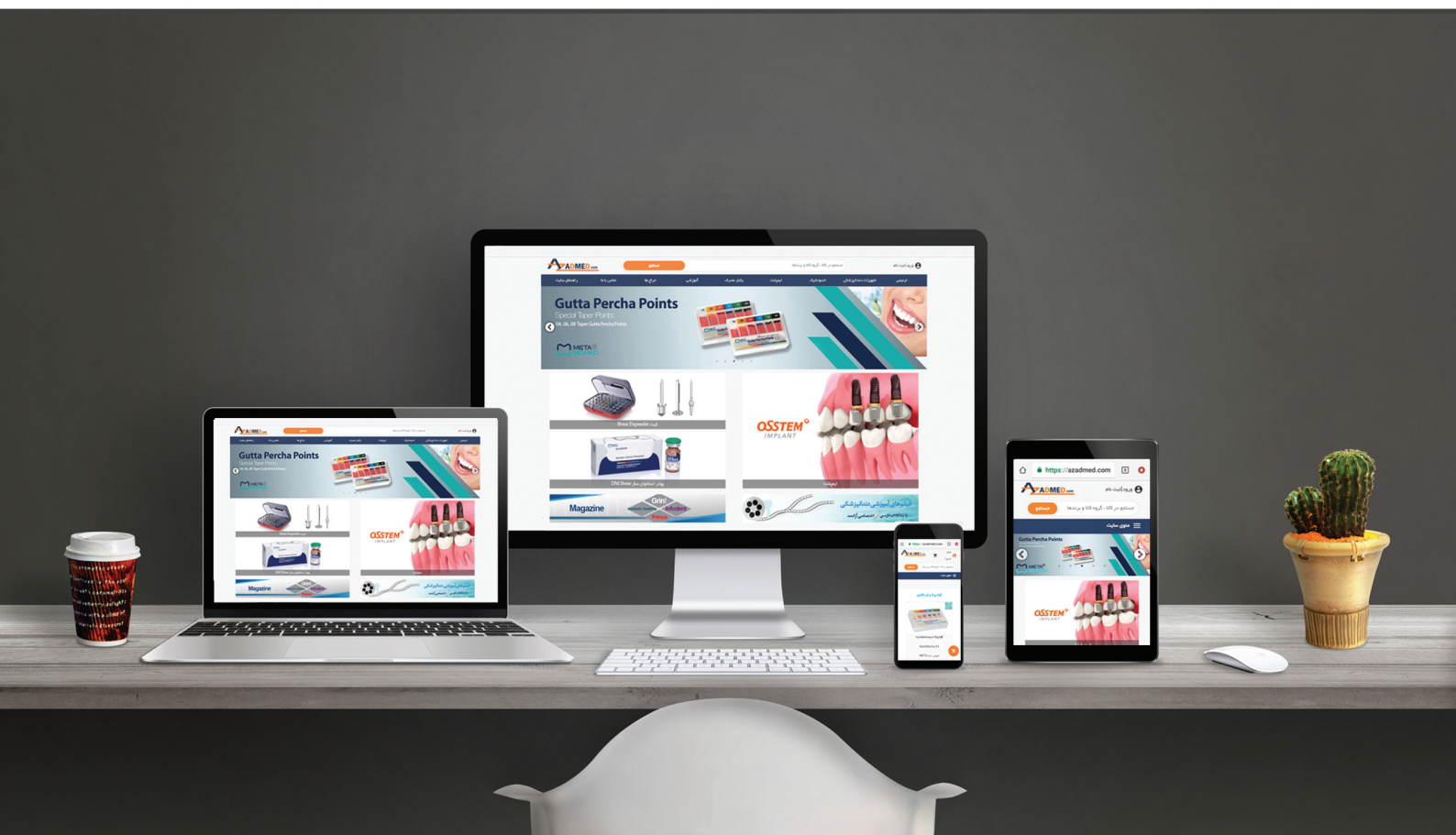




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Oral Science & Rehabilitation

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Biphasic materials are alloplastic bone grafting materials that have been used in both medical and dental fields. Many of the papers on biphasic materials by various authors have found 42% mineralized tissue in their core samples, of which 18% was woven bone, 23% was newly formed lamellar bone and 1% was retained graft particles.

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The use of biphasic material favors new bone formation and allows critical-size defects to heal without interfering in the regeneration process.

Dr. José Luis Calvo Guirado
Co-Editor

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Guided surgery for single-implant placement: A critical review

Abstract

Objective

The objective of this review was to evaluate the scientific evidence on accuracy, as well as esthetic and clinical outcomes of single-tooth implants placed using computer-assisted, template-based surgery.

Case description

Electronic and manual literature searches of clinical studies published between January 2002 and May 2015 were carried out using specified indexing terms. Outcomes were accuracy, Pink Esthetic Score, and clinical outcomes (Implant and prosthetic survival rates, complications, and marginal bone loss).

Results

A total of 706 titles and abstracts were found during the electronic and manual searches, but 563 publications were excluded (inter-reviewer agreement $k = 0.78$). The full texts of the remaining 143 publications were evaluated. A total of 125 papers had to be excluded because they did not fulfill the inclusion criteria ($k = 0.99$). Three manuscripts were added from the reference lists of all of the selected articles. A total of 21 articles were thus selected that fulfilled the inclusion criteria of and quality assessment required for this critical review.

Conclusion

Despite the high accuracy and a cumulative survival rate of 100%, there is little evidence to support the hypothesis that there is a clinical advantage of computer-assisted, template-based implant placement over conventional treatment protocols for the placement of an implant-supported single-tooth restoration. Long-term randomized clinical trials are needed to confirm these preliminary results.

Keywords

Computer-assisted surgery, single-tooth replacement, guided surgery.

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Introduction

Single-tooth replacement by means of osseointegrated dental implants may be considered a reliable treatment option for replacing missing teeth, following both immediate and early protocols.^{1,2} Periimplant soft-tissue esthetics represents one of the major aspect of implant success, particularly in the anterior maxilla, and it may be a main factor in the patient's decision on implant therapy, rather than a conventional fixed or removable dental prosthesis.³ It is well established that sufficient bone volume and a favorable 3-D implant position are prerequisites for long-term functional and esthetic success.³⁻⁵ However, alveolar bone resorption after tooth loss seems to be inevitable with both immediate and delayed implant placement⁶ and loading.⁷ Consequently, prosthetically guided implant positioning might be difficult to achieve.

In recent years, the growing interest in prosthetically guided implant placement, together with the option of fitting prostheses with immediate function, has led to the development of software that integrates the restorative treatment plan (computer-assisted) with minimally invasive (template-based) surgery,⁸⁻¹² along with reduced treatment time and postoperative discomfort.¹² Guided implant surgery using cone beam computed tomography (CBCT), virtual treatment planning software and stereolithographic surgical templates has undoubtedly been a major step toward achieving optimal 3-D implant positioning with respect to both anatomical and prosthetic parameters. Computer-assisted, template-based implant placement offers the potential for better predictability and flapless implant surgery, resulting in reduced intraoperative discomfort and postoperative morbidity.¹² It also shortens the overall surgery time.

After enthusiastic preliminary reports,^{13, 14} some independent prospective studies^{9, 10, 15-17} drew attention to the potential deviations of 3-D directions between virtual planning and the actual final position of the implant. This approach is technique-sensitive and perioperative complications have to be taken into account.

Although, in general, tooth-supported templates are more accurate than mucosa-supported ones,⁸ the application of guided surgery to enhance single-tooth implant positioning and esthetic outcome has not been widely reported in the literature. Potential advantages of flapless implant placement in the esthetic zone may in-

clude reduced mucosal recession and maximum preservation of periimplant papillae.^{5, 18, 19}

Computer-assisted, template-based implant placement may help clinicians to perform successful implant therapy avoiding elevation of large flaps or even eliminating flaps completely, causing less pain and discomfort to patients.¹² One might assume that, in the case of complex anatomy, as well as post-extraction implant placement, both patients and clinicians could benefit from computer-assisted, template-based surgery. In such advanced cases, correct estimation of the bone condition and the implant position, as well as precise drilling, according to the preoperative planning may be essential in ensuring the successful placement of an implant.

The aim of the present critical review was to evaluate the scientific literature regarding accuracy, esthetic, and clinical outcomes of single-tooth implants placed using computer-assisted, template-based surgery.

Materials and methods

The review was written according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (<http://www.prisma-statement.org>). The protocol of this systematic review was adapted to the PICO format (P = population/patients: patients who received single implants placed using guided surgery; I = intervention: single-implant placement using guided surgery; C = comparator/control: single-implant placement using a conventional free-hand approach; O = outcomes: accuracy, esthetics and implant survival rate).

Search strategy

An electronic literature search was carried out with the intention of collecting relevant information about the accuracy, clinical application and esthetic outcomes of single implants placed using computer-assisted, template-based surgery. The following electronic databases were consulted: PubMed database of the U.S. National Library of Medicine, Scopus scientific abstract and citation database and the Cochrane Library. In accordance with the AMSTAR (A Measurement Tool to Assess Systematic Reviews) checklist, the grey literature in the New York Academy of Medicine Grey Literature Report was screened in order to find possible unpublished works.

The electronic databases were searched using the following MeSH (Medical Subject Headings) terms: ("Surgery, Computed/r-Assisted"[Mesh] OR "Therapy, Computed/r-Assisted"[Mesh] OR "Computer-Aided Design"[Mesh]) AND ("Dental/ Oral Implants"[Mesh] OR "Dental Implants, Single-Tooth"[Mesh] OR "Dental Prosthesis, Implant-Supported"[Mesh]). Free-text terms ("Implant treatment" OR "Computed guided" OR "Single-tooth gap" OR "Guided surgery") were added to all searches.

The initial search included data from human, *ex vivo* and *in vitro* studies written in English and published between 2002 and May 2015 in refereed journals. No restrictions were implemented regarding the study design. The search included original research, clinical reports, technical notes and systematic reviews. Studies using static computer-assisted, template-based implant systems and dynamic navigation systems were included in the present review. All of the abstracts were evaluated according to established criteria on the topics of this review, in order to select relevant manuscripts for further full-text evaluation. For evaluation of randomized controlled or comparative studies, it was required that the enrolled population have at least five patients in each group. Clinical reports and technical notes were considered of interest when providing relevant scientific information on the subject. For evaluation of implant and prosthodontic survival rates, it was required that patients had been followed for at least one year after implant placement. However, no specific follow-up period was required for evaluation of surgical or prosthetic complications during implant placement/loading or for assessing patient-centered outcomes of surgery and the immediate postoperative period.

Afterward, manual searches of the reference lists of selected manuscripts were conducted, limited to the following journals: *Clinical Implant Dentistry and Related Research*, *Clinical Oral Implants Research*, *International Journal of Oral and Maxillofacial Implants*, *International Journal of Computerized Dentistry* and *European Journal of Oral Implantology*. Additionally, a new search excluding "Dental/Oral Implants, Single-Tooth" from the previously used MeSH terms was performed, followed by a manual search, in order to find single-tooth dental implants placed using computer-assisted, template-based surgery in larger cohorts of patients. The authors of each selected manuscript were contacted, if necessary, in order to obtain missing or supplementary

information. Finally, the authors of the current review used personal contacts in an attempt to identify unpublished or ongoing eligible studies. Two reviewers (MT and SMM) performed the literature search independently. A third reviewer (LC) reassessed both the included and excluded studies.

The following outcome variables were defined:

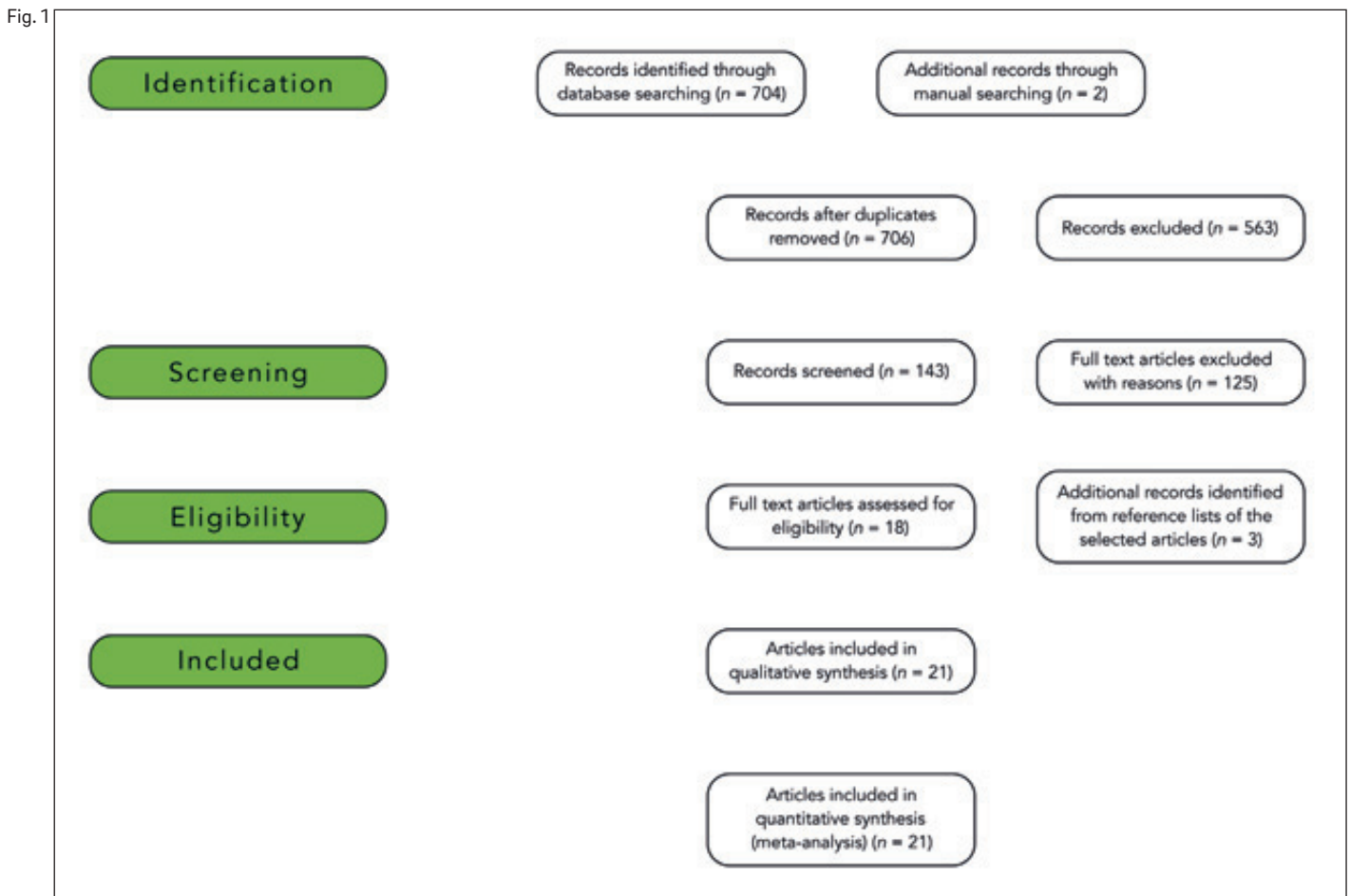
- accuracy, defined as the difference in location or angulation between the computer planning and the actual position of the placed implant: deviation at the entry point, deviation at the apex, deviation in height and deviation of the axis;
- esthetic outcome: Pink Esthetic Score (PES);
- clinical outcomes: implant and prosthetic survival and success rates, any biological and biomechanical complications, and marginal bone loss.

Based on randomized controlled trials in previously published systematic reviews, the following question was addressed: Is there scientific evidence to support the hypothesis that there is a clinical advantage of using computer-assisted, template-based implant placement compared with conventional treatment protocols for the placement of an implant-supported single-tooth restoration?

Results

A total of 706 potentially relevant titles and abstracts were found during the electronic ($n = 704$) and manual ($n = 2$) searches. During the first stage of study selection, 563 publications were excluded based on their title and abstract (inter-reviewer agreement $k = 0.78$). For the second stage, the full texts of the remaining 143 publications were thoroughly evaluated. A total of 125 papers had to be excluded at this stage because they did not fulfill the inclusion criteria of the present review (inter-reviewer agreement $k = 0.99$). Three manuscripts were added from the reference lists of all of the selected full-text articles. Finally, a total of 21 articles were selected that fulfilled the inclusion criteria of and quality assessment required for this critical review.

The 21 selected studies included one *in vitro* comparative study,²⁰ four prospective single-cohort studies,^{19, 21–23} one case series,²⁴ six case reports,^{25–30} eight reviews of the literature,^{8, 31–37} and one randomized controlled trial.³⁸ A diagram of the search strategy is presented in **Figure 1**.



Accuracy of computer-assisted, template-based surgery for implant-supported single-tooth restorations

There are no *in vivo* randomized controlled trials in the scientific literature that report on the accuracy of computer-assisted, template-based implant placement compared with a free-hand approach for the treatment of a single-tooth gap. Three *in vivo* prospective studies, and one randomized controlled trial reported the 3-D accuracy of 65 implants placed using computer-assisted, template-based surgery.^{19, 22, 23, 38} All of the data are summarized in **Table 1**. Farley et al., in a split-mouth, randomized controlled trial, reported that computer-assisted, template-based implant placement was more accurate than conventional guides, but only for coronal horizontal distances.³⁸ One *in vitro* comparative study (80 implants) reported the 3-D accuracy of single-tooth implants placed using navigated implant surgery compared with conventional implant placement.²⁰

Kramer et al. compared *in vitro* the accuracy of conventional ($n = 40$) versus navigated ($n = 40$) implant placement.²⁰ For each group, identical maxillary casts were used to place implants for single-tooth replacement of either the left central incisor ($n = 20$) or the right canine ($n = 20$). The authors concluded that variation in implant position, angulation and depth was reduced for implants that were placed using the navigation protocol.²⁰

In a prospective study, Behneke et al. analyzed the factors that may influence the transfer accuracy of CBCT-derived, laboratory-based surgical guides for implant placement in partially edentulous patients.²² Nineteen implants were placed to restore a single-tooth gap in 19 partially edentate patients. The accuracy of computer-assisted, template-based implant placement was evaluated using the image fusion technique. Measurements were done to calculate linear and angular deviations between virtually planned and actually placed implants. A relevant improvement of the accuracy could be achieved by final drilling or implant placement

Fig. 1
Diagram of the search strategy.

Table 1

In vivo accuracy of computer-assisted, template-based surgery for implant-supported single-tooth restorations (mean $\pm$ standard deviation).

