conclusion that *IL-1β* and *TNF-α* levels assessed in the PICF may be a valuable diagnostic/preventive tool for patients in which the risk of peri-implantitis is considered high or when diagnosis is still unclear. This was considered of great importance given that no differences were outlined for early and later stages of disease, therefore stressing the importance of an early and aggressive approach in the treatment of disease.

Shortcomings of the analysis evidenced by the authors were that, in the included studies, the reports did not include the sensitivity of the ELISA's tests employed or the correct kit name. Secondly, the cytokine expression should be evaluated at multiple time points during the course of disease, but this was not possible because these were cross-sectional studies reporting a *single-moment* fluid collection. Thirdly, it was recalled that focusing on just two or three cytokines may lead to not consider other unstudied inflammatory molecules which may have a great impact in the development of peri-implantitis.

Table 11.1 *Meta-analysis* evaluating the inflammatory profile of healthy subjects, mucositis, and peri-implantitis

	Studies included	Groups of comparison	Effect size MD in pg/ml (95 % CI)	Increased in	Statistically significant
Faot et al. (2015)	*Cross-sectional and interventional studies*				
Subgroup 1		*Healthy* versus *mucositis IL-1β release*	278.79 (99.52–458.06)	Mucositis	*YES (P value 0.002)*
Subgroup 2		*Mucositis* versus *peri-implantitis IL-1β release*	–27.76 (–247.86 to 192.23)	Mucositis	*NO (P value 0.80)*
Subgroup 3		*Healthy* versus *peri-implantitis IL-1β release*	175.83 (70.33–281.33)	Peri-implantitis	*YES (P value 0.001)*
Subgroup 4		*Healthy* versus *peri-implantitis TNF-α release*	61.60 (8.66–114.55)	Peri-implantitis	*YES (p value 0.02)*

In conclusion, raised levels of specific cytokines in the PICF of implant patients can be employed as a diagnostic tool for early detection/follow-up of peri-implantitis patients. Before incorporating these techniques in everyday clinical practice, it should be important to standardize the methods of collection and analysis of the crevicular fluid samples, and more long-term studies should elucidate the real impact on the prognosis of the implants undergoing these tests.

11.1.2.3 Smoking

Smoking of cigarettes is an established risk factor for the development of periodontitis, and it is totally reasonable that the same is valid for peri-implantitis. However, it is still not established if a true correlation exists between peri-implantitis and smoking habits.

It has been shown [12] that smoking reduces significantly the diversity of peri-implant *microbiome*, leading to a shift toward a preponderant presence of microbes traditionally considered pathogenic.

This narrowed *microbiome* becomes further reduced when mucositis is triggered; at this time, loss of several species is evident and just few, pathological, microorganisms survive in this altered niche.

In smokers, the depletion of the so-called core microbiome (the population of bacteria present in most of the study population) is evident already in the healthy state; this can be considered an additional risk factor in respect to nonsmokers.

Smoking has also been found to impair the normal immune response, resulting in elevated white blood cells and granulocyte count which may contribute to triggering or aggravating the peri-implantitis. Cigarette smoke has also been associated with an upregulation of the receptor for the advanced glycation end products (RAGE) whose interaction with its ligands elicits a strong inflammatory reaction.

Nicotine, in particular, has been found to stimulate the production of IL-6 and IL-8, negatively regulate the expression of the extracellular matrix and osteoblastic transcription factor genes, and inhibit the epithelial cell growth [13].

Beyond the molecular and microbiological evidence, when clinical studies are evaluated, controversial results emerge. Some studies seem to show a correlation between smoking habits, and others fail to do so.

In the review of Renvert and Quirynen [14], only two out of five prospective clinical trials included in the analysis revealed a statistically significant difference between smokers and nonsmokers. For this reason, the authors concluded that the available information on the risk of smoking associated with peri-implantitis development, albeit plausible, needs further research to be demonstrated.

A meta-analysis [15] tried to clarify this point analyzing prospective studies. Patient-based analysis did not show a significant difference between the smokers and nonsmokers. On the other hand, the implant-based analysis evidenced a higher risk of peri-implantitis for smokers. These results may be explained by the fact that a small number of studies were included and the study did not allow to reach enough statistical power for patient-based evaluation. In light of these limitations, the authors did not arrive at definitive conclusions, and no clinical recommendations could be extrapolated.

In conclusion, in vitro studies seem to show that smoking may be a risk factor for the development of peri-implantitis in the implant population, especially for the stimulus in the production of inflammatory molecules and for the narrowing of the core microbiome.

On the other hand, clinical studies show controversial results in this regard. And although smoking should be discouraged for every implant patient, evidence-based information does not allow to draw strong conclusions on this topic.

11.1.2.4 Genetics

Given the importance of cytokines in development of peri-implantitis, polymorphism of the genes that control the production of these molecules has been investigated as potential risk factors. It is possible that the host genetic susceptibility may be related to increased incidence of peri-implantitis in some individuals. From a clinical perspective, genetic tests may

potentially lead to the possibility of predicting which patients are predisposed to biological complications, even though practical applications of genetic testing are still not fully clear.

In detail, the most studied genes are those controlling *IL-1A, IL-1B, IL-6,* and *TNF-α* [16].

A meta-analysis [17] attempted to evaluate the association between a variety of IL-1 polymorphisms (IL-1A, IL1-B and IL-1RN) and implant failure.

Authors find a significant association between the T allele of IL-1B and increased risk of implant failure/loss (OR 1.28 95%CI 1.01–1.62). Also, the genetic variants IL-1A (−889) and IL1B (+3954) composite genotypes were associated with an increased risk (OR 1.76 95% CI 1.21–2.57) while, if just one variant was present individually, this resulted in no risk difference. The authors pointed out that ethnicity was a source of heterogeneity, with European descents less prone to show an association of risk. Undoubtedly, more large cohort studies, especially stratifying populations with diverse ethnic background, are needed to clarify the association between specific genetic polymorphism and dental implant failure.

It is still premature to consider a clinical application of genetic testing for patients undergoing implant treatment, mainly because the available results do not allow to draw robust conclusions regarding the association of risk between specific genetic variants and implant failure/loss.