Study	No. of implants	Entry point in mm (range in mm)	Apex point in mm (range in mm)	Angle in $^{\circ}$ (range in $^{\circ}$)
Behneke et al. ^{22, †}	19	0.21 $\pm$ 0.16 (0.01–0.92)	0.32 $\pm$ 0.34 (0.03–0.59)	1.35 $\pm$ 1.11 (0.07–3.33)
Fürhauser et al. ^{19, ‡}	27	0.84 $\pm$ 0.44 (0–1.6)	1.16 $\pm$ 0.69 (0–2.6)	2.7 $\pm$ 2.6 (0–12.7)
Ersoy et al. ^{23, §}	9	0.74 $\pm$ 0.4	1.66 $\pm$ 0.28	3.71 $\pm$ 0.93
Farley et al. ^{38, °}	10	1.45 $\pm$ 0.06 (0.50–2.67)	1.82 $\pm$ 0.6 (0.60–2.69)	3.68 $\pm$ 2.19 (0.78–7.98)

Table 1

* Implant 3D software (med3D, Heidelberg, Germany).

** NobelClinician (Nobel Biocare, Zurich, Switzerland).

§ Stent Cad (Media Lab, La Spezia, Italy).

° iDent software (iDent Imaging, Ft. Lauderdale, Florida, U.S.).

with template guidance in both single-tooth gap and reduced residual dentition cases. A mean error of 0.21 $\pm$ 0.16 mm (range of 0.01–0.92 mm) at the entry point and of 0.32 $\pm$ 0.34 mm (range of 0.03–0.59) at the apex, and 1.35 $\pm$ 1.11 $^{\circ}$ (range of 0.07–3.33 $^{\circ}$) of apex radial deviation were reported for single-tooth gap surgery.²² The amount of coronal, apical and angular deviation was about half of that reported by Vasak et al. using the NobelGuide system for the rehabilitation of partially edentulous maxillae and mandibles, although all maximal deviations measured in both clinical studies were within the safety margins recommended by the planning software manufacturer.¹⁰

According to a recent systematic review and meta-analysis of computer-assisted, template-based implant surgery for different types of edentulism, the clinician should consider a mean error of 1.12 mm at the entry point and of 1.39 mm at the apex.³⁵ However, the same report indicates that the clinician should be aware that maximal deviations of 4.5 mm and 7.1 mm, respectively, have been reported—which is clinically relevant.³⁵ These average deviations are slightly higher than those reported by Fürhauser et al. using stereolithographic templates for the rehabilitation of single-tooth implants in the anterior maxilla (the mean deviation between planned and actual implant position measured 0.84 $\pm$ 0.44 mm at the implant shoulder [range of 0.0–1.6 mm] and 1.16 $\pm$ 0.69 mm at the implant apex [range of 0.0–2.6 mm]).¹⁹ Mean angular deviation was 2.7 $\pm$ 2.6 $^{\circ}$ (range of 0.0–12.7 $^{\circ}$) and was significantly correlated to apical deviation, but not to inaccuracy at the implant shoulder.

A retrospective study by Ersoy et al. on the 3-D accuracy of nine single-tooth implants placed

by guided implant surgery reported a mean error of 0.74 $\pm$ 0.40 mm at the implant neck and 1.66 $\pm$ 0.28 mm at the apex and an angular deviation of 3.71 $\pm$ 0.93 $^{\circ}$.²³ No minimum and maximum deviations were reported for the implant-supported single-tooth restorations. The authors reported a statistically significantly higher accuracy between single and both partially and edentulous patients, in favor of single-tooth gap restorations.

A possible explanation of these results was recently published in a systematic review and meta-analysis by Tahmaseb et al., who reported that the tooth-supported guides tended to be slightly more accurate than mucosa- or mucosa- and pin-supported guides.³⁵ These results are also in accordance with those of the third EAO Consensus Conference on computer-guided implant therapy and soft- and hard-tissue aspects, that tooth- and mucosa-supported templates can give more accurate results than bone-supported templates.⁸

Esthetic outcomes of implant-supported single-tooth restorations performed using computer-assisted, template-based surgery

There are no *in vivo* randomized controlled trials in the literature that report esthetic outcomes of computer-assisted, template-based implant placement compared with free-hand surgery for the treatment of single-tooth gaps. In a prospective study, Fürhauser et al. reported the 3-D accuracy of 27 single-tooth implants placed for delayed replacement of maxillary incisors, using stereolithographic templates.¹⁹ The es-

thetic outcomes were evaluated using the PES.³⁹ In this study, the mean deviation between the planned and actual implant position was calculated by superimposition of postoperative CBCT scans, with a mean follow-up of 2.3 years. The authors found that the 3-D inaccuracy is low in guided implant surgery, but that it may significantly compromise the implant esthetics in the anterior maxilla. Particularly, deviations toward the buccal side ≥ 0.8 mm resulted in significantly worse implant esthetics (median PES of 9.5) compared with more accurate implant positions (median PES of 13).¹⁹ These results confirm the hypothesis that the 3-D implant position has an important influence on the esthetic outcome. A positioning of the implant that is too buccal may result in an increased crown length compared with the contralateral tooth and in midfacial recession over time.

Clinical outcomes of implant-supported single-tooth restorations performed using computer-assisted, template-based surgery

There are no *in vivo* randomized controlled trials in the literature that report the survival or success rates of implants placed using computer-assisted, template-based surgery compared with free-hand surgery for the treatment of single-tooth gaps. One randomized controlled trial, and four *in vivo* prospective studies^{19, 21–23, 38} treating single-tooth gaps were identified. In two studies,^{19, 21} NobelClinician Software (Nobel Biocare, Gothenburg, Sweden) was used. In the other three studies, Implant 3D software (med3D, Heidelberg, Germany),²² Stent Cad (Media Lab, La Spezia, Italy),²³ and iDent software (iDent Imaging, Ft. Lauderdale, Florida, U.S.)³⁸ were used.

A total of 125 single implants were placed in 123 patients (18–68 years old). In all five studies, no implant failed, resulting in a cumulative survival rate of 100%.^{19, 21–23, 38} A mean follow-up period was reported only in two studies,^{19, 21} ranging from 12 to 52 months.

Conclusion

Despite the high accuracy and a cumulative survival rate of 100%, there is little evidence to support the hypothesis that there is a clinical advantage of computer-assisted, template-based implant placement over conventional treatment

protocols for the placement of an implant-supported single-tooth restoration.

- Single implants placed using computer-assisted, template-based surgery are associated with higher accuracy than single implants placed using a navigation system.
- Tooth-supported templates used to treat cases of partial edentulism provide more accurate results than do mucosa-supported templates used in completely edentulous patients.
- Tooth-supported templates for implant-supported single-tooth restorations provide even more accurate results than those for partially edentulous patients.
- Clinicians should inform patients that computer-assisted, template-based surgery implies greater planning time and additional costs. However, the higher cost should be analyzed in terms of cost-effectiveness and in light of the reduction of surgery time and postoperative pain and swelling, as well as the possible increased accuracy.
- The avoidance of critical anatomical structures, as well as the esthetic and functional advantages, with prosthodontically driven implant positioning must also be considered.
- Long-term randomized clinical trials and future reviews of literature on the topic of single-tooth replacement with implants are needed.

Competing interests

This review was performed at the request of the Foundation for Oral Rehabilitation. This foundation is an independent international initiative that unites professionals from various disciplines to improve oral health care and support humanitarian leadership. The study was self-supported and the authors declare no competing interests.

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Open-healing approach to avoid flap mobilization and subsequent morbidity

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Abstract

Objective

This retrospective analysis evaluated the outcome of bone regeneration using membranes in an open-healing approach.

Materials and methods:

In 119 patients with 160 surgical areas, ridge preservation or bone augmentation was performed. Bone defects were filled and covered with a membrane that was left exposed during healing. Outcome parameters were the need to perform an unplanned augmentation and complication rates during wound healing.

Results

Bone augmentation was performed in 33.1%, ridge preservation in 41.9% and ridge preservation combined with bone augmentation in 13.1% of the surgical areas. In 78.8% of the surgical areas, a native bilayer collagen membrane was used. Healing was uneventful in 90.6% of the surgical areas. Complications occurred in 9.4% of the surgical areas and included premature membrane resorption, hematoma, membrane loosened by tongue, pain, wound dehiscence and fractured bone plate during augmentation surgery. One patient developed an abscess, one lost an implant. The graft was partially lost in 1.9% of the surgical areas.

Implants could be inserted as planned in a two-stage procedure in all but the one surgical area in which the abscess had occurred. In this area, an unplanned re-augmentation was required. In 86.9% of the surgical areas, no re-augmentation was necessary. Secondary augmentation was performed in 12.5% according to the treatment plan.

Conclusion

Using suitable membranes, open healing may allow uneventful wound healing and sufficient bone formation. This approach may help to avoid soft-tissue problems associated with extensive flap mobilization and tension.

Keywords

Collagen membrane, open healing, ridge preservation, augmentation.

Introduction

The aim of implant therapy is to ensure an optimal functional and esthetic outcome as well as good long-term results. The use of regenerative techniques is often necessary to maintain or augment sufficient bone and soft-tissue for implant placement. Among the bone substitutes, a deproteinized bovine bone mineral (DBBM) has been shown to be effective in bone augmentation^{1–4} and ridge preservation procedures.^{5–8} Studies with long-term follow-ups have shown that the regenerated bone is maintained over time.^{9,10} Histological analyses have indicated that the slow resorption rate of DBBM is responsible for the long-term stability of the augmented bone volume.¹¹

DBBM is often used in combination with a semipermeable membrane. According to the principle of guided bone regeneration (GBR), the membrane is used to exclude epithelial cells from the bone defect, thereby allowing bone formation.¹² In the early days of GBR, nonresorbable ePTFE (expanded polytetrafluoroethylene) barriers were successfully used to cover bone defects.^{13,14} However, postoperative wound dehiscence occurred frequently. It was often associated with infections that required early membrane removal and impaired bone regeneration.^{15–17} A resorbable native bilayer collagen membrane (NBCM) was shown to reduce the risk of membrane exposure and achieve comparable results to the ePTFE barriers with regard to bone regeneration.¹⁶ If wound dehiscence occurred with the NBCM, healing was uneventful. Other studies have confirmed the promising healing characteristics of this membrane.^{18,19}

In general, it is recommended to achieve complete, but tension-free, primary wound closure over the collagen membrane. However, when bone augmentation procedures are performed, closing the flap without tension may become challenging. Splitting of the periosteum and extensive soft-tissue mobilization may then be necessary. This may increase morbidity, swelling and the rate of wound dehiscence because of impaired blood supply in a thinned flap. In addition, an insufficient vestibular depth, lack of keratinized tissue or scars may compromise the esthetic results and require additional surgical interventions.

A possible approach to avoid flap mobilization is to allow open healing of the membrane. We started to use various collagen membranes and

Materials and methods

Evaluation included patients from a private practice who were treated between August 2005 and June 2014 using an open-healing approach. Patients underwent implant therapy to replace hopeless or missing teeth. Surgical interventions were performed as well as pre- and postoperative care administered according to our standard procedures. Membranes were applied in ridge preservation and in bone augmentation procedures, which were performed simultaneously with or before implant placement.

In ridge preservation procedures, hopeless teeth were extracted atraumatically. The extraction socket was cleaned and all granulation tissue was removed carefully. A DBBM (Geistlich Bio-Oss, Geistlich Pharma, Wolhusen, Switzerland) was applied into the socket according to the manufacturer's instructions and covered with a membrane. In three-wall defects, that is, if the buccal bone wall was partially or completely missing, and if the defect was narrow and deep, a soft-tissue pond was prepared and the ice-cream cone technique²⁰ was used.

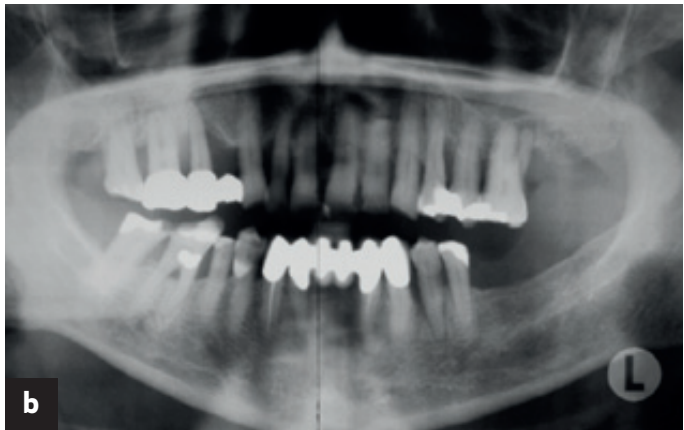
In patients with missing teeth, a reduced full-thickness flap was prepared. If sufficient primary stability could be ensured, implants were placed immediately according to the manufacturers' instructions. Bone augmentation was performed using DBBM or autogenous bone harvested from the drill hole. If the defect was large or if several bone walls were missing, mechanical stability was ensured using a titanium mesh (Synthes, Umkirch, Germany). A membrane was applied overlapping the defect. Membrane margins were placed under the flap and the flap was sutured tension-free, leaving the membrane partially exposed.

The following membrane materials were used:

- Geistlich Bio-Gide (NBCM; Geistlich Pharma)
- Jason membrane (JM; botiss biomaterials, Berlin, Germany)
- Socket Repair Membrane (SRM; Zimmer Biomet, Freiburg, Germany)
- DynaMatrix (DM; Keystone Dental, Alfter, Germany)
- Geistlich Mucograft Seal (CMXs; Geistlich Pharma)
- Histoacryl (HIA; B. Braun Medical, Melsungen, Germany).

Antibiotics were prescribed in accordance with current guidelines, that is, in patients at higher risk, such as valvular heart disease or inflammation due to tooth fracture prior to tooth extraction. Suture removal took place after two weeks. In order to allow maturation of bone and soft tissue, sites were allowed to heal for at least six months before implant placement or secondary augmentation procedures were performed. A typical clinical case is shown in **Figures 1a–m**.

ing complications and membrane type or defect morphology (number of bone walls) was evaluated using the exact chi-squared test or Fisher exact test for general frequency tables at the 5% level of significance. Additionally, a Spearman rank correlation coefficient was calculated for healing complications and defect morphology. The univariate results were confirmed by a multivariate logistic regression using healing complications as the main variable and defect morphology and membrane type as co-variables.



Figs. 1a & b

Fig. 1
Initial (a) clinical and (b) radiographic situation prior to tooth extraction. Owing to periodontal bone loss, teeth in the upper and lower jaws were extracted.

Evaluation

In many cases, one membrane was used to cover multiple neighboring defects. These sites were defined as one surgical area. The data were retrospectively analyzed for defect morphology (number of remaining bone walls), size of surgical area (number of neighboring sites), indication, complications during healing, loss of graft material, possibility of performing flapless implantation and need for follow-up augmentation procedures (none, planned or unplanned). The primary outcome parameter was the need to perform an unplanned augmentation during the implant procedure. The secondary outcome parameter was complication rate during wound healing. In addition, the data were analyzed to determine whether unfavorable defect morphology might increase the frequency of healing complications and whether the membranes differed with regard to healing complications.

Statistics

Explorative analysis of the data was performed using R (Version 3.2.2; R Foundation Vienna, Austria). A possible correlation between heal-

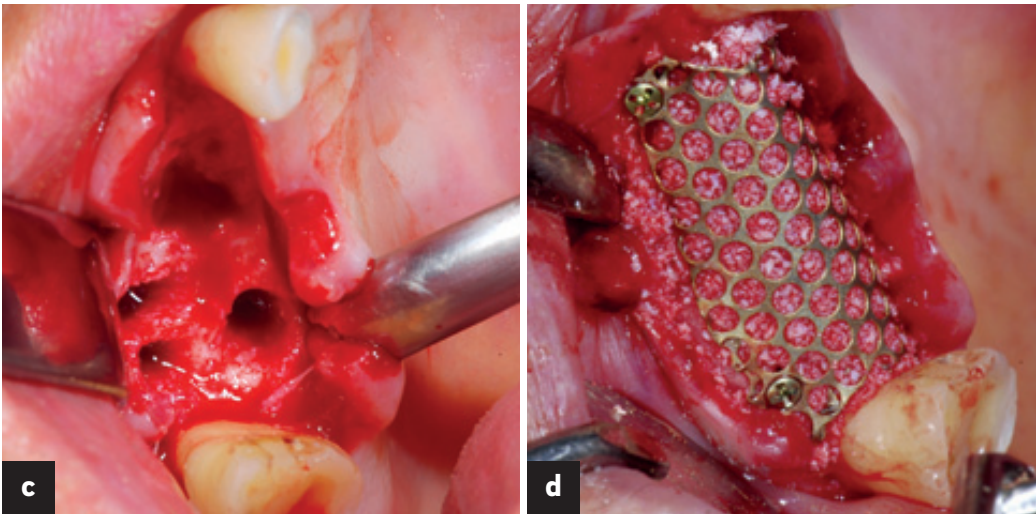
Results

During the observation period, a total of 127 patients with 171 surgical areas were treated using the open-healing approach. Eight patients were lost to follow-up because they did not show up for implant placement. Therefore, the analysis included 160 surgical areas in 119 patients. Of the patients, 49.6% were male and 50.4% female. Mean patient age was 54.3 ± 13.0 years (aged 29–88 years). The maximum number of surgical areas per patient was four. A surgical area contained 1.89 ± 1.26 sites on average (**Table 1**). The number of missing bone walls per surgical area is shown in **Table 2**.

DBBM was used in 98.1% and autogenous bone in 1.9% of the surgical areas. In 78.8% of the surgical areas, NBCM was used (**Table 3**). A titanium mesh was additionally applied in 11.3% of the surgical areas. Of these surgical areas, 88.9% were covered with NBCM, 5.55% with JM and 5.55% with DM.

Bone augmentation procedures were performed in 33.1% of the surgical areas. They included bone splitting, horizontal, and/or vertical bone augmentation and sinus floor elevation. Ridge preservation alone was performed in 41.9%

Figs. 1c & d



Figs. 1e & f

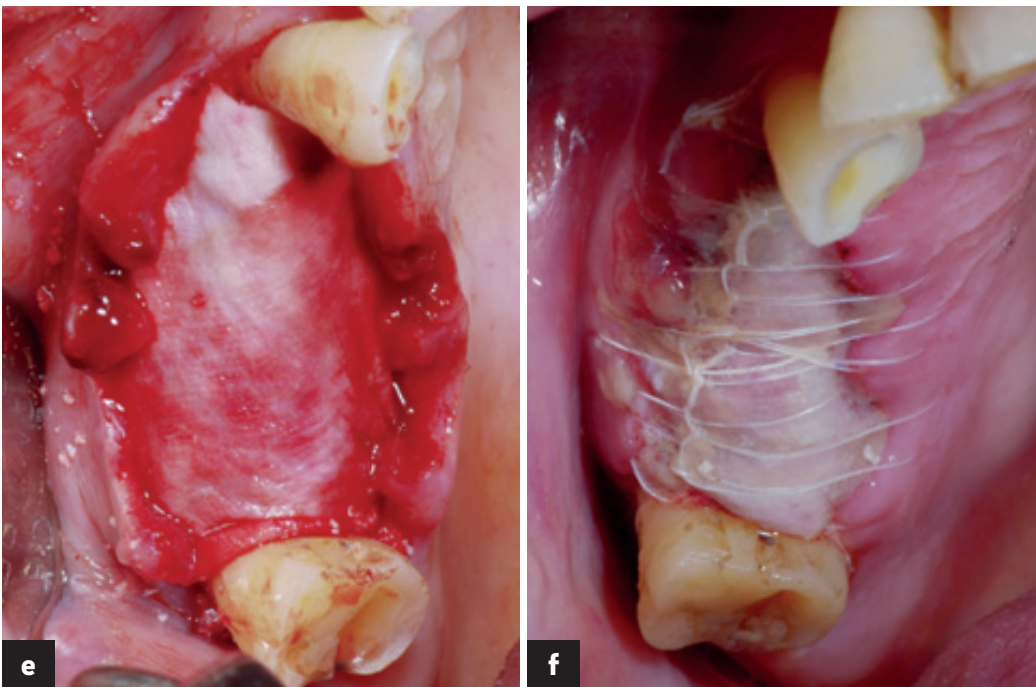


Fig. 1g

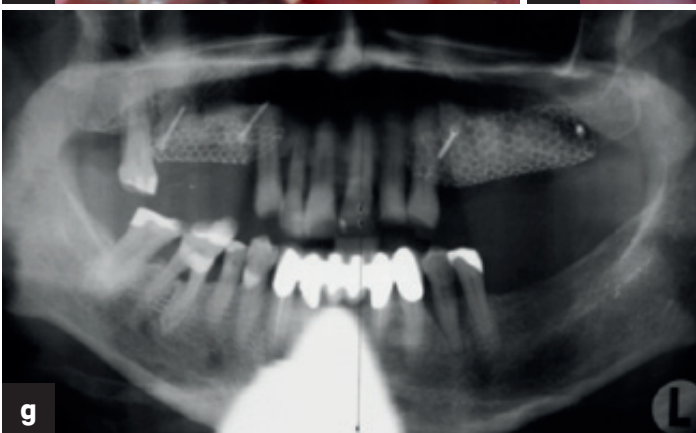


Fig. 1
Intraoperative view:
(c) Ridge situation after atraumatic extraction and reduced flap elevation.
(d) The extraction sites were filled with DBBM, and titanium nets were placed bilaterally to stabilize the augmented volume (first quadrant is shown here).
(e) Placement of a native bilayer collagen membrane (NBCM) over the titanium mesh. The flap was sutured without tension, leaving the NBCM exposed.
(f) Clinical situation two days after surgery.
(g) Radiographic situation two weeks after surgery.



Figs. 1h & i

Fig. 1j

Fig. 1
During healing:
(h) Nine days and
(i) three weeks after surgery.
The membrane had resorbed
and the titanium mesh was
visible. (j) After three months,
the titanium mesh was
removed.
After healing:
(k) Six months after surgery,
implants were placed using
minimally invasive surgery.
(l) Final restoration and
(m) radiographic view after
15 months.
(n) Stable clinical situation
five years after augmentation.



Figs. 1k & l



Figs. 1m & n

of the surgical areas. In 13.1%, ridge preservation was combined with bone augmentation. The ice-cream cone technique was used in 14% of the surgical areas (26% of all areas undergoing ridge preservation). In 1.25% of the surgical areas, bone defects were treated owing to implant removal.

A total of 32.5% of the surgical areas included an extraction site in which immediate implant placement was performed. In 10.6% of the surgical areas, implants were placed into healed bone simultaneously with the augmentation procedure.

Healing was uneventful in 90.6% of the surgical areas. Complications during healing occurred in 15 areas (9.4%; **Table 4**). Five of these areas had undergone ridge preservation, three areas ridge preservation combined with bone augmentation and seven areas augmentation procedures. The complications included premature membrane resorption (five areas: four covered with NBCM; one covered with JM), hematoma (three areas: two covered with NBCM; one covered with JM) and membrane loosened by tongue (one area covered with NBCM). One patient developed an abscess (area covered with JM), one implant was lost (area covered with NBCM) and another patient complained about pain six weeks after surgery (area covered with NBCM). The patient was successfully treated with antibiotics. Other complications were an exposed titanium mesh (one area covered with NBCM), wound dehiscence (one area covered with NBCM) and a fractured bone plate during the augmentation surgery (one area covered with NBCM). The graft was partially lost in three surgical areas (1.9%; one area covered with JM; two areas covered with NBCM).

The number of complications per defect morphology type is given in **Table 5**. The number of morphology categories was too large to test for a correlation between the number of present bone walls and frequency of healing complications. When only the two most frequent defect morphologies, that is, three- and four-wall defects, were compared with each other, no clear indication of a correlation was found. In both morphology types, the percentage of healing problems was very similar. When defect morphology was coded as a figure (e.g., 2–3 was 2.5), a rank correlation of -0.052 was calculated. This indicated that defects with a higher number of bone walls slightly tended to have fewer healing complications. Healing complications occurred in 9.52% of the surgical areas covered with NBCM and in 8.82% of the areas covered with a different membrane type. The data did not indi-

cate any correlation between membrane type and healing complications.

Implantation or secondary augmentation

The average healing phase until implantation and/or secondary augmentation was 5.2 ± 8.1 months (0–58 months). Implants could be inserted as planned in a two-stage procedure in all but one surgical area. Flapless implantation was possible in 58.8% of the surgical areas.

In 86.88% of the surgical areas, no secondary augmentation was necessary (**Table 6**). Secondary augmentation procedures were performed according to the treatment plan in 12.5% of the surgical areas. They ranged from minor to extensive interventions and included sinus floor augmentation in nine surgical areas (three internal sinus lifts), bone spreading in three and bone splitting in two. There was only one surgical area in which an abscess required an unplanned re-augmentation and implant insertion was therefore not possible as planned.

Discussion

In this analysis, different collagen membranes and matrices, as well as tissue glue, were used in ridge preservation and augmentation procedures in an open-healing approach in a variety of indications and defect types. The clinical outcomes were evaluated retrospectively. The primary outcome parameter was the necessity to perform unplanned augmentation since this was regarded to be a partial failure of the regenerative treatment. The treatment was judged to be successful if no re-augmentation had to be performed or if an additional bone augmentation could be performed as planned at the time point of the first intervention. There was just one case in which an unplanned re-augmentation had to be performed owing to an abscess. Therefore, the surgical approach using open healing was successful according to the criterion of no unplanned re-augmentation being required in 99.4% of the surgical areas.

However, owing to the retrospective and uncontrolled nature of this study, it is not known whether a closed-healing approach might have resulted in improved bone regeneration or might have reduced the extent of a planned secondary augmentation. Exposure of resorbable membranes may be associated with premature mem-

Table 1

Size and number of surgical areas.

Table 2

Defect morphology of surgical areas.

Table 3

Types of membranes used to treat surgical areas.

Table 4

Type of complication and types of membranes used per surgical area in which a complication was recorded (surgical areas with complications $n=15$).

Sites per surgical area	Number of surgical areas (%)
1	85 (53.13)
2	33 (20.63)
3	33 (20.63)
4	6 (3.75)
5	1 (0.63)
6	1 (0.63)
12	1 (0.63)

Table 1

Number of bone walls surrounding defects	Number of surgical areas (%)
1–4 [†]	1 (0.63)
2	14 (8.75)
2–3 [‡]	10 (6.25)
3	67 (41.88)
3–4 [§]	9 (5.63)
4	59 (36.88)

Table 2

[†] Surgical area contained sites with one, two, three and four bone wall defects.

[‡] Surgical area contained sites with two and three bone wall defects.

[§] Surgical area contained sites with three and four bone wall defects.

Membrane type	Number of surgical areas treated (%)
NBCM	126 (78.8)
HIA	19 (11.9)
DM	8 (5.0)
SRM	3 (1.9)
JM	2 (1.3)
CMXs	1 (0.6)
Not documented	1 (0.6)

Table 3

Type of complication	Number of surgical areas (%)	Membrane type used per surgical area in which complication developed
Premature membrane resorption	5 (3.1)	NBCM ($n = 4$) JM ($n = 1$)
Hematoma	3 (1.9)	NBCM ($n = 2$) JM ($n = 1$)
Membrane loosened by tongue	1 (0.6)	JM ($n = 1$)
Abscess	1 (0.6)	JM ($n = 1$)
Implant loss	1 (0.6)	NBCM ($n = 1$)
Patient complained about pain	1 (0.6)	NBCM ($n = 1$)
Exposed titanium mesh	1 (0.6)	NBCM ($n = 1$)
Wound dehiscence	1 (0.6)	NBCM ($n = 1$)
Fractured bone plate during augmentation surgery	1 (0.6)	NBCM ($n = 1$)

Table 4

Table 5

Defect morphology (number of bone walls present)	No complication (%)	Complication (%)	Membrane type used per surgical area in which complication developed
1–4	1 (100.0)	0 (0.0)	–
2	12 (85.7)	2 (14.3)	NBCM (<i>n</i> = 2)
2–3	8 (80.0)	2 (20.0)	NBCM (<i>n</i> = 2)
3	62 (92.5)	5 (7.5)	JM (<i>n</i> = 2) NBCM (<i>n</i> = 3)
3–4	8 (88.9)	1 (11.0)	NBCM (<i>n</i> = 1)
4	54 (91.5)	5 (8.5)	DM (<i>n</i> = 1) NBCM (<i>n</i> = 4)

Table 5

Number of complications per defect morphology and types of membranes used per surgical area with complications.

Table 6

Number of secondary augmentations performed after healing.

Table 6

Secondary augmentations	Number of surgical areas (%)
Not necessary	139 (86.88)
Planned	20 (12.50)
Unplanned†	1 (0.63)

† Re-augmentation.

brane degradation and a shortened barrier function.¹⁹ Various studies have shown controversial results regarding the effect of secondary wound dehiscence occurring during healing. Moses et al. evaluated bone healing of buccal periimplant bone dehiscence defects with or without membrane exposure.²¹ Using NBCM, they found a mean defect reduction of 95% in the case of uneventful healing, while defect resolution was significantly reduced to 53% when the membrane was exposed. In a dog study, a significant negative effect of membrane exposure on defect fill was found too.²² In contrast, other studies demonstrated only a slight, nonsignificant reduction in defect fill if exposed membrane sites were compared to nonexposed ones.^{16, 19} In ridge preservation, positive results using the membrane in an open-healing approach have been described before. Filipek et al. compared open and closed healing in extraction sites in 40 patients.²³ When analyzing the dimensions of the alveolar ridge six months after tooth extraction, they did not find any significant difference between open and closed healing. In another study, Cardaropoli et al. achieved good results using open healing with regard to ridge dimension.⁸

However, the control treatment was spontaneous extraction socket healing and there was no control treatment with closed healing.

Owing to its retrospective nature and the lack of a control group, the current analysis does not allow drawing of clear conclusions on whether open healing may have a certain negative effect on the outcome of the regenerative procedure. The positive result regarding the low necessity of re-augmentation indicates that open healing may be a suitable clinical procedure. However, prospective studies should compare the outcome of open and closed healing under standardized clinical conditions.

In this study, the second outcome parameter was the incidence of complications during healing. Healing was uneventful in 90.6% of the surgical areas. In 2.5% of the surgical areas, the complications were associated with the surgical intervention (hematoma and one broken bone plate). In 6.9% of the areas, the complications may have been related to the open-healing approach. These complications were premature resorption, membrane loosening by tongue, exposed titanium mesh and wound dehiscence. A certain rate of healing complications has been

reported with closed healing too. In a study using NBCM in periimplant defects, Zitzmann et al. found wound dehiscences in 16% of the defects at the time point of suture removal.¹⁶ Von Arx and Buser reported a complication rate of 9.5% during healing in horizontal ridge augmentation.¹ The sites re-epithelized spontaneously within two to four weeks and the authors concluded that the membrane did not cause infections when exposed.

Moses et al. found wound dehiscences in 39% of patients treated with cross-linked collagen membranes.²¹ In a multicenter randomized, controlled clinical trial, bone augmentation procedures using DBBM and NBCM were applied in 90% of 208 patients undergoing immediate implant placement with transmucosal healing.²⁴ After one week, flap dehiscences were noted in 12% of the cases. After two weeks, the percentage had decreased to 6.0% and after six weeks to 1.5%, indicating proper secondary healing even in the case of membrane exposure. In the retrospective analysis presented here, the overall complication rate of 9.4% indicates that open healing is not associated with an increased risk of healing complications compared with closed healing. Studies have indicated that native collagen membranes may facilitate angiogenesis.²⁵ and allow for less compromised wound healing in comparison with cross-linked collagen materials.¹⁹ Therefore, native collagen may promote uneventful soft-tissue healing under open-healing conditions too. Apart from material-related wound dehiscence, iatrogenic factors like suture technique may play an even more important role, but to our knowledge, no study has reported on the rate and effect of tensionless wound closure compared with flaps under tension. However, further studies are needed to investigate wound healing when the flap is not closed over the membrane.

Owing to the large variety of defect morphologies, no clear correlation could be found between defect morphology and healing complications, although there was a small trend for a higher complication rate in defects with a higher number of missing bone walls. However, the positive outcomes for all defect morphologies indicate that open healing is not limited to a certain defect type.

While NBCM was applied in most of the areas, a few other materials were used too. The number was too small to draw a clear conclusion on possible differences in healing between these different membrane types. Further studies

are necessary to compare the suitability of various membranes for open healing.

Conclusion

The retrospective analysis of patients treated in a private practice indicates that open healing using suitable membrane materials allows uneventful healing and sufficient bone formation. Thereby, soft-tissue problems associated with extensive flap mobilization and tension may be avoided. There was no control group and the data set included different indications, defect morphologies and defect sizes. While this limits the power of the study, it reflects the situation in private practice. Furthermore, if open healing allows for achieving good results in a nonuniform patient group, one may conclude that it could have the potential to become a general clinical option. Prospective studies with control groups are needed to further investigate this surgical approach.

Competing interests

The author declares that he has no competing interests.

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Periimplant soft-tissue management in patients with a fibula free flap reconstruction: Case series and description of a new technique

Abstract

Objective

Objective: The aim of the present pilot case series study was to present a new technique for managing the periimplant soft tissue before implant placement, the soft-tissue template technique.

Materials and methods

This study was designed as a pilot case series study. At least six months after reconstruction with a fibula free flap, all crestal soft tissue, including skin and muscle, was removed, leaving only periosteum attached to the reconstructed alveolar crest. The soft tissue was then remodeled according to a new technique. One month after complete soft-tissue healing, implants were inserted with a flapless technique using a computer-guided template. Three to six months later, a screw-retained prosthesis was delivered. Outcome measures were implant survival and periimplant mucosal response, based on probing pocket depth (PPD) and bleeding on probing (BOP).

Results

Six patients (four males and two females) with a mean age of 48.4 years were treated. A total of 32 implants were inserted. No dropout occurred during the entire follow-up period. No implant failed and the overall implant survival rate was 100% 12 months after definitive prosthesis delivery. All of the patients presented with healthy soft tissue, stable PPD and good BOP values at the one-year follow-up. The mean PPD values were 3.6 ± 0.6 mm and the mean BOP values were $9 \pm 4.8\%$.

Conclusion

Within the limitations of the study, this technique appeared to improve the quality of transplanted periimplant soft tissue. Further clinical trials are needed to validate this approach.

Keywords

Free flap, fibula, periimplant soft tissue.

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Introduction

Bone continuity defects after oncological jaw resection or for other reasons may result in a series of problems, such as facial contour disfigurement, large oronasal and oroantral communications, saliva retention, and impaired speech, swallowing and mastication. Fibula and iliac crest free flaps have demonstrated high reliability for reconstruction of mandibular and maxillary large bone defects. They are used as both osseomuscular and osseomyocutaneous flaps and allow the simultaneous reconstruction of bone continuity and both intraoral (cheek mucosa, palate, floor of the mouth, etc.) and cutaneous (chin, cheek, etc.) soft-tissue deficiencies.^{1,2} Additionally, patients with oral cavity defects often present with loss of teeth and alveolar and basal jawbone, which can lead to significant impairment of mastication. With this microvascular reconstructive option, dental prosthetic rehabilitation is possible even if the prosthesis-based rehabilitation remains a challenge.^{3,4}

Implant-based dental restorations in patients reconstructed with fibula flaps have been shown to offer many benefits, such as sufficient stabilization of the prosthesis, even in patients with marked irregularities of the hard- and soft-tissue anatomy, and they can compensate for small local soft-tissue deficiencies, contributing to an improved aesthetic result (i.e., by supporting the lip profile). A recurring problem during implant-prosthesis rehabilitation after reconstruction with vascularized free flaps is the hyperplastic granulomatous reactive tissue that can grow around the implant abutments of the prosthesis.

The reconstructed soft tissue lacks the physiological properties and function of native mucosa. Normal attached gingiva and alveolar mucosa differ from soft tissue reconstructed with skin and muscle. After implant-prosthesis restoration, excessive soft-tissue bulk, movement, chronic inflammation and hypertrophy are readily observed around implants and risk compromising the long-term implant success. This phenomenon, which has been described by others,⁵ is an unresolved problem. Various clinical reports suggest different approaches, with contradictory results.⁶

Some have harvested keratinized mucosa from the hard palate and grafted it around the implants after removing the skin.⁷ Others prefer skin grafts associated with remodeling and deepening of the fornix. Both procedures are

often associated with soft-tissue remodeling as a result of the prosthesis.⁷⁻⁹ The aim of the present pilot case series study was to present a new technique for managing the periimplant soft tissue before implant placement, the soft-tissue template technique.