11.1.2.5 Diabetes Type 2

Diabetes has been linked to an increased incidence of periodontitis in affected individuals. For analogy, researchers investigated a link with peri-implantitis as well.

Diabetes type 2 is one of the leading causes of mortality and morbidity worldwide, and its incidence and prevalence are expected to rise greatly in the next decades. The impaired insulin action in type 2 diabetes leads to a hyperglycemic state that is considered the main cause of damage to tissues and organs characteristic of the disease. Glycated hemoglobin values (HbA1c) reflects the glycemic control of the past 2–3 months and for this reason can be used as a diagnostic/follow-up marker in diabetic patients.

Pathogenesis of diabetic complications is not fully clear, but the nonenzymatic formation of the so-called advanced glycation end products (AGE), formed when an excess of glucose is present, plays a huge role in tissue damage activating the abovementioned RAGE receptors and are a main cause of damage between the other factors.

While some research has been conducted evaluating the survival of implants in diabetics, only two studies are available specifically addressing the issue of peri-implantitis in the diabetic population.

Gomez-Moreno et al. [18] evaluated the peri-implant changes in a cohort of type 2 diabetes patients over a 3-year follow-up. The evolution of hard and soft tissues (probing depth, bleeding on probing, and MBL) was evaluated at 1, 2, and 3 years' time points. No significant difference was found for all the variables analyzed apart BOP values that seemed to significantly increase with higher values of HbA1c.

Cautiously, the authors suggested that implant therapy for diabetic patients can be a predictable treatment option provided that the patients have a good glycemic control over time.

The other study [19] focused on the pro-inflammatory gene expression at chronic periodontitis and peri-implantitis sites in patients with diabetes type II. It was found that the levels of TNF-α, CCR5, and CXCR3 were distinctive biomarkers of peri-implantitis, but in subjects affected by diabetes, these molecules were over-expressed together with IL-6 and IL-8 at a statistically significant level.

It is difficult, with the limited evidence available, to arrive at strong conclusions regarding the association of type 2 diabetes and the risk of developing peri-implantitis. Nevertheless, it is advisable that a patient undergoing any implant treatment is strictly controlled from a medically point of view in order to decrease the incidence of mucositis and peri-implantitis.

11.1.2.6 The Case of Cement-Related Peri-implant Disease

Cement-retained restorations are considered to contribute to substantial cases of peri-implantitis such that has been proposed the adoption of the

term "cement-related" peri-implant disease [20]. It is possible that excess cement left in the peri-implant space may favor the bacterial overgrowth and also contribute itself to an inflammatory reaction responsible of bone loss around the site (Fig. 11.3). Only retrospective and prospective cohort studies are available on this topic. Nevertheless, important information can be gained by analysis of the literature.

Wilson et al. [20] reported that 81 % of the implants restored with a cemented crown and with signs of peri-implantitis had extracoronal residual cement evident. Also, in affected patients, the first signs of peri-implantitis did not become apparent until 4 months up to 9.5 years after placement. Moreover, some patients were reported to be completely resistant to cement excess.

A retrospective case analysis of 129 implants [21] investigated if residual cement could be considered a cause of peri-implant disease. The authors analyzed implants with and without extracoronal cement excess. Additionally history of past periodontal disease was recorded.

It was found that 85 % of implants with cement remnants were affected by peri-implantitis; all implants with excess cement in patients with a positive history for periodontal disease developed peri-implantitis. Within the limitations of a study of this kind, the authors concluded that residual cement, especially in patients with a history of periodontal disease, can be associated with development of peri-implant disease.

Wilson et coll. [22] analyzed the foreign bodies from soft tissue biopsies, obtained during flap surgery, of implants with cement-retained restorations and affected by peri-implantitis.

The foreign bodies, found in 34 of 36 specimens analyzed, showed to be surrounded by chronic inflammatory infiltrates, dominated by plasma cells. The predominant composition of the foreign bodies was found to be Ti and dental cement. One hypothesis was that Ti was deposited due to friction at the moment of implant placement or due to the wear during the maintenance phases, a third possibility was that the particles were produced as a result of corrosion of the dental implant.

Regarding the cement remnants in the peri-implant space, they could have been introduced at the moment of cementation or during follow-up visits during attempts of removing the excess cement.

Also zirconium was found at SEM analysis; this can derive from zirconium dioxide that is added to dental cements as a radiopaque material or from the abutment when zirconia restorations were employed.

In conclusion, it seems clear that the use of cemented restorations can act as a independent risk factor for peri-implant disease. On the other hand, most is in the hand of the clinician who can act on controlling the amount of cement applied and also checking the presence of any extrusion in the peri-implant space. In order to do so, intraoral x-rays are performed before the patient leaves the

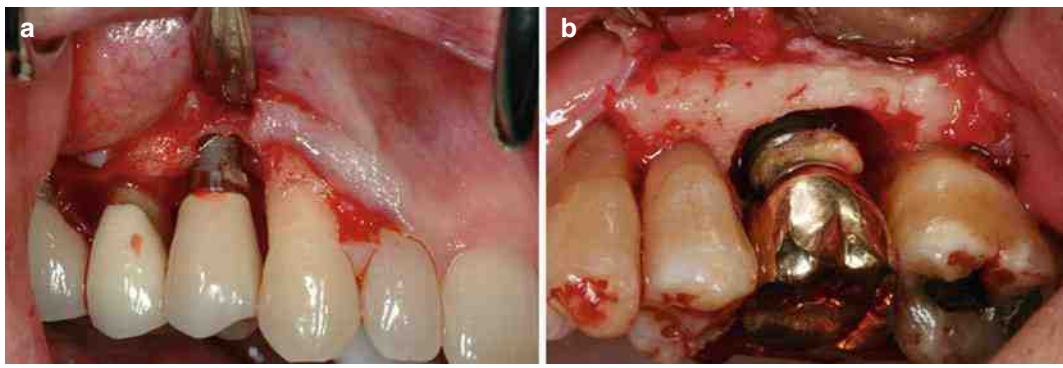

Fig. 11.3 (**a**, **b**) Cement excess in the peri-implant space was the cause of peri-implantitis (Reproduced with permission from Wadhwani et al.)

office because the sole visual inspection is not sufficient to detect any excess cement. Even the smallest amount of cement is removed carefully.