Materials and methods

This study was designed as a pilot case series study aimed at evaluating a new technique for periimplant soft-tissue management (soft-tissue template technique) in patients reconstructed with fibula free flaps after mandibular or maxillary resection for oncological reasons. Patients were selected and consecutively treated at the Maxillofacial Surgery Unit, University Hospital of Sassari, Sassari, Italy. The study was conducted in accordance with the principles outlined in the Declaration of Helsinki of 1964 for biomedical research involving human subjects, as amended in 2008. The patients were duly informed about the nature of the study. Written informed consent to surgical treatment was obtained from each patient.

Patients were not admitted to the study if any of the following exclusion criteria were present: general contraindications to implant surgery; subjected to irradiation in the head and neck area less than one year before implantation; untreated periodontitis; signs or symptoms of cancer recurrence; poor oral hygiene and motivation; uncontrolled diabetes; alcohol abuse; psychiatric problems or unrealistic expectations; active infection or severe inflammation in the area intended for implant placement; and inability to attend the follow-up visits.

Clinical procedures and description of the technique

At least six months after reconstruction with a fibula free flap (**Fig. 1**), all crestal soft tissue, including skin and muscle, was removed, leaving only periosteum attached to the reconstructed alveolar crest (**Fig. 2**). Immediately after removing the soft tissue, an impression was taken of the crest and residual teeth using a silicone material to customize an acrylic soft-tissue template. The template was shaped to cover the entire crest and have a large vestibular flange used to deepen the fornix. A small space was left between the crest and acrylic template. The

Fig. 1
Reconstructed soft tissue six months after surgery.

Fig. 2
Clinical view fibula free flap after soft-tissue removal.

Fig. 3
A patient wearing the soft-tissue template.

Fig. 4
Reconstructed soft tissue one month after treatment.

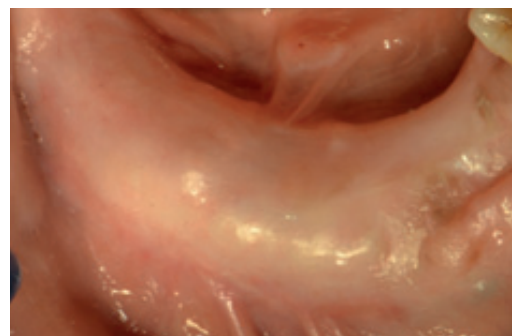
Fig. 5
Occlusal view after implant placement.

Fig. 6
Final prosthesis five years after loading.

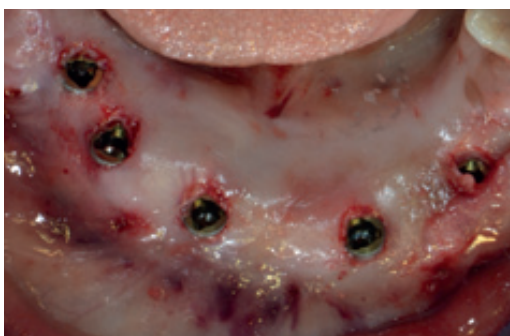
Fig. 7
Panoramic radiograph five years after loading.



Figs. 1 & 2



Figs. 3 & 4



Figs. 5 & 6

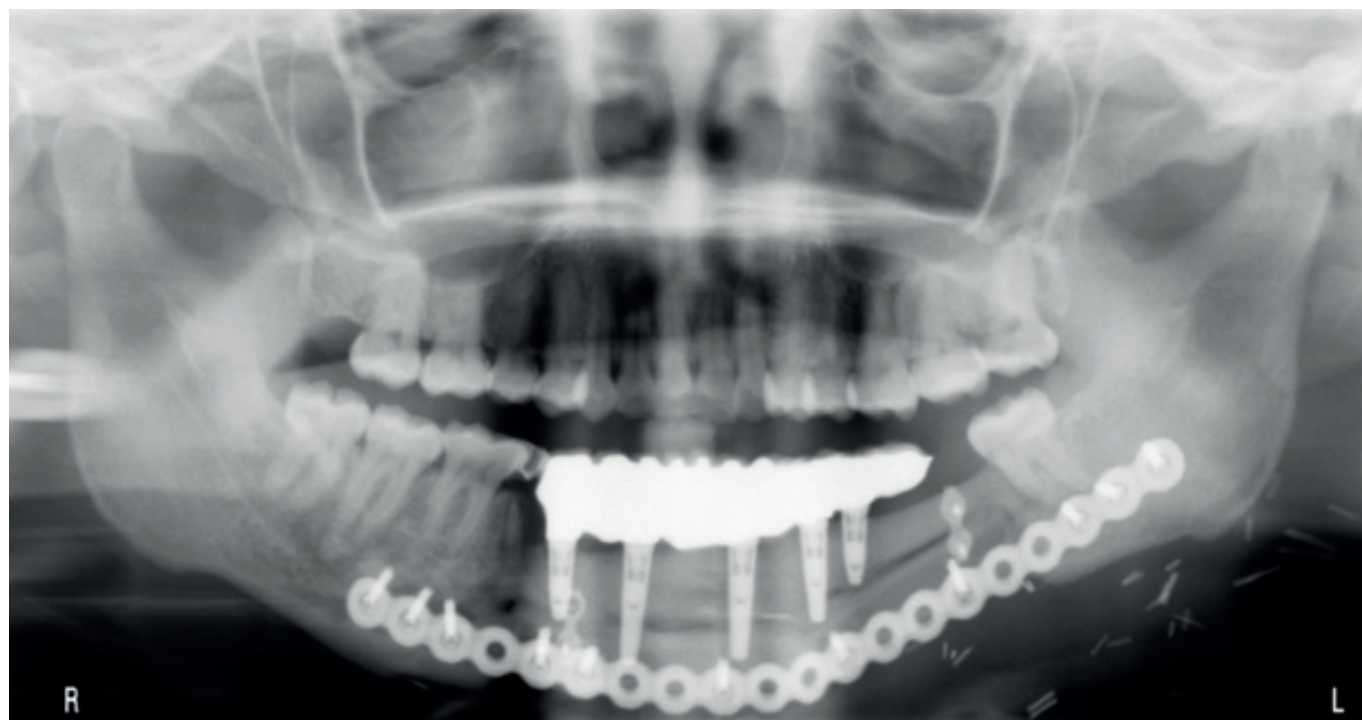


Fig. 7

soft-tissue template was delivered 24 h after surgical soft-tissue removal and the patient was asked to apply corticosteroid cream under the template b.i.d. for one month (**Fig. 3**). Subsequently, the new tissue appeared more similar to the gingiva, with reduced thickness and greater attachment to the underlying bone (**Figs. 4–6**). One month later, implants were inserted with a flapless technique using a computer-guided implant template. Three to six months later, a definitive screw-retained implant-supported bridge was delivered.

Outcome measures were:

Implant failure: Implants that had to be removed at implant insertion owing to lack of stability, implant mobility, removal of stable implants dictated by progressive marginal bone loss or infection, and any technical complications (e.g., implant fracture), rendering the implant unusable. The stability of individual implants was assessed at delivery of the definitive prosthesis by tightening the abutment screw at a torque of 20 N cm and 12 months after definitive prosthesis delivery.

Complications: Any biological (pain, swelling, suppuration, etc.) and/or technical complication (fracture of the framework and/or the veneering material, screw loosening, etc.) was considered.

Periimplant mucosal response: Probing pocket depth (PPD) and bleeding on probing (BOP) were measured by a blinded operator with a periodontal probe (PCP-UNC 15, Hu-Friedy, Chicago, Ill., U.S.) 12 months after definitive prosthesis delivery. Three vestibular and three lingual values were collected for each implant and averaged at patient level. An independent hygienist performed all of the periodontal measurements.

Results

Six patients (four males and two females) with a mean age of 48.4 years were considered eligible and treated. A total of 32 implants (NobelReplace Tapered Groovy, Nobel Biocare, Göteborg, Sweden), ranging from 8.0 mm to 16.0 mm in length and from 3.5 mm to 5.0 mm in width, were placed. No dropout occurred during the entire follow-up period. No implant failed and the overall implant survival rate was 100% one year after definitive prosthesis delivery. All of the patients presented with healthy soft tissue, stable PPD

and good BOP values at the one-year follow-up. The mean PPD and BOP values were 3.6 ± 0.6 mm and $9 \pm 4.8\%$, respectively.

Discussion

Fibula and iliac crest osseomyocutaneous free flaps have been demonstrated to be very reliable for the reconstruction of large composite facial defects after resection of tumors, osteoradionecrosis or gunshot trauma. Moreover, implant-supported prosthetic rehabilitation is reliable with this microvascular reconstructive option because of sufficient volume and good bone quality.^{4,9} Nevertheless, prosthesis-based implant treatment still represents a major challenge in these difficult cases. The surgical procedure for implant placement can be more difficult owing to limited opening of the scar-contracted oral cavity or the presence of large volumes of soft tissue with little information on the profile of the underlying bone, which is necessary for a valid surgical guide. Moreover, the need to limit the exposure of frequently irradiated bone or scarred fields reduces surgical precision. Furthermore, scars and the thickness of the soft tissue can interfere with the prosthetic procedures, such as taking fixture impressions, and may lead to imprecise results.

A detailed soft-tissue analysis of these patients is essential. It is clear that normal attached gingiva and alveolar mucosa differ from soft tissue reconstructed with skin and muscle. A frequent complication arising from the reconstruction of intraoral soft tissue with skin is the hyperplastic/inflammatory response of the skin and subcutaneous tissue around implant abutments and the formation of a granulomatous tissue, which may cause pain and bleeding during brushing. This phenomenon, Although no specific data are available concerning this phenomenon, which has already been described by others,⁵ it is possible to speculate that the reconstructed skin is not a suitable tissue around implants and may react negatively in the oral environment. In our opinion, many of the techniques described for managing the transplanted tissue, such as palatal epithelial connective tissue grafts or free skin grafts, present some limitations owing to the difficulty in obtaining a real engraftment. A unique solution to this problem does not exist and therefore it requires an individualized approach. The approach described in this article appears to be useful especially because it does not

require grafting and it appears to radically reduce the thickness of transplanted soft tissue. However, long-term prospective clinical trials eventually supported by histological data are needed to confirm these clinical findings.

or gingiva) from elsewhere. In addition, after implant placement and prosthesis loading, the reconstructed tissue appeared stable, fixed around the abutment and implant neck, and clinically healthy. Further clinical trials are needed to validate this approach.

Conclusion

Within the limitations of the study, this technique appears to minimize the donor site morbidity that results from harvesting tissue (skin

Competing interests

The authors declare that they have no competing interests.

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Histological and biomechanical effects of implant surfaces sandblasted with titanium dioxide microparticles: An experimental study using the rabbit tibia model

Abstract

Objective

The objective of this study was to investigate the effect of sandblasted, large-grit, acid-etched (SLA) implant surfaces treated with titanium dioxide (TiO₂) microparticles on the implants' stability and resistance to reverse torque.

Materials and methods

Six rabbits received 24 cylindrical dental implants and were placed in two groups ($n = 3$ per group): control group, with smooth surfaces; and test group, with the SLA surface treated with TiO₂ microparticles. All of the animals were sacrificed after four weeks. Half of the implants (one per animal from each group) were used to test removal torque values and half of them were used for the histological analysis.

Results

Reverse torque was significantly different between the groups ($p = 0.0001$). The histological analysis showed higher degrees of bone organization in surface samples from the test group.

Conclusion

Results indicate that blasting implant surfaces with TiO₂ particles is an appropriate treatment option, with minimal risk of contamination by residual debris from the procedure.

Keywords

Implant surface, osseointegration, removal torque, titanium dioxide microparticles.

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Introduction

Per-Ingvar Brånemark, a Swedish professor, demonstrated that osseointegration of titanium implants is such that the bone remains in close contact with the implant surface without any intervention by the connective tissue, although the titanium dioxide (TiO₂) layer interacts directly with the bone tissue.¹ The physical and chemical features of titanium, particularly its intrinsic properties, such as biocompatibility, low specific weight, high strength–weight ratio, low modulus of elasticity, and excellent corrosion resistance, are favorable for the manufacture of dental implants.² Furthermore, titanium surfaces can be modified in an attempt to enhance their biological properties.³ Such modifications are achieved by adding a coat consisting of different types of bioactive substances, by removing portions of the external layer with the use of blasting materials of different particle sizes, or by applying chemical treatments and/or physical ones, such as laser.⁴ Among these, blasting and acid etching have been the most widely used. In addition, their combination has shown improved biological activity of titanium surfaces in terms of implant osseointegration relative to smooth (machined) surfaces.⁵

The modification of the implant surface can thus have benefits regarding the response of the surrounding bone tissue, accelerating the healing process and/or improving the quality of the newly formed bone.^{5–7} Studies have shown that osseointegration is related to microgeometric features, such as the degree of surface roughness, and to factors such as the physical and chemical properties of surfaces.^{7,8} Rough surfaces were found to stimulate osteoblastic gene expression and to enhance bone formation and bone implant fixation.^{9,10} While an associated inflammatory response was reported,¹¹ the overall success rate was satisfactory, with the majority of implants yielding good osseointegration and stability one year after surgery.¹²

Dental implant manufacturers have developed and marketed implants with several types of chemical and physical surface treatments.¹³ However, there is still no consensus on what the optimal conditions for periimplant bone growth are. It is known that bone response can be influenced by implant surface topography at the micrometer level, and it has been hypothesized that a nanometric surface can also have an effect.¹⁴ Notwithstanding, the mechanisms be-

hind an optimal bone response to a given type of surface still remain largely unknown.

Surfaces known as SLA (sandblasted, large-grit, acid-etched) are produced by blasting with microparticles of some materials followed by acid etching. Alumina is one of the most widely used materials, but some authors have highlighted some features of alumina blasting that could compromise osseointegration (e.g., particle detachment during the healing process and absorption by the surrounding tissues).¹⁵ The presence of alumina residues on implant surfaces due to the manufacturing process has been regarded as a potential risk, compromising long-term osseointegration.^{16,17} Alternatively, TiO₂ is used as a blasting material and has shown interesting results in experimental studies. Particularly, TiO₂-blasted implants were associated in humans with a significant enhancement of bone-to-implant contact (BIC) when compared with machined surfaces.^{18–20} Under unfavorable clinical conditions, such as in the presence of poor-quality bone, fast and predictable osseointegration would be beneficial, allowing prosthetic rehabilitation. In the case of insufficient bone quantity or anatomical limitations, or in the presence of local and systemic conditions that could compromise long-term osseointegration, implants with a rough surface show better bone apposition and BIC than do those with smooth surfaces.^{21,22} Therefore, the aim of the present *in vivo* study was to evaluate the behavior of surfaces shortly after implantation by measuring removal torque and analyzing histological parameters.

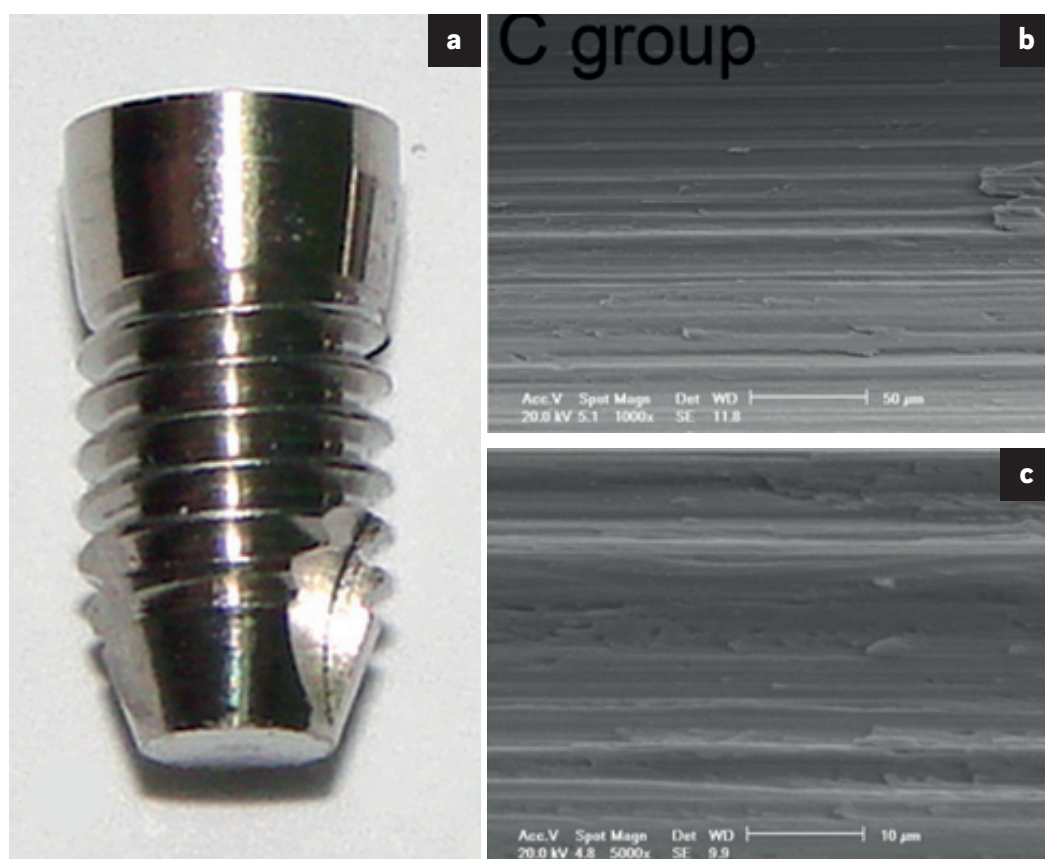
Materials and methods

Twenty-four cylindrical self-tapping implants with internal hexagon packaged and ready for sale were used for *in vivo* testing. Twelve implants with a machined surface (**Fig. 1**) were used in the control group (C group). Twelve implants with surfaces sandblasted with 50–150 µm TiO₂ microparticles at a 5 atm pressure for 1 min, ultrasonically cleaned with an alkaline solution, rinsed in distilled water and then conditioned with maleic acid (**Fig. 2**) were used in the test group (T group). The implants (Implacil De Bortoli, São Paulo, Brazil) were 4 mm in diameter and 8 mm in length.

Six mature New Zealand white rabbits were used in this study. This study was approved by the Ethics Committee (#004-09-2015) of the

Figs. 1a–c

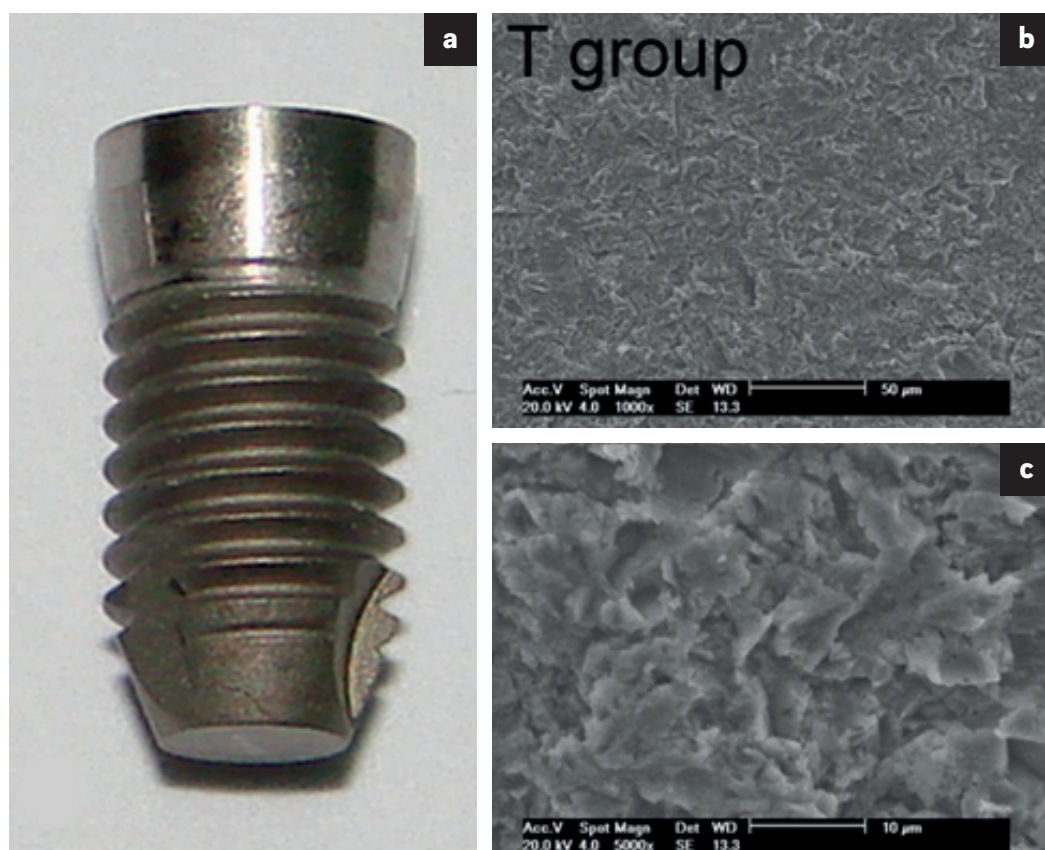
(c) Image of the implant used as control (C group), with smooth surface.
(b & c) SEM images of the surface at 1,000× and 5,000× magnification.



Figs. 1a–c

Figs. 2a–c

(c) Image of the implant used as test (T group), with SLA surface.
(b & c) SEM images of the surface at 1,000× and 5,000× magnification.



Figs. 2a–c

Figs. 3 & 4

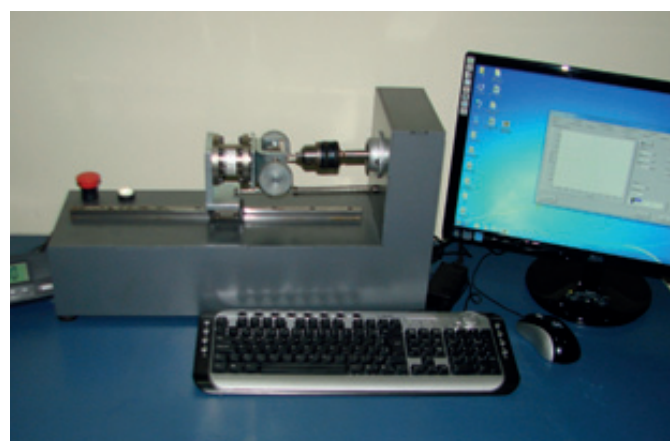


Fig. 3
Image of the implants inserted into the tibia.

Fig. 4
Image of the computerized torque machine used in the removal torque test.

Itapiranga Faculty of Veterinary Medicine, Itapiranga, Brazil. The rabbits were anesthetized by intramuscular ketamine (35 mg/kg; Agener Pharmaceutica, Brazil). Thereafter, a muscle relaxant (Rompum 5 mg/kg, Bayer, Brazil) and a tranquilizer (Acepran 0.75 mg/kg, Univet, Brazil) were injected intramuscularly. Additionally, 1 mL of local anesthetic (3% prilocaine-felypressin, Astra, Mexico) was injected subcutaneously at the site of surgery to improve analgesia and control bleeding. A skin incision with a periosteal flap was used to expose the bone in the proximal tibia. The preparation of the bone site was done with burs under copious saline irrigation. Two implants were inserted into the tibial metaphysis of each rabbit (**Fig. 3**), one most proximal at 5 mm from the articulation and the other 10 mm to the distal, thus avoiding differences in bone typology in this area. The implant position was randomized for each animal at www.randomization.com. The tibia was chosen as the implant site because it provides easier surgical access. The implant insertion was performed by hand with a torque of < 20 N until locking of the implant in the opposite cortical portion of the osteotomy, as part of the implant shoulder just out in relation to the top of the cortical bone crest, thereby avoiding excessive compression of the bone due to implant design. The periosteum and fascia were sutured with catgut and the skin with silk. Postoperatively, a single dose of 600,000 IU of benzathine penicillin (Benzetacil, Eurofarma Laboratórios, Rio de Janeiro, Brazil) was used. After surgery, the animals were placed in individual cages with 12-h cycles of light, controlled temperature (21 °C), and food and water *ad libitum*. No complications or deaths occurred in the postoperative period. All of the animals were euthanized after four weeks using an intravenous overdose

of ketamine (2 mL) and xylazine (1 mL). A total of 24 implants were retrieved. The implants of all right tibiae were immediately analyzed using a torque-testing machine (CME, Técnica Industrial Oswaldo Filizola, Guarulhos, Brazil), which was fully controlled by DynaView Torque Standard/Pro M software (**Fig. 4**).

All of the implants of the left tibiae were used for histological analysis and were placed in 10% formalin after removal and taken to the Biotecnos Laboratory (Santa Maria, Brazil). After the fixation period, they were dehydrated in an ascending series of alcohols and embedded in glycol methacrylate resin (Technovit 9100 VLC, Kulzer, Hanau, Germany) to produce undecalcified sections. Undecalcified cut and ground sections that contained the central part of each implant and had a final thickness of 15 µm were produced using a macro-cutting and -grinding system (Iso-met 2000, Buehler, Braunschweig, Germany). The sections were stained with picro-sirius-hematoxylin, and histomorphometric analysis was then carried out. The specimens prepared for the analysis of the tissue around the implant were examined under a light microscope (EOS 200, Nikon, Tokyo, Japan). After digitizing the phase of each specimen under a light microscope, the percentage of bone-to-implant contact (BIC%) was measured using the Image Tool software for Microsoft Windows (Version 5.02). BIC% was calculated as the percentage of the total length of bone in direct contact with the implant surface, from the first crestal bone contact to the most apical contact.

The statistical analysis was performed using the *t*-test for comparison between groups. Two correlation measurements were used to assess the relationship between the groups: Pearson's correlation coefficient (with $-1 < R < 1$; when *R* is

Fig. 5

Removal torque values (N cm) at four weeks in both groups.

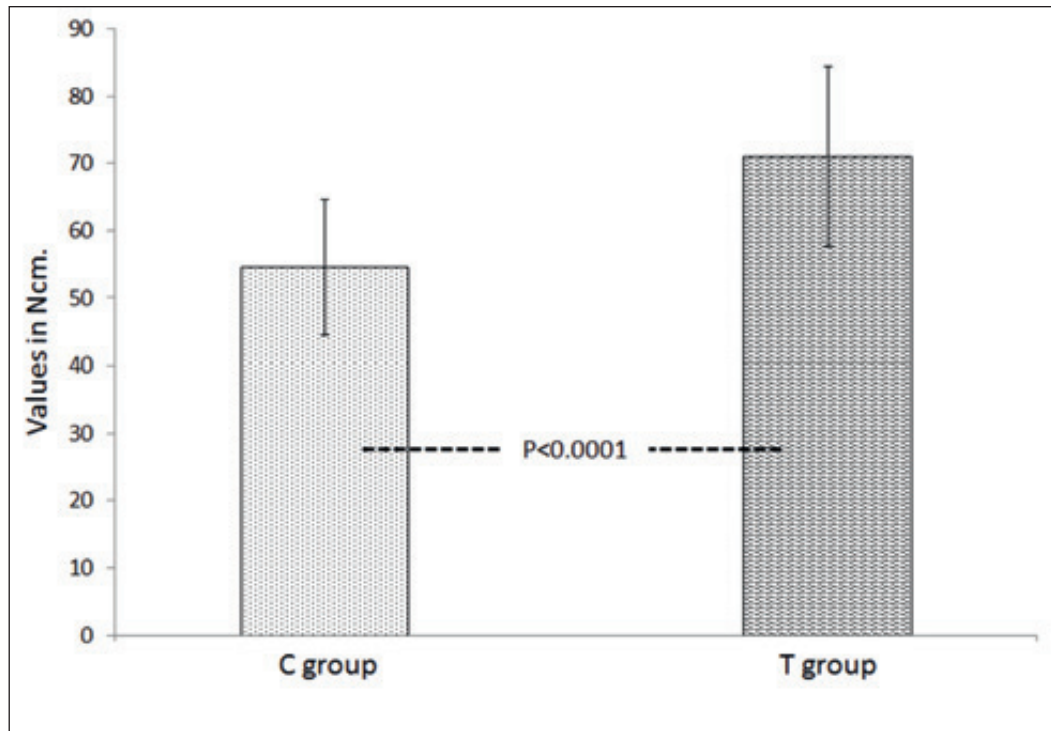


Fig. 5

close to ± 1 this indicates that the variables are correlated; however, the relationship is linear) and Spearman's rank correlation coefficient, similar to Pearson's correlation coefficient, with $-1 < R < 1$. This measurement was more comprehensive because we assessed whether the relationship between the variables was nonlinear. All of the tests were performed using specific software (MedCalc, MedCalc Software, Belgium). The level of significance was set at $\alpha = 0.05$.

Results

The surgical procedures were uneventful and all of the animals presented appropriate healing within the first weeks after surgery. Inspections made during two postoperative weeks indicated no infection or inflammation. The biomechanical tests indicated osseointegration of all of the implants, but torque after four weeks was higher in the T group (71.0 ± 13.4 N cm; median of 73.5) than in the C group (54.5 ± 10.0 N cm; median of 56.5). The mean $\pm$ standard deviations and the statistical comparison are presented in **Figure 5**. The paired statistical tests showed that torque was significantly higher in the T group than in the C group at four weeks ($p < 0.0001$).

BIC% was higher in the T group ($64.8 \pm 7.4\%$; median of 66.0) after four weeks than in the C group ($50.4 \pm 7.9\%$; median of 49.5). These

data and statistical significance ($p = 0.0005$) are shown in **Figure 6**. The new bone formed around the implants in the C group was not completely mineralized (**Fig. 7**). In the T group, however, better organization and mineralization were found after four weeks (**Fig. 8**) and there was better stimulation of the medullary bone portion (**Fig. 9**).

The Kolmogorov–Smirnov test identified that only the BIC% of the T group had nonparametric data. Thus, the correlation between reverse torque and BIC% (machined) was determined by Pearson's correlation coefficient ($R = -0.52$; $p = 0.08$; 95% CI $[-0.84-0.07]$), whereas the correlation between reverse torque and BIC% (treated) was determined by Spearman's correlation coefficient ($R = 0.08$; $p = 0.79$; 95% CI $[-0.51-0.62]$). The statistical data are summarized in **Table 1**.

Discussion

Over the past decades, several *in vivo* studies have examined the effect of implant surfaces on bone healing and apposition.^{23, 24} Modifications in implant surface morphology and roughness were initially attempted to hasten host response to implants and to increase the level of mechanical interlock between the bone and implant surface, thus improving initial stability and sub-

Fig. 6

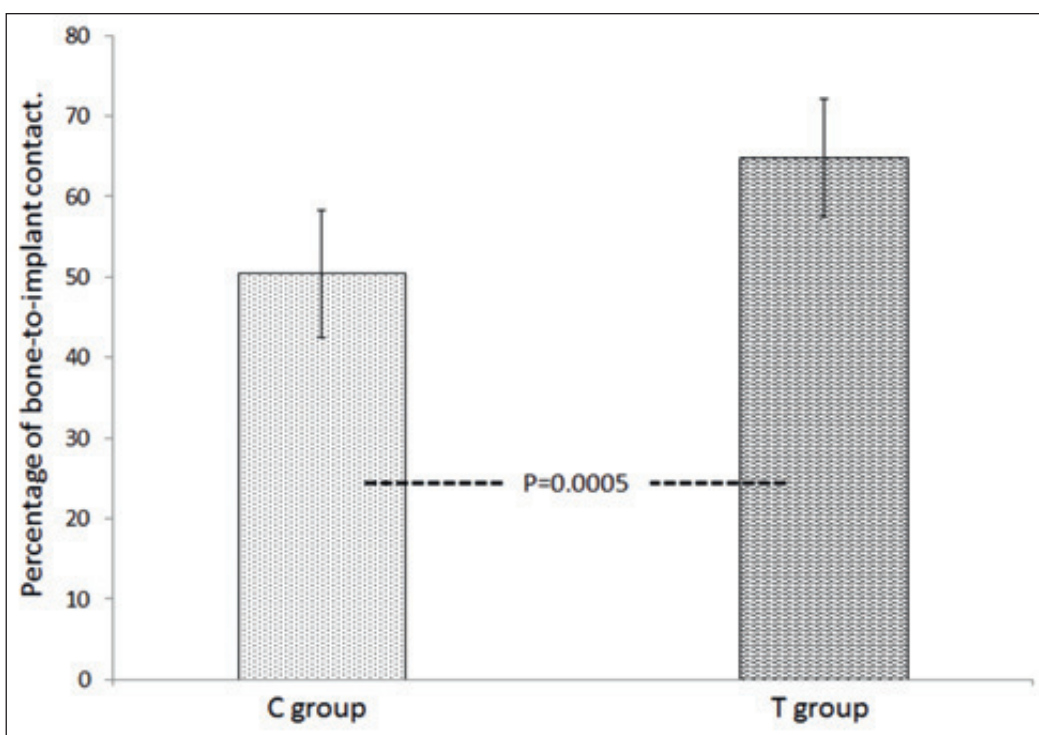


Fig. 6

BIC values (%) at four weeks in both groups.

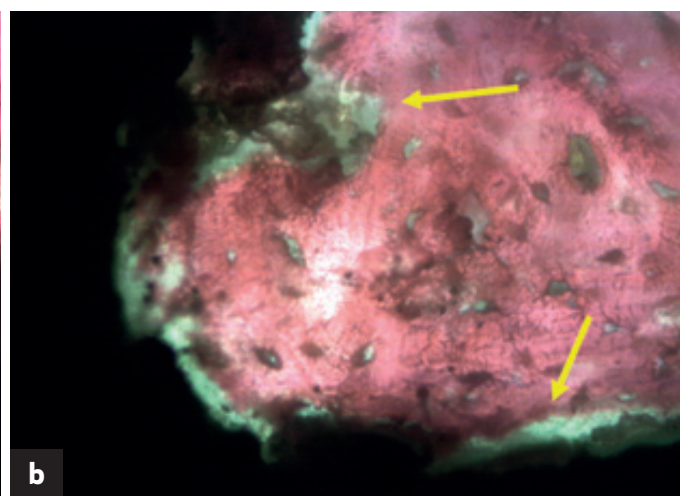
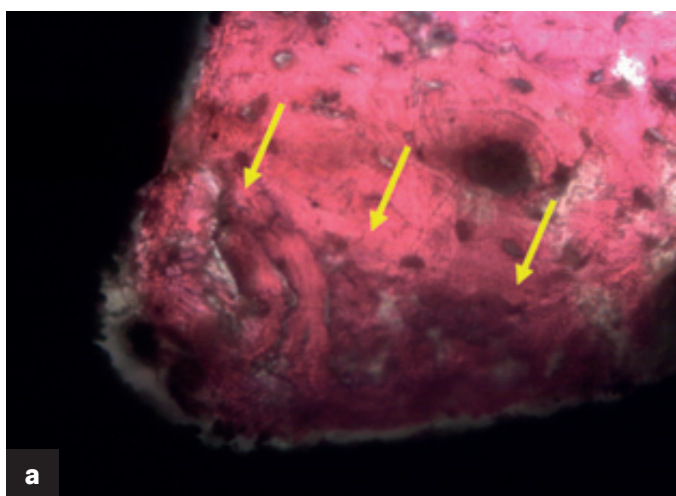
Figs. 7a & b

Histological images showing bone maturation and mineralization in the C group after four weeks, with new bone formation around the implants showing incomplete mineralization. (a) 200× and (b) 400× magnification. Staining with picro-sirius-hematoxylin.

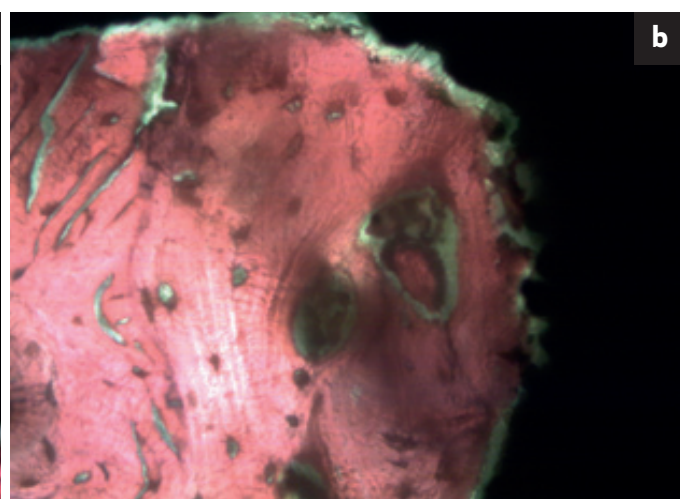
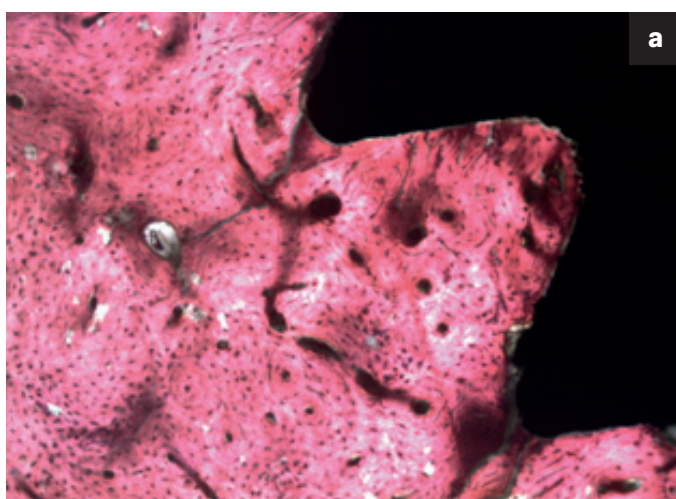
Figs. 8a & b

Histological images showing bone maturation and mineralization in the T group after four weeks, with more advanced new bone formation around the implants in the new bone organization areas. (a) 100× and (b) 400× magnification. Staining with picro-sirius-hematoxylin.