Finally, when cement excess is detected at follow-up visits already having caused some inflammatory reaction in the form of mucositis or peri-implantitis, nonsurgical or surgical removal can be attempted. Nonsurgical approach is feasible when the amount of cement to remove is clearly visible at an intraoral x-ray and accessible; in this way, hand instrument, ultrasonic devices, and copious irrigation with chlorhexidine should ensure the resolution of the inflammation. If access to the excess material is not possible with a closed approach, a flap surgery is mandatory and removal of cement, granulation tissue, and surface decontamination with chlorhexidine are performed (Fig. 11.4).

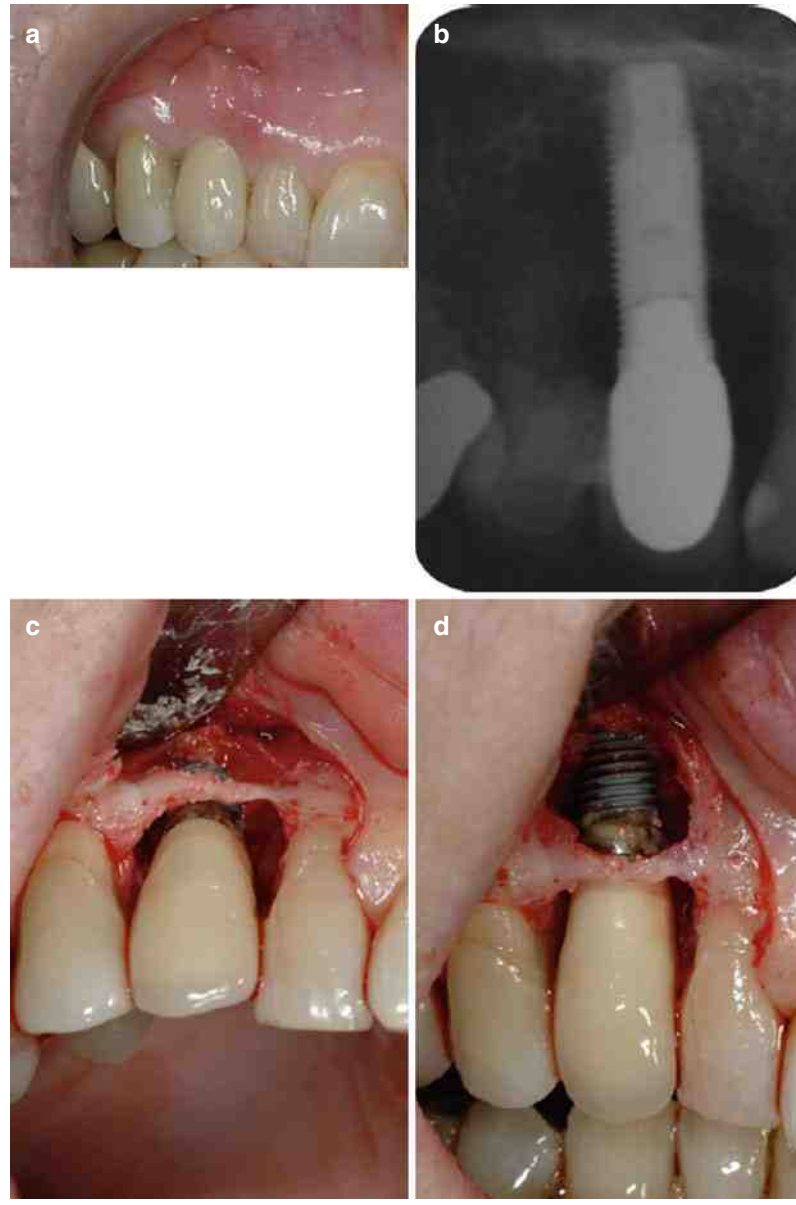

Fig. 11.4 Extensive lesion caused by cement excess left in place for 3 years (Reproduced with permission from Wadhwani et al.)

11.2 Diagnosis and Treatment of Peri-implant Disease

11.2.1 Diagnosis

The diagnosis of mucositis and peri-implantitis is important in order to adopt promptly those interventions that can arrest or slow the progression of the disease. The diagnostic criteria described in the seventh European Workshop on Periodontology can be considered reliable and simple to apply in clinical practice (Fig. 11.5).

A review assessed the ideal probing force to apply in order to avoid damage to the peri-implant tissues [23], and it was concluded that a force of 0.25 N could not cause a permanent damage to the tissues. How the clinician may caliber his probing force remains questionable, aside from the existence of probes with force indicator; a more general advice remains to probe the peri-implant sulcus very gently.