Figs. 7a & b



Figs. 8a & b



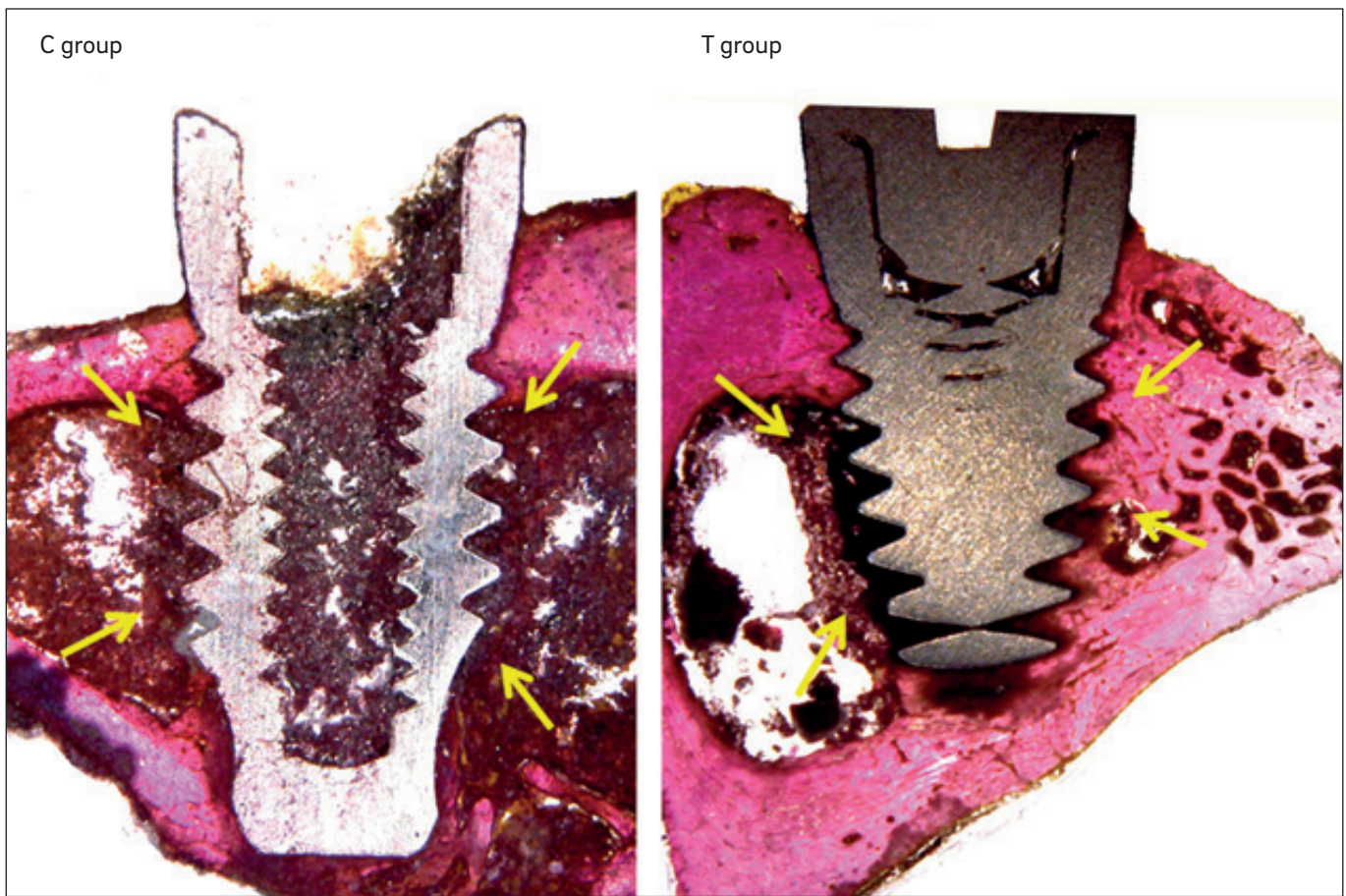


Fig. 9

Fig. 9

Histological images showing bone maturation and the BIC after four weeks. There was visibly better stimulation of the medullary bone portion in the T group in comparison to the C group (yellow arrows).

Table 1

Mean $\pm$ SD and median (reverse torque and BIC%) values at baseline and at eight weeks.

Groups	Reverse torque (N cm)		BIC (%)		Coefficient of correlation
	Mean $\pm$ SD	Median	Mean $\pm$ SD	Median	
Control	54.5 $\pm$ 10.0	56.5	50.4 $\pm$ 7.9	49.5	0.08
Test	71.0 $\pm$ 13.4	73.5	64.8 $\pm$ 7.4	66.0	0.79
P-value		< 0.00001*		0.0005*	

Table 1

* Between-group comparisons (Wilcoxon's test; significance level: $p < 0.05$).

sequent stress dissipation during functional loading.^{25, 26}

Histological investigations have shown that the surface texture created by blasting leads to greater BIC than that of machined surfaces,²⁷ which is a desirable response, as it allows improvement of the overall biomechanics of the system. Blasting the implant surface with gritting agents made of materials other than alumina may change the surface composition and implant biocompatibility.²⁸ Abrasive blasting increases surface roughness and metal surface reactivity.²⁸

With the use of a blasting material such as alumina, a potential risk of contamination by remnants of blasting particles, with dissolution of aluminum ions into the host tissue, cannot be excluded.²⁸ It has been reported that aluminum ions may inhibit normal differentiation of bone marrow stromal cells and normal bone deposition and mineralization,^{29–31} and aluminum has been shown to induce net calcium efflux from the cultured bone.³² Moreover, aluminum may compete with calcium during the healing of the implant bed. Aluminum has been shown to ac-

cumulate at the mineralization front and in the osteoid matrix itself.³³ Therefore, other alternative sandblasting methods were developed in order to roughen the implant surface, such as the use of resorbable particles based on calcium³⁴ and TiO₂,^{35, 36} both of which are unproblematic if small residues remain after surface treatment procedures.

The effects of sandblasting the implant surface with titanium oxide as an alternative to aluminum oxide have been investigated previously.^{19, 20, 27, 28, 37–40} The research protocols took into account biomechanical (removal torque), interfacial and histological analyses, as well as histomorphometric and microhardness measurements. Only one study observed and analyzed specimens using both scanning electron microscopy (SEM) and histomorphometry, as well as the removal torque test, in dogs.³⁷ This study demonstrated that implants blasted with TiO₂ particles had a better anchorage than implants with a machine-produced surface, in spite of there being no difference in BIC.³⁷

Animal models are essential in providing phenomenological information on biological reaction to endosseous implants.⁴¹ The removal torque test is among the *in vivo* mechanical tests commonly used to evaluate the strength of the interaction between the bone and implant surface.^{42–44} High resistance to implant removal encountered during these tests indicates good integration between the bone and implant surface, or in the case of porous materials, a high degree of bone ingrowth into the pores of the implant.⁴⁴ The present study evaluated the extent of osseointegration and the characteristics of the bone around the surface within four weeks after implantation.

Previous research has shown that surface characteristics influenced BIC, with statistically significant differences on different implant surfaces.⁴¹ Histomorphometric and removal torque

measurements are two representative tests used to assess the nature of the implant–tissue interface.⁴⁵ In this study, both surface biocompatibility and osteoconductive properties were confirmed by the biomechanical tests. Such interaction was more pronounced for the textured surface compared with the machined one, indicating a possible synergistic interaction of the mechanical interlock between the bone and implant surface and higher bone formation compared with the machined surface. The reverse torque values may appear rather high even for implants with a machined surface. This has to do with the experimental model chosen. In fact, the cortical bone of rabbit tibia is very compact and may firmly interlock with the implants. However, the aim of the present study was not to estimate parameter values that could be directly transferred to patients, but to compare two different surfaces using both *in vitro* and *in vivo* approaches. The results confirm that TiO₂-blasted surfaces allow for greater osteoconductivity and accelerated bone formation compared with machined surfaces and are therefore recommended for anticipated loading protocols.

Conclusion

Despite the limitations of this study, TiO₂ blasting displayed a positive effect on osseointegration and on the biomechanical features of the implants. The histological results confirmed the hypothesis that the SLA surface using blasting with TiO₂ microparticles positively affects the osseointegration of titanium dental implants.

Competing interests

The authors declare that they have no conflict of interests related to this study.

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A systematic review on the definition of periimplantitis: Limits related to the various diagnoses proposed

Abstract

Objective

The aim of this comprehensive systematic review was to present the different definitions of periimplantitis proposed in the literature.

Materials and methods

Electronic and manual literature searches were conducted by three independent reviewers to identify manuscripts reporting data on the definition of periimplantitis with clinical diagnosis, written in English and published up to October 2015. Several databases were referenced, including PubMed, Embase, the Cochrane Library and the Grey Literature Database.

Results

Forty-nine articles were considered suitable for the review. Current evidence suggests the use of unequivocal case definitions for periimplantitis, defined by changes in the level of crestal bone, presence of bleeding on probing and/or suppuration, with or without concomitant deepening of periimplant pockets. However, several reference points were used to measure these changes, including different levels of severity and years of follow-up.

Conclusion

The available scientific literature suggested an absence of a unanimous definition of periimplantitis. Future studies that apply consistent case definitions should be considered.

Keywords

Periimplantitis, diagnosis, dental implant, periodontitis, risk factors.

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Introduction

The term "periimplantitis" was introduced in the early 1960s to describe infectious pathological conditions of the periimplant tissue.¹ Today, periimplantitis is the most frequent complication of dental implants and occurs with a frequency ranging from 1% to 47% at implant level.^{2–9} Different from periimplant mucositis (defined as the presence of reversible inflammatory soft-tissue infiltrate, without additional bone loss beyond the initial physiological bone remodeling),¹⁰ periimplantitis has been described as being characterized by an inflammatory process around an implant, including both soft-tissue inflammation and progressive loss of supporting bone beyond the physiological crestal bone remodeling.¹⁰ However, as highlighted in recent literature reviews and consensus conferences, different definitions of periimplantitis have been reported.^{5–8, 11} This may be due in part to the lack of consensus on terminology, etiology, diagnosis and prognosis systems.^{4, 5, 12}

Periimplantitis has been described as a disease with an infectious component that is similar to chronic periodontitis.¹³ The 8th European Workshop on Periodontology has agreed that the definitions published in 2008¹⁰ and 2011⁸ should be adopted. The suggested definition should include the following: changes in the level of crestal bone, positive bleeding on probing (BOP) and/or suppuration (SUP), with or without concomitant periimplant pockets (probing pocket depth, PPD).⁸ Nowadays, although plaque accumulation is still considered the main etiological factor,¹⁴ it has been shown that there are other potential related risk factors of the disease, including patient, surgical and prosthetic factors that may certainly contribute to its development.^{15–22}

In the MeSH (Medical Subject Headings) database, the term "periimplantitis" was introduced in 2011 and defined as an inflammatory process with loss of supporting bone in the tissue surrounding functioning dental implants.²³ Despite this very clear and comprehensive disease definition, inconsistencies and confusion emerge in applying the terminology clinically. All of these factors together have led to different interpretations and definitions of this common emerging disease. Besides, recently, the noninfectious foreign-body reaction hypothesis has further complicated the understanding of this issue.²² The aim of the present systematic review was to present the different definitions of periimplantitis proposed in the literature.

Materials and methods

The present paper was prepared in partial fulfillment of a consensus statement held in Rome, Italy, in January 2016. This systematic review was written according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (<http://www.prisma-statement.org/PRISMAStatement/PRISMA-Statement.aspx>).

The focused question was: Is there an unanimous definition of periimplantitis, including clinical diagnosis. The research question was adapted to the PICO format:

P = population: human patients derived from clinical studies, systematic reviews, narrative reviews, consensus statements, commentaries or editorials, who presented with at least one dental implant in function for a minimum of one year, affected by periimplantitis;

I = intervention: clinical data collected with the aim of establishing the severity of the periimplant disease and of defining novel criteria by which to classify periimplant diseases;

C = comparator/control: clinical outcomes of periimplantitis compared with clinical signs of periodontitis, as well as with healthy patients;

O = outcomes: clinical parameters and radiographic assessment of periimplantitis: BOP, PPD, bleeding index, presence of SUP and marginal bone loss (MBL).

Search strategy

An initial search strategy encompassing the English literature from 1967 up to October 2015 was performed online to identify relevant studies that met the inclusion criteria. The following electronic databases were consulted: PubMed database of the U.S. National Library of Medicine, Embase (Excerpta Medica dataBASE) and the Cochrane Library. According to the AMSTAR (A Measurement Tool to Assess Systematic Reviews) checklist, the Grey Literature Database was screened in the New York Academy of Medicine Grey Literature Report in order to find possible unpublished works. Screening was performed independently and simultaneously by two examiners (MT and AM). A third reviewer (LC) reassessed the included and excluded studies. The electron-

PubMed screening	Embase database keyword strategy	Cochrane Library keyword strategy
((((((((((dental implantation[Mesh] OR dental implants[Mesh]) AND "Peri-Implantitis/classification" [Mesh] OR "Peri-Implantitis/diagnosis" [Mesh] OR "Peri-Implantitis/radiography" [Mesh])))) OR (((dental implant* [Mesh]) AND "Periimplantitis" OR "peri-implant pathology" OR "peri-implant disease")))) OR ((dental implant* [Mesh] AND ("bacterial contamination" OR "presence of bacterium" OR "microbiological colonization" OR "peri-implant microflora")))))) AND hasabstract[text] AND Humans[Mesh] AND English[lang])	frequency'/exp OR 'frequency' OR 'prevalence'/exp OR 'prevalence' OR 'epidemiology'/exp OR 'epidemiology' OR 'incidence'/exp OR 'incidence' AND ('peri implantitis'/exp OR 'peri implantitis')	frequency'/exp OR 'frequency' OR 'prevalence'/exp OR 'prevalence' OR 'epidemiology'/exp OR 'epidemiology' OR 'incidence'/exp OR 'incidence' AND ('peri implantitis'/exp OR 'peri implantitis')

Table 1

Table 1
Search strategy for the selected databases.

Fig. 1
PRISMA flowchart of search strategy.

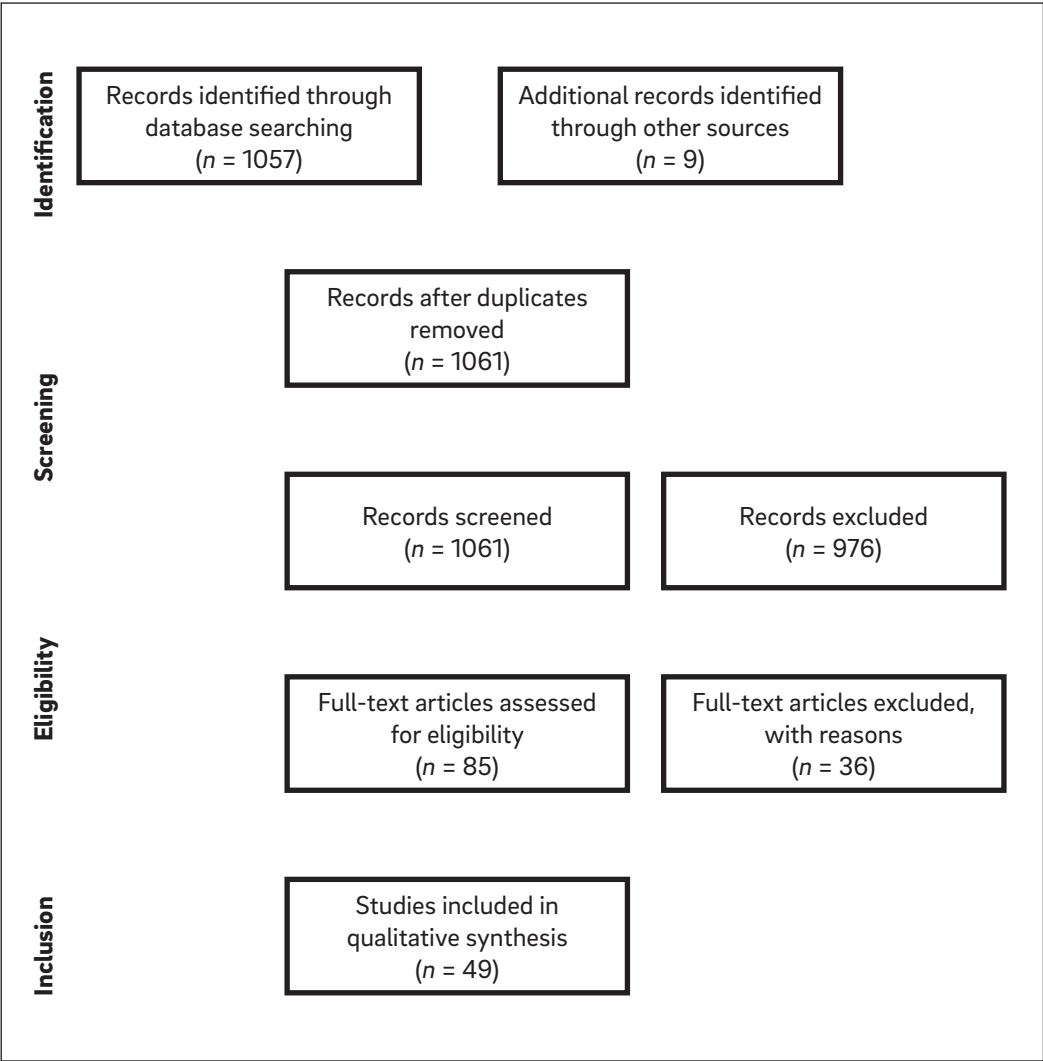


Fig. 1

ic databases were searched using a combination of boolean keywords, including MeSH and several free-text terms (**Table 1**).

Eligibility criteria

The following inclusion criteria were defined for the selection of articles:

- written in English;
- entailing clinical examination of human patients;
- randomized controlled clinical trials of implants of ≥ 1 year in function;
- prospective and retrospective cohort studies of implants of ≥ 1 year in function;
- cross-sectional studies of ≥ 1 year in function; and
- systematic reviews, narrative reviews, consensus statements, commentaries or editorials.

Articles were excluded if they were

- animal studies;
- *in vitro* studies;
- reports of locally or systemically compromised sites and/or conditions;
- reports with < 15 cases;
- reports involving mini-implants, one-piece implants or blade implants; or
- reports on implants < 1 year in function.

Papers without abstracts, but with titles related to the objectives of this review were selected so that the full text could be screened for eligibility. Full-text papers were obtained for all abstracts and titles that appeared to meet the inclusion criteria and were assessed for inclusion by the same two examiners. The reference lists of the selected studies was screened for additional papers that may have met the eligibility criteria of the study. Additionally, manual searches of the reference lists of selected systematic reviews were conducted, limited to the following journals: *Clinical Implant Dentistry and Related Research*, *Clinical Oral Implants Research*, *International Journal of Oral and Maxillofacial Implants*, *Journal of Clinical Periodontology* and *Journal of Periodontology*. Any disagreement between the two reviewers was resolved after an additional discussion. Furthermore, inter-investigator agreement was calculated in the second stage. A final reviewer (LC) evaluated possible inconsistencies between the two reviewers. All of the full texts

of the selected papers were stored in shared folders accessible to all of the reviewers.

Qualitative assessment of parameters to define periimplantitis

A descriptive evaluation was performed to analyze qualitatively the range of parameters considered to define periimplantitis as an irreversible inflammatory condition that results in hard-tissue breakdown. Accordingly, the following common parameters were appraised: PPD, BOP, SUP and radiographic MBL. Such parameters from the various articles were pooled to analyze the variance or uniformity among the reported case definitions of periimplantitis. Graphs for presenting the variance were generated. While PPD was classified into three different groups (< 3 mm, 3–5 mm and > 5 mm), radiographic MBL was categorized into four main ranges, depending on the main reference taking prosthesis delivery as the baseline: ≤ 1 mm, > 1 –2 mm, > 3 –4 mm and ≥ 5 mm.

Results

Screening process

The combinations of search terms and a manual search of references in selected articles resulted in a list of 1,061 titles. Of these, 976 articles were excluded on the basis of the evaluation of the title and abstract, leaving 85 articles eligible for inclusion ($\kappa = 0.84$). After application of the eligibility criteria, a total of 49 articles were considered for review. After full-text article selection and reading, the relevant information from each article was extracted. A diagram of the search strategy is shown in **Figure 1**.

Definitions of “periimplantitis”

Eighteen manuscripts, including narrative and systematic reviews, consensus statements and original papers, were selected and data were extracted. In 1965, Levignac reported a periimplant soft-tissue inflammation with subsequent destruction of bone and labeled it “periimplantitis.”¹ In the 1987, Mombelli et al. described periimplantitis as an infectious disease that shares features with chronic periodontitis.¹³ The same author emphasized the infectious nature of this patho-

Table 2

Original articles included in the systematic review on the clinical diagnosis of peri-implantitis.

logical condition, focusing on the bacterial load of the implant surface and the subsequent appearance of a soft-tissue inflammatory reaction adjacent to dental implants that sometimes resulted in loss of supporting bone.^{11, 24, 25} Like periodontitis, the etiopathogenesis of periimplantitis was shown to be triggered by bacterial infection that activates a cytokine cascade, leading to inflammatory bone loss.⁷

"Periimplantitis" became an accepted term in the consensus report from the 1st European Workshop on Periodontology in 1993.²⁶ It has been described as an irreversible inflammatory destructive reaction around implants in function that results in loss of supporting bone.²⁶ The 6th European Workshop on Periodontology presented a modified definition, not only to acknowledge that periimplantitis is a treatable condition, but also to include the collective term of "peri-implant disease" for both periimplant mucositis and periimplantitis.¹⁰

In order to improve the quality of research on periimplant diseases, the 7th European Workshop on Periodontology recommended the use of unequivocal case definitions: changes in the level of crestal bone and presence of BOP and/or SUP, with or without concomitant deepening of peri-implant pockets.⁸ Finally, the American Academy of Periodontology in 2013 defined "periimplantitis" as an inflammatory reaction associated with the loss of supporting bone beyond the initial biological bone remodeling around an implant in function.⁷

The extent and severity of periimplant diseases have been rarely reported.^{27, 28} Froum and Rosen proposed a combination of BOP and/or SUP, PPD and extent of radiographic MBL around the implant to classify periimplantitis into early, moderate or advanced disease categories.²⁸ Likewise, Decker et al. proposed a prognosis system based on the diagnosis for each category following the Kwok and Caton prognosis classification for natural dentition.²⁷ In their study, the authors stated that PPD, extent of radiographic MBL, presence of SUP and implant mobility were found to be the most critical factors for categorizing cases as having a favorable, questionable, unfavorable or hopeless prognosis.²⁷

Recently, Albrektsson et al. modified the concept of periimplantitis as a loss of bone surrounding an implant as a clinically unfavorable, disbalanced foreign-body reaction, specifically stating that osseointegration is a process whereby bone reacts to the dental implant by forming a calcified structure adjacent to it.²² Indeed, at

times, this foreign-body reaction may actually result in osteoclastic activity that may destroy the supporting bone.²² The authors believe that the term "periimplantitis" is quite appropriate, because it is not a primary disease, but a complication of a clinically unfavorable, disbalanced foreign-body reaction that is the starting point of the pathological process and consequent tissue sequelae.²²

Currently, as foreseen by the consensus of the 7th European Workshop on Periodontology,⁸ it is assumed that the infection itself is always caused by plaque and its products; However, numerous risk factors are recognized as being specifically associated with periimplantitis, such as surgical- or prosthetic-related factors,^{19, 20, 29} implant characteristics,²¹ smoking³⁰ and host response.^{30, 31}

Definition of periimplantitis with clinical and radiographic diagnosis

Thirty-one manuscripts (**Table 2**) were selected and data were extracted. Informations from 1,711 patients with 5,432 implants were analyzed. The term "periimplantitis" has generally been used to describe any implant with varying degrees of bone loss, and a clear definition was either not presented or was extracted directly from the terminology.

Four main characteristics have been used to define "periimplantitis". Interestingly, all of the authors consider BOP and SUP as indicators of periimplantitis. This approach considers purely plaque- and foreign-body-induced periimplantitis, where an inflammatory response is often triggered by the biofilm or its products and/or foreign substances, such as residual cement. Moreover, 22 studies clearly reported PPD as a crucial parameter for determining periimplantitis. No study considered PPD < 3 mm as indicative of periimplantitis. While the vast majority (64%) of the studies defined PPD = 3–5 mm as indicative of periimplantitis, the remaining 36% considered PPD > 5 mm as the reference (**Fig. 2**). A radiographic MBL ≥ 0.5–1 mm, > 1–2 mm, > 3–4 mm and ≥ 5 mm, taking prosthesis delivery as baseline, was considered as defining periimplantitis in 15%, 45%, 35% and 5% of the studies, respectively (**Fig. 3**). As such, it was speculated that a radiographic MBL < 1 mm should be considered as physiological bone remodeling.

Table 2

Author	Year	Sample size (P/I) [†]	BOP and/or SUP	Radiographic MBL	Mean follow-up (year)		PPD (mm)		
					< 5	≥ 5	≤ 3	3–5	≥ 5
Canullo et al.	2015	56/125	Yes	> 3 mm compared with baseline				Yes	
Canullo et al.	2015	53/113	Yes	> 3 mm compared with baseline					Yes
Canullo et al.	2015	53/110	Yes	> 3 mm compared with baseline				Yes	
Casado et al.	2013	215/754	Yes	≥ 1 mm (1 year), then ≥ 0.2 mm yearly					
Casado et al.	2013	100/291	Yes	Yes (not defined)					
Marrone et al.	2013	103/266	Yes	> 2 mm		Yes		Yes	
Cecchinato et al.	2013	133/407	Yes	> 0.5 mm	Yes			Yes	
Costa et al.	2012	80/212	Yes	Yes (platform as reference)		Yes			Yes
Mir-Mari et al.	2012	245/964	Yes	≥ 2 threads		Yes			
Rodrigo et al.	2012	22/68	Yes	Yes, defined as significant		Yes		Yes	
López-Píriz et al.	2012	117/268	Yes	> 1 mm	Yes				
Lee et al.	2012	60/117	Yes	Yes (not defined)					
Charalampakis	2011	281 I	Yes	≥ 1.8 mm (1 year)		Yes		Yes	
Fischer et al.	2011	23/136	Yes	> 4 mm		Yes			
Dierens et al.	2011	50/59	Yes	≥ 3 threads		Yes			
Corbella et al.	2011	61/244	BI ≥ 2	Not reported	Yes			Yes	
Dvorak et al.	2011	177/828	Yes	Yes (not defined)		Yes			Yes
Rinke et al.	2011	89 P	Yes	Yes (not defined)		Yes			Yes
Schmidlin et al.	2010	39 I	Yes	Yes (not defined)		Yes			Yes
Simonis et al.	2010	55/131	Yes	≥ 2.5 mm (≥ 3 threads)		Yes		Yes	
Wahlström et al.	2010	46/116	Yes	> 2 mm		Yes		Yes	
Zetterqvist et al.	2010	112/304	Yes	> 5 mm		Yes			Yes
Koldslund et al.	2010	109/372	Yes	Yes (not defined)		Yes			Yes
Gotfredsen	2009	19/19	Yes	> 2 mm		Yes			
Máximo et al.	2008	113/374	Yes	≥ 3 threads				Yes	
Gatti et al.	2008	62/227	Yes	> 2 mm		Yes			Yes
Ferreira et al.	2006	212/578	Yes	Yes (not defined)		Yes		Yes	
Roos-Jansåker et al.	2006	218/999	Yes	≥ 3 threads (1 year)		Yes			
Brägger et al.	2005	89/160	Yes	Not reported		Yes		Yes	
Karoussis et al.	2003	53/112	Yes	Yes (not defined)		Yes		Yes	
Rutar et al.	2001	45/64	Yes	Yes (not defined)		Yes		Yes	

[†] P = patients; I = implants; BI = bleeding index.

Fig. 2

Percentage of the included studies relating to different PPD ranges used to define periimplantitis.

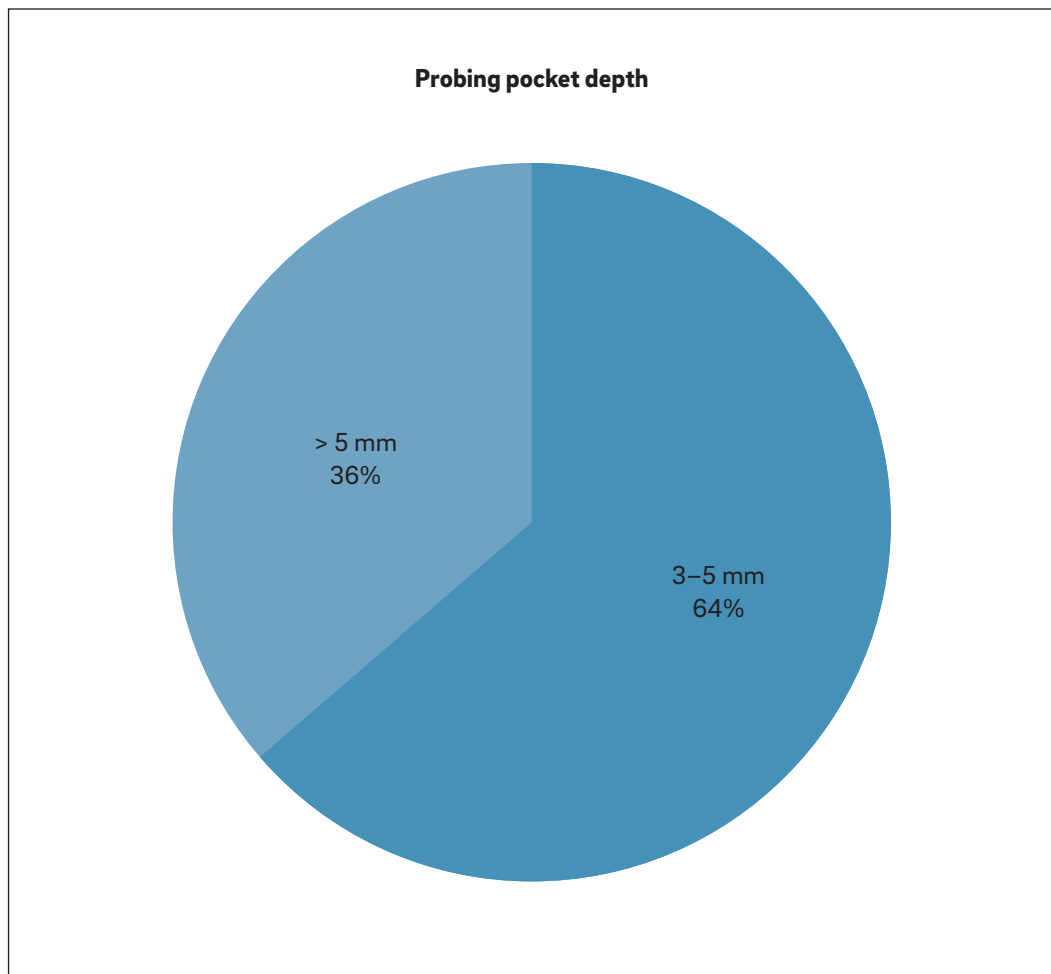


Fig. 2

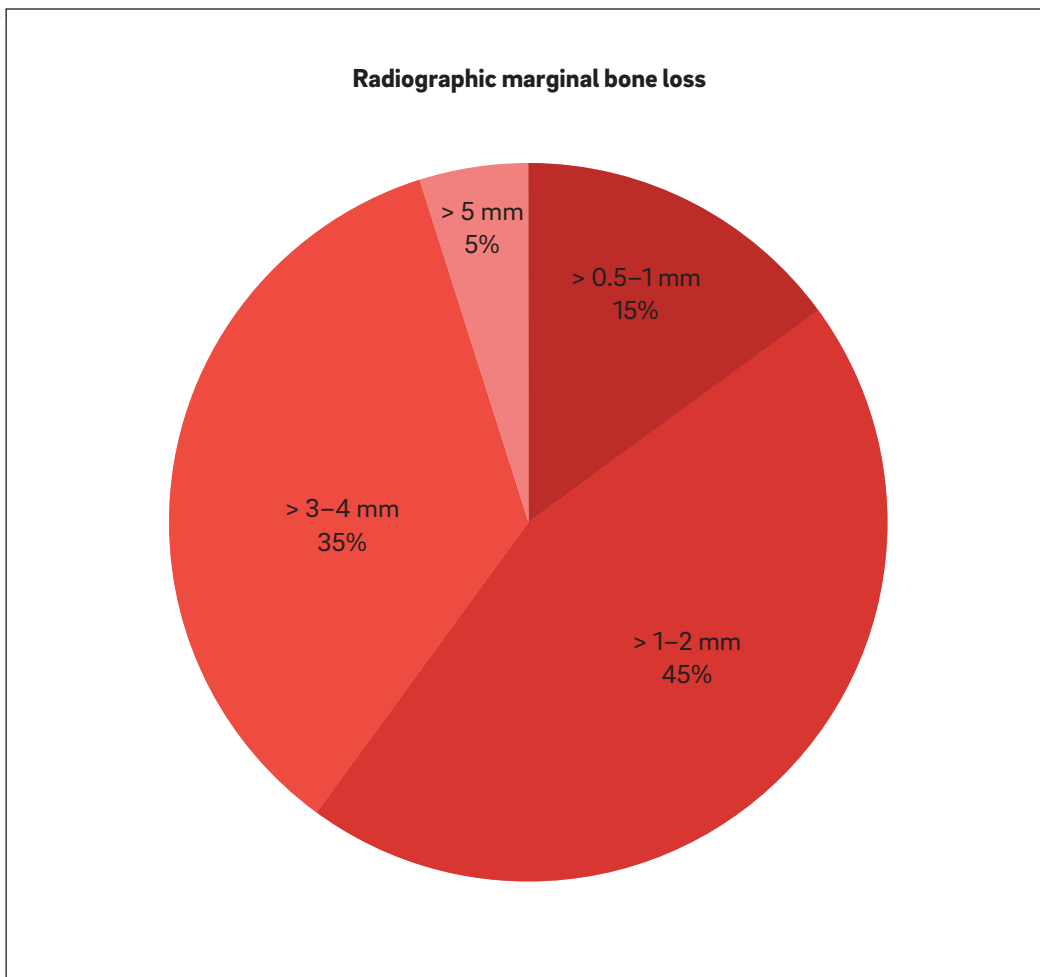
BOP and/or SUP were prerequisite in all of the analyzed studies. In most of the studies, the combination of clinical and radiographic measurements were used for case definition. In two prospective studies,^{32,33} the radiographic MBL were not reported, and clinical measurements alone were used to assess biological complications. In these cases, the presence of BOP and/or SUP on probing and $PPD \geq 4$ mm were prerequisite for a diagnosis of periimplantitis. In nine studies, one randomized controlled trial,³⁴ three prospective^{35–37} and five retrospective studies,^{38–42} BOP and radiographic assessments were performed alone, without reporting any PPD measurements. In these cases, a MBL ranging from 0.5 mm³⁹ to > 4 mm³⁴ was considered to be associated with periimplantitis.