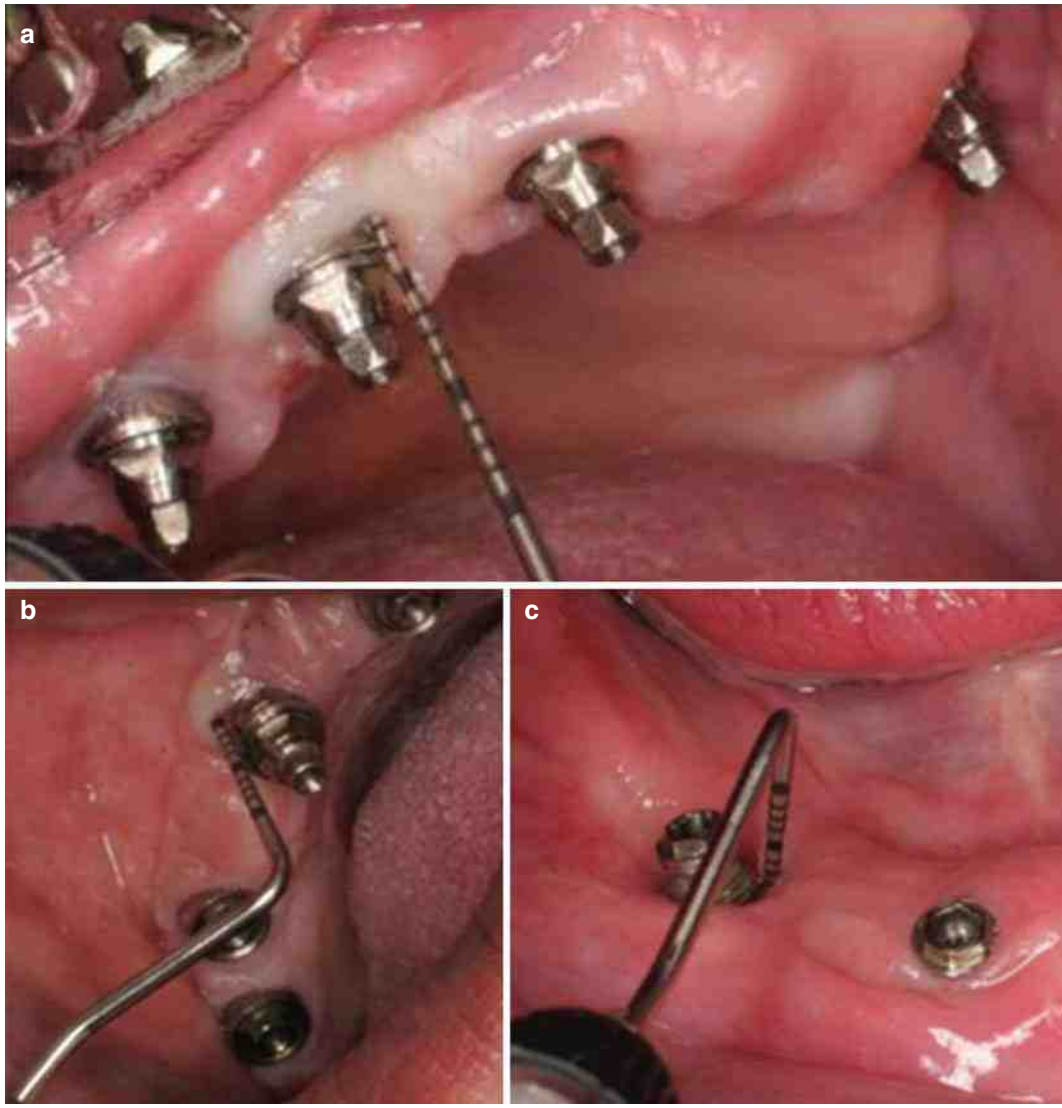

Fig. 11.5 (**a–c**) Healthy peri-implant tissues (**a**). Mucositis characterized by slight bleeding (**b**). Peri-implantitis diagnosed by signs of bone loss (**c**) (Reproduced with permission from Serino et al.)

Bleeding on probing (BOP) by itself is considered a sign of mucositis, i.e., inflammation without destruction of the tissues. *Clinical attachment level (CAL)* is difficult to determine due to the fact that an arbitrary reference point needs to be established; moreover, it depends by the initial positioning of the implant. In general, it is assumed that a *probing depth (PD)* up to 4–5 mm should not be considered pathological.

In summary, a diagnosis of peri-implantitis can be performed with the presence of bleeding on probing and a sulcus depth of ≥5 mm. The presence of pus is a clear sign of peri-implantitis as well.

Regarding the radiological signs, it is advisable that a patient suspected of having pathological peri-implant changes undergoes x-ray examination in order to detect the bone resorption radiographically. Intraoral radiography is a simple and reliable diagnostic tool, although the possibility of underestimating the MBL, and being a 2D examination, can miss an early bone loss.

Cone-beam computed tomography has gained popularity in the last years for the low dose of x-rays compared to the past and a great quality of the 3D image which allows to detect even the earliest manifestations of bone loss.

11.2.2 Management of Mucositis and Peri-implantitis

Once diagnosis is made clinically and radiographically, it is important to establish how the pathology should be treated. Different options include [25]:

- Nonsurgical therapy
- Surgical interventions
- Adjunctive treatments to nonsurgical or surgical intervention
- Implant removal

11.2.2.1 Debridement and Adjunctive Treatments

Nonsurgical option refers to the debridement of the supra- and subgingival space in order to remove the bacterial plaque and calculus which is the main cause of inflammation. This kind of treatment is mainly reserved to mucositis, while for conclamated peri-implantitis, surgical approach is usually needed.

Debridement can be performed with manual instruments (Fig. 11.6 and 11.7) or ultrasonic devices (Fig. 11.8) [26].

Curettes used for titanium implants should not be made of *steel*; in fact this material has a hardness higher than Ti. For this reason, they damage the implant surface with the risk of creating more roughness and irregularities ideal for biofilm formation.

Curettes manufactured in Ti are safe from this point of view and should not lead to damage of the implant surface.

Carbon fiber, *Teflon,* and *plastic* curettes, although safer because much softer than Ti, are prone to rupturing and also possess a reduced debriding capacity compared with the titanium ones.

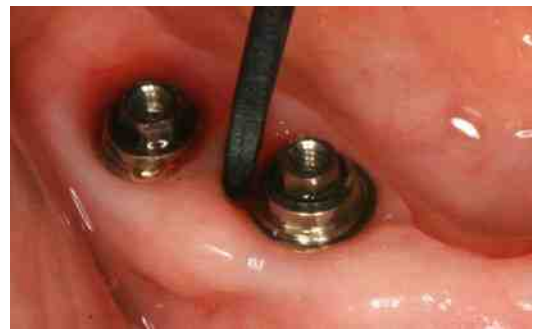

Fig. 11.6 Plastic curette (Reproduced with permission from Figuero et al.)

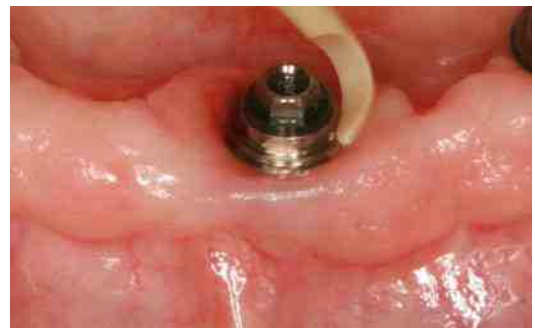

Fig. 11.7 Carbon fiber curette (Reproduced with permission from Figuero et al.)

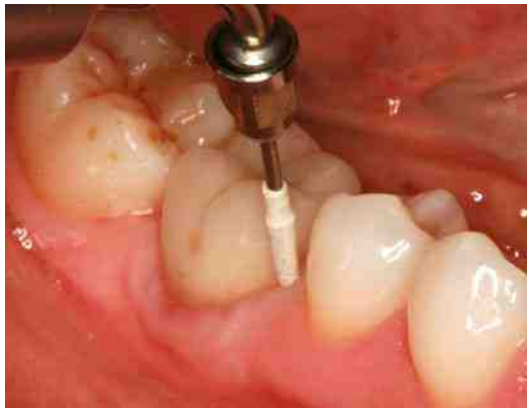

Fig. 11.8 Ultrasonic tip covered by PEEK (Reproduced with permission from Figuero et al.)

Ultrasonic tips covered in PEEK are ideal for use on Ti surfaces; they allow a debridement with less effort from the side of the dentist and with less discomfort for the patient. Their efficacy is similar to the manual instruments.

Laser has also been considered for surface decontamination, specifically, erbium:yttrium-aluminum-garnet (Er: YAG) and CO_2. Both types of lasers seem to not increase significantly the temperature of the implant during the procedure, therefore avoiding the risk of necrosis of the surrounding healthy bone. Additionally, from in vitro studies emerged a potential bactericidal effect against pathogenic bacteria.

Air-abrasive devices, which are based on a powered air-abrasive system of sodium carbonate, seem to damage hard and soft tissues. A device based on glycine powder seems to act more gently.

Adjunctive treatments with the aim of increasing the antibacterial effect of debridement include [27]:

- Locally applied antibiotics such as tetracycline in impregnated fibers which are removed after 10 days or chips that gradually resorbs by themselves.
- Chlorhexidine 0.12 % or 0.20 % irrigations once daily for 3 months after debridement
- Chlorhexidine 0.12 % rinses once daily for 3 months
- Mixed topical application of 0.1 % chlorhexidine gel after debridement followed by daily rinses of chlorhexidine 0.2 % for 2 weeks
- Full course of systemic antibiotics such as metronidazole or azithromycin after debridement

11.2.2.2 Surgical Treatment

Regarding surgical therapy for peri-implantitis, various techniques have been proposed [28]:

- Simple access flaps for cleaning and decontamination
- Apically repositioned flap
- Access flap and regenerative procedures

Access flap surgery has the same objectives that were traditionally established for periodontal surgical treatment, i.e., removal of the granulation tissue, mechanical debridement, and implant surface decontamination and polishing. The incision is usually intrasulcular and aimed at visualizing the exposed implant threads up to the healthy bone level (Fig. 11.9). Curettes made in Ti may be used for surface decontamination. At this point, one of the previously described topical adjunctive measures can be adopted, and eventually the flap is repositioned around the implant neck and sutured.

Some authors [35] prefer to polish the Ti surface completely in order to eliminate as much as possible the irregularities which can favor further bacterial colonization.

Apically repositioned flap can be used instead when deep peri-implant pockets are present, so to allow the patient to perform better self-hygiene procedures. Additionally, a repositioned flap in theory should allow to avoid the recurrence of the disease, because profound pockets would serve as an ideal environment for pathogenic bacteria.

Usually, after raising the flap, an osteoplasty is performed in order to reduce the depth of the pocket, the implant surface is treated with curettes for decontamination, and finally the flap is repositioned apically and sutured. Shortcomings of this approach include the fact that bone reduction would lead to an exposure of the implant threads; therefore, it cannot be applied in esthetic areas.

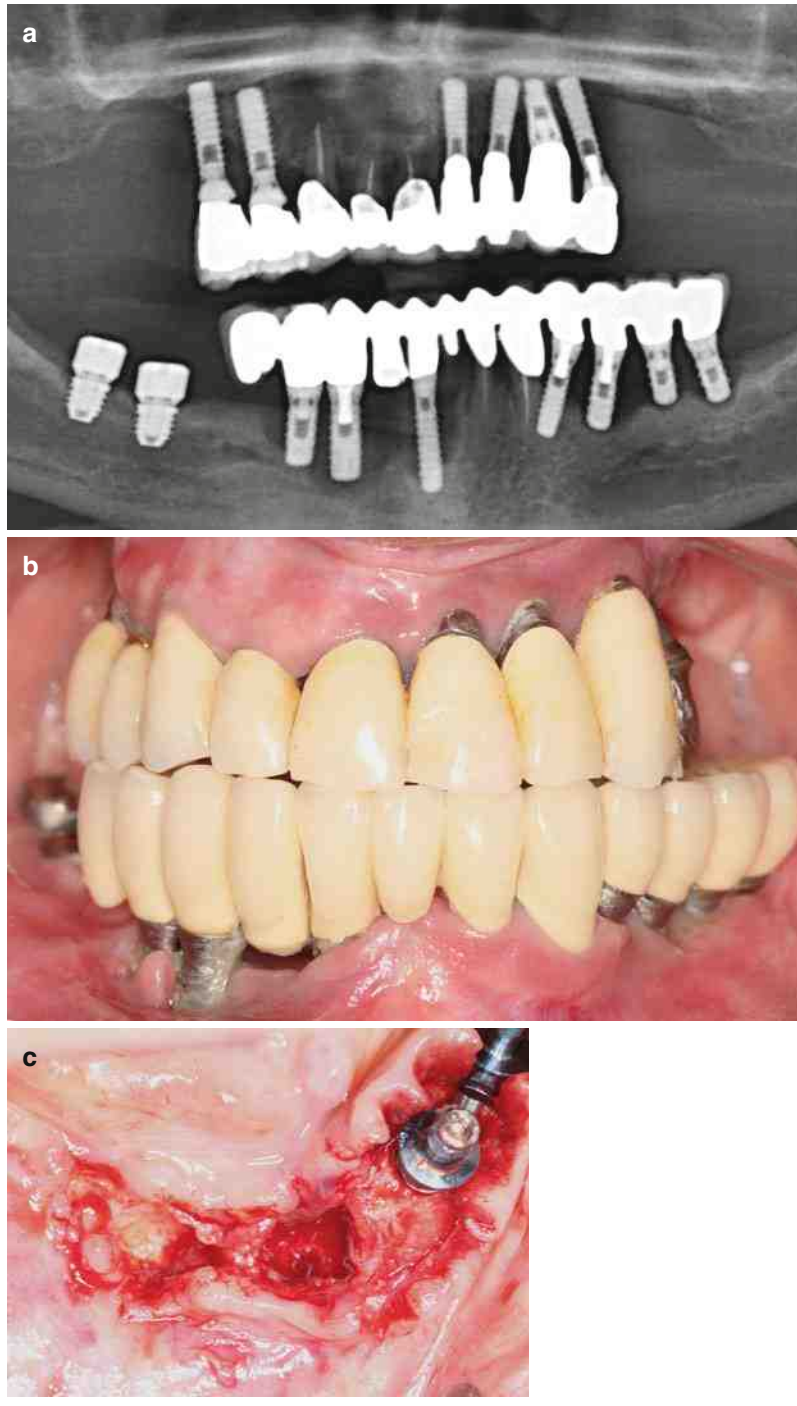

Fig. 11.9 (**a–e**) Mandibular implants in the anterior region affected by peri-implantitis (**a**) cannot be treated and are extracted (**b, d**). The two implants in the molar region and two newly placed implants are used for rehabilitation after healing is completed (**e**)

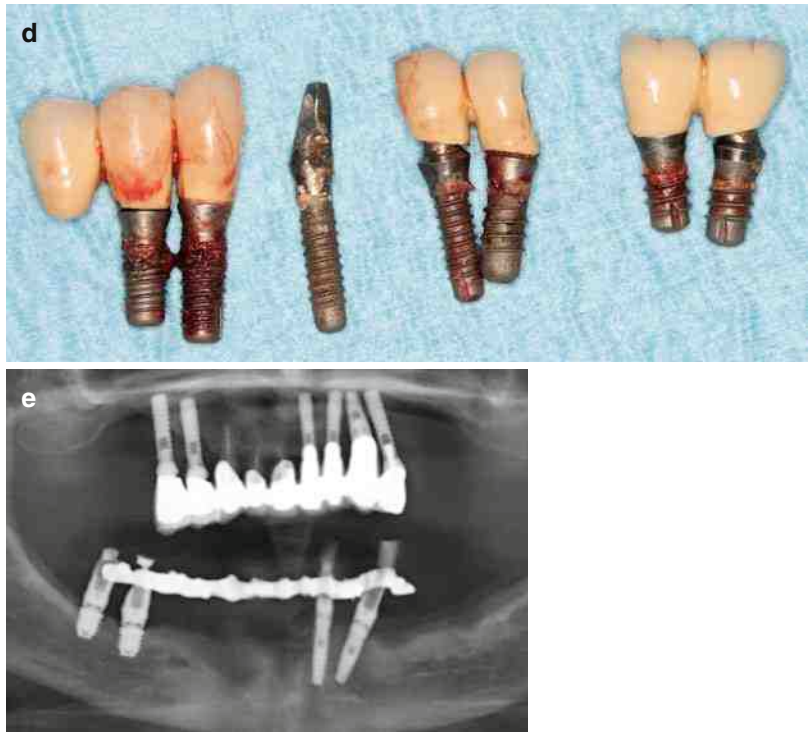

Fig. 11.9 (continued)

Moreover, bone removal could compromise the insertion of future implants in case of treatment failure.

Regarding regenerative techniques in case of peri-implantitis, these are chosen just to avoid the contraindications of a resective approach. Bone grafting materials have been variously employed, and the use of protective membranes has also been advocated. Surgical access is made with a simple access flap, and after careful debridement, the chosen material is grafted in the defect (Fig. 11.10).

11.2.3 Comparison of the Various Treatments

Effects of chemotherapeutic and mechanical agents on titanium surfaces have been investigated in a series of reviews. One important aspect to clarify is the biocompatibility of Ti surfaces after those treatments. It remains to be established if, after treatment of peri-implantitis through bacterial plaque removal and decontamination with various means, alterations of the implant surface may further impair what is called the process of re-osseointegration.

Louropoulou et al. [29, 30] reviewed the published in vitro experiments evaluating the effect of instrumentation on Ti implant surfaces. They found that the debris of the materials used for instrumentation may impair the proliferation of cells. This could happen with steel or gold, but it was most evident with plastic curettes. Moreover, plastic instruments seemed to be unable to clean the structured Ti surfaces.

The air-abrasive devices with sodium bicarbonate powder seemed to give the best results in terms of maintenance of biocompatibility of rough Ti surfaces; the same was not true for the machined ones.

Another review [31] analyzed the effect of chemotherapeutic agents on contaminated Ti surfaces. The most used decontaminant was chlorhexidine 0.12%, which anyway did not seem to reduce significantly the biofilm over Ti

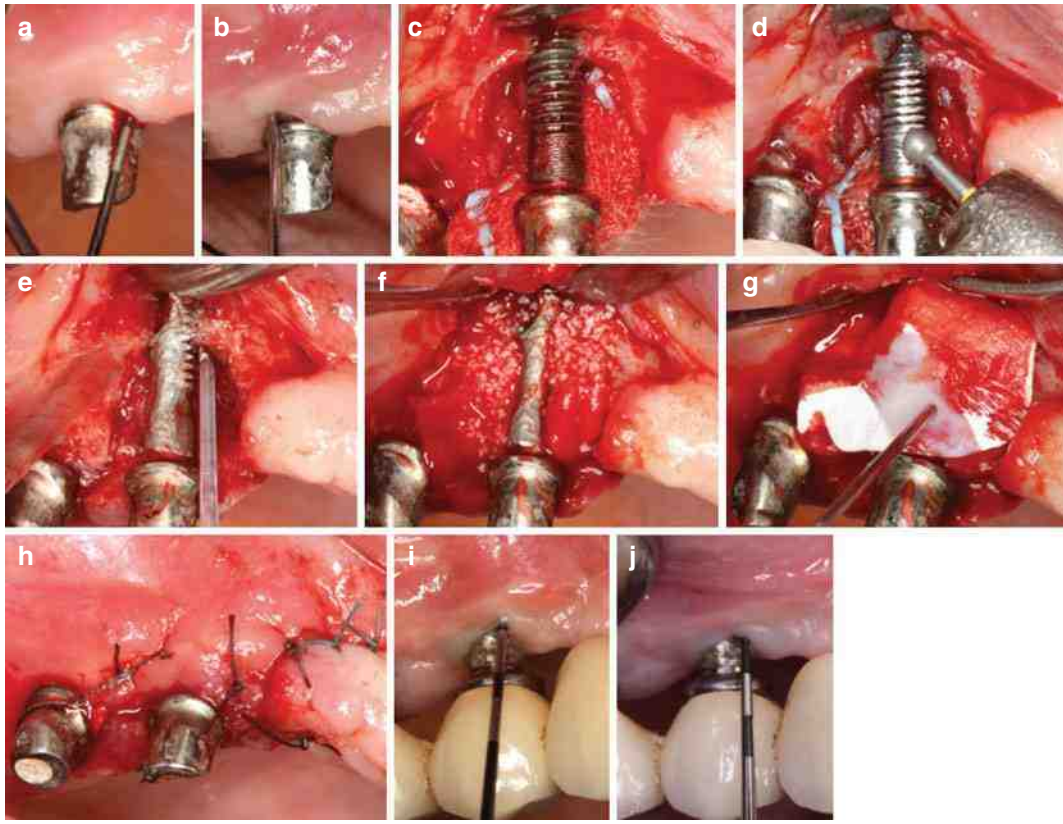

Fig. 11.10 (**a–j**) Access flap surgery in an attempt to treat a deep periodontal pocket (**a–c**). The implant surface is polished with the handpiece (**d**). GTR procedure is adopted and the flap is repositioned apically (**e–h**). Preop (**i**) and postop (**j**) probing depth (Reproduced with permission from Schwartz and coll. [47])

surfaces, although data reported in the literature are scarce. In vitro studies also showed a good potential for citric acid on bacterial killing on implant surfaces, but the effect of this compound was not found to be investigated.

Regarding the decontamination capacity of mechanical instruments, a review on in vitro experiments [32] showed that the steel and plastic curettes seem to be ineffective in removing bacteria and calcified deposits from the implant surface. The carbon tip piezoelectric scaler (Vector™) instead showed a good capacity of biofilm removal from both SLA and machined Ti surfaces. Good results were obtained with air-abrasive devices and a sodium bicarbonate powder, which allowed to remove effectively bacteria and bacterial products from machined SLA and TPS Ti surfaces.

Limitations of the in vitro studies on cleaning and decontamination of Ti surfaces reside in the fact that the majority of the experiments are conducted on Ti strips, cylinders, and sheets that microscopically resemble the implant surface, but on the macroscopic level, they do not allow to reproduce exactly what would happen with a threaded implant in the mouth. Nevertheless, the authors suggested that some mechanical instruments seemed to possess greater potential in the treatment of peri-implantitis. In detail, the air-abrasive devices with the use of sodium bicarbonate or glycine, and the carbon tip Vector™ scaler. Also, the analysis of the literature allows to understand that a complete biofilm removal is not a feasible objective; for this reason, combination of treatments should be employed in clinical studies.

A review of re-osseointegration in vitro and on animal and clinical studies was performed recently [33], with the conclusions that re-osseointegration of a contaminated surface is possible. Variability in the results resides in the fact that various surfaces, decontaminating agents, and materials are available. The authors stress the fact that surface decontamination by itself does not seem to guarantee optimal results, and combined therapies with mechanical devices and chemicals should lead to obtain re-osseointegration in the treatment of peri-implantitis.

A Cochrane Review [34] of interventions has been performed including the RCTs that compared the different nonsurgical and surgical options available.

No trials were found directly comparing nonsurgical vs. surgical approach.

Regarding *nonsurgical interventions,* the following comparisons were made on the following studies [35–43]:

Local antibiotics vs. *ultrasonic debridement* metronidazole gel 25 % injected into the pocket a depth at 3 mm of depth, US debridement with carbon fiber tip at the lowest power for 15 s. Both treatments repeated at 1 week. No statistically significant difference was found for PD.

Air-abrasive device vs. *manual debridement* Vector™ system was used; aerosol spray was made of HA particles. Carbon fiber tip curette was employed for debridement. Both interventions repeated after 3 months. No significant difference for MBL change and PD after 6 months.

Er:YAG laser vs. *manual debridement with chlorhexidine subgingival application*. The laser beam was directed at the implant surface under water irrigation from coronal to apical and parallel to the implant surface. For the manual debridement, plastic curettes were used followed by chlorhexidine 0.2 % irrigation. The meta-analysis of recurrence of peri-implantitis did not show a significant benefit for either intervention.

Er:YAG laser vs. *air-abrasive device*. The laser was applied in the same way as described before. The air-abrasive device consisted of a nozzle placed in the pocket for around 15 s and moved circumferentially around the implant; the flow utilized a hydrophobic powder. The results were inconcludent for the end points analyzed.

Adjunctive local antibiotics to local debridement vs. *chlorhexidine subgingival application*. Full-mouth debridement with plastic curettes plus 8.5 % doxycycline irrigation in the peri-implant sulcus and 0.2 % chlorhexidine. In the control group, just chlorhexidine 0.2 % irrigation was performed. No significant differences for CAL and PD were observed.

The following comparisons of surgical treatments were included from the analysis of the literature:

Resective surgery followed by adjunctive implant plus two different antibiotics and surface smoothening vs. *same treatment without surface smoothening*. Scaling with curettes was performed followed by bone peaks removal; finally, in one group the implant surface was polished with burs and the flap repositioned apically. In the control group no polishing was performed. Results showed no superiority of one treatment over the other.

Augmentation with synthetic vs. *animal-derived substitutes*. Synthetic grafts made of nanocrystalline hydroxyapatite were placed in the defect after debridement with plastic curette. Animal-derived grafts were bovine-derived xenografts. In both groups, a resorbable porcine collagen barrier was applied.

A statistically significance difference was outlined for CAL and PD 4 years after treatment in favor of xenograft.

Surface debridement with laser vs. *plastic curettes debridement before bone augmentation*. Er:YAG laser was used in the first group with the beam directed to the exposed implant surface under water irrigation with coronal to apical movements. In the control group, plastic curettes were used for debridement. In both groups, bovine xenograft was eventually placed in the defect. After 6 months, no statistically significant difference was recorded between the two groups.

Limitations of this review were that the number of patients included in the trials was small. Moreover, the authors noted that many studies are sponsored by the companies manufacturing the devices employed in the studies; in this way, a "marketing" bias should be considered. Finally, short follow-ups do not allow to draw strong conclusions.

In summary, no reliable evidence could be extrapolated from the review. The fact that many alternative treatments are available does not allow to make head-to-head meta-analysis feasible; therefore, it results in the difficulty to operate a synthesis of all the trials. Nevertheless, the use of adjunctive antibiotic therapy to manual debridement is suggestive of better results in terms of CAL and PD. Regarding surgery, bovine-derived grafts with a resorbable barrier gave better results for CAL and PD when compared to synthetic bone substitutes.

It results evident that, given the multiple approaches available for the treatment of peri-implantitis, multiple combinations of comparisons are possible. Moreover there is a great heterogeneity in methods and reporting of results. When this occurs, it may lead to difficulty in translating the results of the available studies on clinical practice. And in fact, the selection of a given treatment for peri-implantitis patients is still subjective.

A methodological way of synthesis that may help in this kind of scenario is the use of network meta-analysis (NMA), a statistical tool that allows to combine the results of various studies in a way to draw a realistic picture of the state of the evidence.

The NMA of Faggion et al. [44] attempted to compare different peri-implantitis treatments. Eleven studies (RCTs and controlled trials) were included for the analysis, and results at 4, 6, and 12 months were included. Results for CAL gain and PD reduction were better for surgical compared to nonsurgical approaches. When adjunctive treatments were added for comparison, again the surgical procedures plus bone grafts and non-resorbable membranes gave the best results in respect to CAL and PD at 12 months.

A Bayesian network meta-analysis was conducted by the same group of authors [45], but this time only nonsurgical treatments were compared, and only PD was used as end-point estimate and only RCTs were included.

Results pointed at debridement in conjunction with antibiotics as the best treatment in regard to PD reduction when compared to debridement only. It was followed by debridement plus PerioChip (Fig. 11.11 and Table 11.2).

The results of network meta-analysis allow to gain new insights into the effectiveness of the various treatment options, although some limitations should be kept in mind.

A limited number of studies still limit the analysis of the different treatment modalities for peri-implantitis. The surrogate end points reported in most studies (CAL and PD) may not reflect the characteristics of the true end point (implant failure). Also low-quality trials may limit the strength of a network meta-analysis.

On the other hand, given the abovementioned premises of lack of large clinical trials in the treatment of peri-implantitis and the great heterogeneity between the various studies, a synthesis via an NMA is the only way available to draw some relevant conclusion.

At the current state, it seems that prevention is the best way to face peri-implant diseases. Careful patient selection allows to avoid the implant treatment in those patients predisposed to the development of peri-implantitis, poor oral hygiene and cigarette smoking being the most important risk factors. After implant placement, a lifelong follow-up with regular checkups is mandatory in order to reduce the incidence of peri-implantitis.

When signs of peri-implant mucositis occur, a prompt nonsurgical intervention should be employed in order to avoid a development to conclamated peri-implantitis.

Finally, it is possible to conclude that the search of the best treatment option for patients affected by peri-implantitis remains an open question. Undoubtedly surgical approaches seem to give the best results at short-term follow-up periods. Reviews seem to show that laser therapy does not confer an advantage over traditional systems. Also, there is no evidence

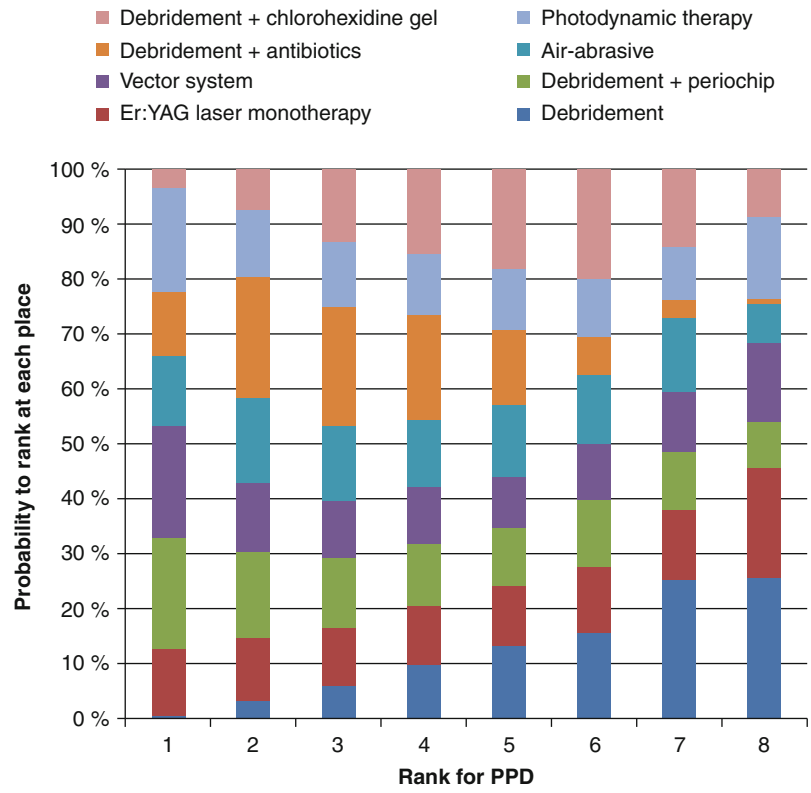

Fig. 11.11 Results of the Bayesian network meta-analysis by Faggion et al. (Reproduced with permission)

Table 11.2 Network meta-analysis comparing various peri-implantitis treatment options

	Studies included	End-point	Estimates in mm compared to nonsurgical treatments (HPD 95 %)
Faggion et al. (2013)	RCTs and controlled trials		
Surgical therapy + bone grafts + non-resorbable membranes		PPD CAL	3.52 (–0.19 to 6.81) 2.80 (–0.18 to 5.59)
Faggion et al. (2013)	RCTs		
Debridement + antibiotics		PPD	0.490 (–0.647 to 1.252)

of the superiority of one grafting material over another, mainly for the lack of direct comparative studies. Barrier membranes do not provide a clear improvement in surrogate end point results.

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