Before 2012, changes in the level of crestal bone were either not defined or not clearly reported, making the diagnosis of periimplantitis difficult.^{6, 8, 32, 33, 41, 43–49} However, even in studies that defined the entity of MBL, different diagno-

stic criteria were used. In one long-term study, periimplantitis was defined as the presence of BOP, $PPD \geq 4$ mm and $MBL > 0.5$ mm.³⁹ However, another study used $MBL > 4$ mm as a reference value.³⁴ Most of the studies considered $MBL > 2$ mm for the diagnosis of periimplantitis.^{36, 50–54} Previously, our group used a radiographic $MBL > 3$ mm, from the baseline radiograph taken at the time of prosthesis delivery, to diagnose periimplantitis.^{19, 55, 56} In three other studies, MBL was considered in relation to the time that the prosthesis was in function.^{35, 57, 58} All of the studies but five calculated MBL in millimeters. In the other studies, the implant threads were used as reference.^{36, 42, 58–60}

Eight studies applied $PPD > 5$ mm for the diagnosis of periimplantitis.^{43, 44, 47, 53, 59, 61–63} Marone et al. defined periimplantitis as the presence of BOP, $PPD > 5$ mm and $MBL > 2$ mm.⁵¹ Charalampakis et al. applied the criteria of the presence of BOP and/or SUP, $PPD \geq 5$ mm and $MBL \geq 1.8$ mm after one year in function.⁵⁷ Zetter-

Fig. 3

**Fig. 3**

Percentage of the included studies relating to different radiographic MBL values used to define periimplantitis.

qvist et al. included cases of PPD > 5 mm and MBL $\geq$ 3 mm.⁶² Two other studies, one prospective⁶³ and one retrospective,⁶⁴ applied the presence of BOP and/or SUP, PPD > 5 mm and radiographic signs of MBL, without specifying the baseline bone level. Positive BOP and/or SUP, radiographic MBL $\geq$ 3 mm and PPD $\geq$ 6 mm were used by Koldslund et al.⁴⁷

At the 7th and 8th European Workshop on Periodontology, periimplant mucositis and periimplantitis were described as follows: "changes in the level of crestal bone, presence of bleeding on probing and/or suppuration; with or without concomitant deepening of peri-implant pockets."^{6, 8} Periimplant mucositis was defined with positive BOP and/or SUP and periimplantitis with positive BOP and/or SUP, in combination with radiographic MBL $\geq$ 2 mm. The same parameters were used by Zitzmann and Berglundh to define periimplantitis.⁶⁵ However, Atieh et al. used the same criteria, plus PPD $\geq$ 5 mm, as the definition of periimplantitis in their systematic review paper.⁴

Discussion

Periimplant diseases present in two forms: periimplant mucositis and periimplantitis.¹⁰ Both are characterized by an inflammatory reaction in the tissue surrounding an implant. Periimplant mucositis has been defined as a reversible inflammatory reaction in the soft-tissue surrounding an implant in function, whereas periimplantitis has been defined as a more profound inflammatory lesion characterized by a deepened periimplant pocket and loss of supporting bone around a functional implant.^{10, 24}

Studies published in early 2010 suggested that mucositis and periimplantitis are equivalent to periodontitis, since both are described as an imbalance between bacterial load and the host response.^{8, 25} Based upon this, both diseases are closely related to the formation of a biofilm containing microbiota rich in Gram-negative bacteria in the presence of a susceptible host.⁶⁶ However, it has been shown that microorganisms may

be present, but are not a necessity for periimplantitis.⁶⁶ In addition, both periodontitis and periimplantitis share several common systemic risk factors or indicators (e.g., smoking, poor oral hygiene, diabetes or history of periodontitis, osteoporosis).^{10, 64, 66, 67} Similarly, periimplantitis, as occurs with periodontitis, seems to be influenced by a particular genetic profile (i.e., interleukin-1 polymorphism).⁶⁸ Others have rejected the description of a disease comparable to periodontitis,^{22, 69, 70} because of the anatomical differences that exist between periodontal and periimplant structures (e.g., different collagen fiber orientation [perpendicular vs. horizontal], vascularity or repair capacity, and the mechanical resilience provided by the periodontal ligament).⁷¹ In fact, periodontitis is characterized by inflammatory destruction of the supporting apparatus of the dentition (periodontium), including the periodontal ligament and alveolar bone. Owing to the different composition of the two supporting tissues, similar tissue reactions around an implant and a tooth seem most unlikely. The term "osseoinsufficiency" was proposed by Zarb and Koka to describe the difference between periimplantitis and periodontitis-induced bone loss.⁷² The anatomical image of bone resorption due to periodontitis or periimplantitis differs, in many situations with very wide bone craters being typical for the implant but not for the tooth. Hence, periimplantitis may be considered distinct from periodontitis in that it significantly differs regarding onset and progression and has poor treatment predictability; consequently, its treatment must be focused on early diagnosis and controlling the risk factors or indicators to prevent it from occurring.

To date, there have been no standardized parameters to clinically differentiate the various stages and severities of periimplantitis.²⁸ The criteria used to diagnose periimplantitis remain inconclusive. Most existing studies used clinical parameters in combination with radiographic findings to define periimplantitis. However, clinical parameters such as BOP and PPD around implants are less predictable, since they are influenced by more confounding factors compared with natural dentition.^{2, 3} Furthermore, any factor that facilitates plaque formation (e.g., poor oral hygiene) or host defense capability (e.g., smoking habit, excessive alcohol consumption, genetic traits, history of periodontitis or use of bisphosphonates) might contribute to the development of periimplantitis.^{16, 73, 74} The diagnosis and progression of periimplantitis may be characterized

by increased measurements for clinical parameters (PPD, BOP, SUP or even mobility), MBL and microbiology. Regarding clinical parameters, PPD is a valid method of assessment, as correlation exists between bone levels recorded and radiographic probe penetration.^{41, 75} Nevertheless, in a cross-sectional study, the intraoperatively measured periimplant bone levels were more apical than the radiographic bone levels.⁷⁶ SUP occurs more frequently in implants with than without progressive bone loss, particularly in smokers, and may be associated with episodes of active tissue destruction.⁴ In a systematic review, Berglundh et al. defined periimplantitis as having a PPD ≥ 6 mm or MBL ≥ 2.5 mm.⁷⁷ Lang and Berglundh, in the 2011 European Federation of Periodontology consensus, stated that clinical and radiographic data should routinely be obtained after prosthesis installation on implants in order to establish a baseline for the diagnosis of periimplantitis during maintenance of implant patients.⁸ A meta-analysis by Derks and Tomasi clearly showed a positive relationship between the prevalence of periimplantitis and function time.⁷⁸ The presence of bone loss and PPD alone may not be enough to establish a diagnosis of periimplantitis.⁷⁸ One important factor that potentially influences the wide range of periimplantitis prevalence is the lack of consensus regarding the clinical parameters. For example, one study reported that if PPD > 4 mm was used as criterion, then 74.8% individuals had periimplantitis, but if this measurement was changed to > 6 mm, then the prevalence dropped to 43.9%.⁴⁷ When radiographic MBL was considered for defining periimplantitis, 25.3% individuals showed > 2 mm, while 13.1% had > 3 mm.⁴⁷ Indeed, if PPD is considered, some further heterogeneity can be found. Probing around implants is influenced by many factors, such as the size of the probe, the probing force, the direction of the probe, the health and thickness of the periimplant soft-tissue, and the design of the implant neck and the superstructure.¹ In fact, the platform-switched design, as well as defective restorations, can complicate probing and, thus, hide the true extent of periimplantitis.^{16, 17, 79} Furthermore, the presence of discrepancies in the buccolingual hard- and soft-tissue levels may result in different PPD readings.

Owing to the lack of standard parameters to determine the presence and severity of periimplant disease, it is difficult to develop a clinical strategy based upon PPD in managing this common problem in implant dentistry. However,

Froum and Rosen proposed a classification system to determine periimplantitis severity based upon PPD, MBL and clinical signs of BOP and/or SUP;²⁸ but this system remains to be validated. Furthermore, in a series of studies by Merli et al., the inter-rater agreement in the diagnosis of periimplant disease was judged as merely good, owing to the unclear definition of periimplantitis and mucositis, with complete agreement obtained only in half of the cases (52%).⁸⁰

The vast majority (45%) of the studies included in the present review found radiographic MBL > 1–2 mm after prosthetic loading. Hence, the following criteria for defining periimplantitis are proposed: a radiographic MBL > 1 mm after implant prosthesis delivery or 2 mm at least six months after implant prosthesis placement as a good indicator of periimplantitis. BOP does not possess a high predictive value owing to the weak soft-tissue connection around dental implants. Likewise, PPD largely relies on implant design (bone vs. tissue level), apicocoronal position and biotype. From the extracted data, it seems logical to consider radiographic MBL as the most uniform and accurate indicator of periimplantitis. Although, the cut-off value depends on the patient's inflammatory pattern, the type of surgery, the apicocoronal implant position, the implant's macrodesign and the crestal module, considering the rapid disease progression over time, strict radiographic control must be followed if any clinical symptom is detected. Furthermore, the clinician must use a combination of the many available clinical parameters, such as PPD, inflammatory status of the mucosa, BOP on light

probing, radiographic MBL, and possibly bacterial and/or periimplant crevicular fluid biomarkers to establish an accurate diagnosis of periimplantitis.²⁸ Unlike in the case of periodontitis, bacterial testing may not be reliable in diagnosing periimplantitis.⁸⁴ This suggests that periodontal and periimplant ecosystems differ significantly and, hence, periimplant disease might not always be approached as an infectious disease. Similarly, such difference has been shown to apply to the pathogenesis.⁸⁵ Furthermore, no evidence was found that primary infection caused marginal bone resorption.⁸⁶

Conclusion

The available scientific literature suggested an absence of a unanimous definition of periimplantitis. Actual definitions of periimplantitis were based solely on clinical parameters without consideration of other potential related risk factors of the disease. Future studies that apply consistent case definitions should be considered.

Competing interests

The authors declare no conflict of interests.

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Surgical treatment of circumferential and semicircumferential defects due to periimplantitis: A prospective case series cohort study

Abstract

Objective

Different surgical treatment strategies for periimplantitis using graft material and membranes have been suggested. However, in these, the microbiological aspects of the periimplant environment were underestimated. The present preliminary study was aimed at analyzing a new clinical approach based on disinfection of the implant connection and of the implant surface, as well as the use of only a self-stabilizing graft material in the treatment of circumferential and semicircumferential bony defects resulting from periimplantitis.

Materials and methods

Ten consecutive patients were selected for the present study. After removal of factors that may potentially have influenced the periimplant pathology, the prosthesis was removed and a full-thickness flap was elevated to allow access to the periimplant defect and the exposed implant surface. Once the defect had been degranulated and the implant surface cleaned, bone powder was used to cover the surface. A resorbable, self-stabilizing material (GUIDOR easy-graft CLASSIC, Sunstar Suisse, Étoy, Switzerland) composed of calcium phosphate particles coated with a thin layer of PLGA was used to fill the defect. No membranes were used and the flaps were closed for a submerged healing. Two months thereafter, a new reopening procedure was performed and the cleaned superstructures and crowns were repositioned. The patients were followed for 12 months thereafter and recalled for customized oral hygiene every three months. Radiographic and periodontal analysis were performed preoperatively and every six months postoperatively. Microbiological analysis was performed preoperatively and at the last follow-up. Three types of sites in each patient were analyzed: (a) the periimplant sulcus of each implant; (b) the gingival sulci of the neighboring teeth; and (c) the connection's inside and the abutment surface of each implant. The presence of ten common periodontal pathogens was measured.

Results

The procedure studied was associated with a pronounced increase in mucosal recession and clinical attachment level with stable periimplant conditions at six and 12 months. Plaque index, bleeding on probing and probing depth values were significantly reduced at six and 12 months.

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Radiographic analysis demonstrated a complete or semicomplete filling of the defect in all of the cases, with a significant bone gain at six and 12 months. Microbiological analysis, in terms of total bacterial count and single pathogens, demonstrated a significant decrease of microbiological contamination in all of the test sites between baseline and the 12 months follow-up: at the sulcus, the neighboring teeth and the connection.

Conclusion

Within the limitations of the present preliminary study, the proposed technique, in combination with a self-stabilizing graft material, offers promising results for the treatment of circumferential and semicircumferential bone defects around implants affected by periimplantitis, without the use of a membrane.

Keywords

Periimplantitis, periimplant disease, surgical treatment, graft material.

Introduction

Different treatment strategies for periimplantitis have been suggested.^{1–3} Despite the unesthetic outcomes, the resective approach was considered the only longitudinally effective strategy.⁴ However, nonsurgical (which basically consisted of simple subgingival mechanical debridement with or without systemic or local anti-infective agent delivery) and regenerative approaches were considered ineffective.⁵ In fact, despite some positive short-term outcomes that have been reported in many studies,^{3, 6} absence of resolution, as well as progression or recurrence after treatment of disease, leading to the loss of implant, were also highlighted.⁵ According to Graziani et al., current literature on periimplant disease prevention and treatment does not provide applicable clinical information.⁷ In fact, the lack of efficacy of the current methods for treating periimplantitis may be due to insufficient understanding of the entire biological etiology of the disease. Therapy concepts for periodontitis have been directly transferred to periimplant disease treatments, neglecting the differences between teeth and implants that may be highly relevant to periimplantitis treatment concepts. In fact, since implant surface and topology differ dramatically on the micro- and macrolevel from tooth structure and shape, conventional bacterial removal and debridement cannot be effective on implants.⁸ At the same time, since implants always present the opportunity for bacterial contamination at the implant–abutment junction,

often positioned at the bone level,⁹ guided bone regeneration techniques or regenerative procedures cannot be successful (at least in the long run) owing to the recontamination of the site through the implant–abutment junction. An additional reason for low surgical outcomes might be the misunderstanding of triggering conditions for the implant disintegration process. In fact, according to Sanz and Chapple, the use of unequivocal case definitions would help in increasing the quality of research on this topic.¹⁰ As it is easy to understand, differences in periimplant environment (soft- and hard-tissue conditions, 3-D implant positioning, triggering factor of disease) could completely change the prognosis and give rise to different treatment plans. However, one of the most important factors affecting surgical outcomes, particularly in the case of regenerative procedures, appears to be the selection of patients, especially as regards the shape of the bone defect.⁶ In fact, self-containing or three-wall bone defects demonstrated a higher clinical and radiographic improvement in terms of bone regeneration.⁶

Circumferential and semicircumferential intrabony defects displayed promising outcomes when treated with the application of a particulate bone material stabilized with a collagen membrane.^{3, 6} Besides loose particulate bone materials, alloplastic biomaterials designed to harden *in situ* are commonly used in dental indications.¹¹ These resorbable materials (GUIDOR easy-graft CLASSIC, Sunstar Suisse, Étoy, Switzerland) are composed of calcium phosphate particles coated

with a thin layer of PLGA, enhancing the material handling and forming a stable scaffold for regeneration within the defect site. This *in situ* hardening PLGA-coated biomaterial has been proven to provide excellent soft-tissue healing after socket grafting and equivalent performance in terms of new bone formation has been found,¹² comparable to the results reported for other bovine and synthetic biomaterials.¹³ The aim of the present preliminary prospective study was to test the outcome of a surgical approach to treating periimplant circumferential and semi-circumferential defects using only a self-stabilizing graft material.

Materials and methods

In January 2013, at the Department of Oral Surgery, University of Valencia, Valencia, Spain, a preliminary prospective clinical trial was designed to test the efficacy of a self-stabilizing graft material in the treatment of bony defects resulting from periimplantitis. Only those patients who had received implant therapy at the Department of Stomatology in the past, had a good-quality periapical baseline radiograph obtained after prosthetic rehabilitation, attended control visits, were older than 18 years, and presented with a circumferential or semicircumferential periimplant bony defect were included in the study.⁶ Exclusion criteria were relevant medical conditions (American Society of Anesthesiologists Physical Status Class III or IV), > 10 cigarettes/day or pipe or cigar smokers, plaque index and bleeding on probing scores > 25%, pregnant or lactating patients, and patients with a history of bisphosphonate therapy (**Fig. 1**).

The patients were informed about the study and the intervention and asked to sign an informed consent document in order to be involved. The investigation was conducted according to the principles embodied in the Declaration of Helsinki of 1975, as revised in 2013. All of the procedures and materials in the present prospective study were approved by the local ethics committee of the University of Valencia (H1447757419931).

Preoperative phase

Factors possibly influencing the periimplant pathology were evaluated and problems solved before the surgical phase. This included occlusal adjustment, modification or change of poorly

designed prostheses, and periodontal treatment when necessary. Two weeks prior to the surgical therapy, all of the patients received professional prophylaxis (total oral district disinfection) and 0.12% chlorhexidine digluconate (rinsing b.i.d.; GUM Paroex 0.12%, Sunstar Suisse) was prescribed. Antibiotic treatment consisting of amoxicillin 850 mg and clavulanate 125 mg every 8 h was administered to all of the patients, starting two days before the surgical treatment and ending one week after the intervention.

Surgical phase

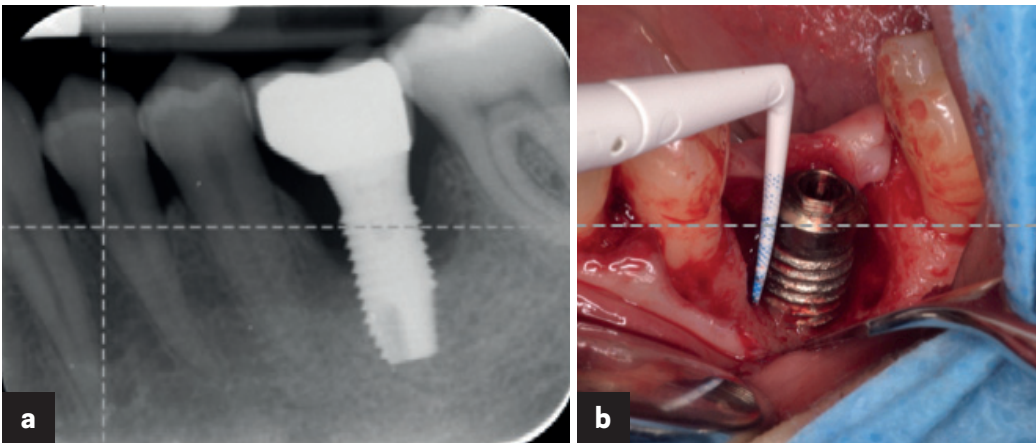
The surgical intervention was performed under local anesthesia with 4% articaine and 1:100,000 epinephrine (Laboratorios Inibsa, Barcelona, Spain). The prosthesis was removed and a full-thickness flap was elevated to allow access to the periimplant defect and the exposed implant surface.

Once the granulation tissue had been removed, the implant surface was mechanically debrided using PTFE curettes and further cleaned with a cotton pellet soaked in 0.2% chlorhexidine digluconate. The inside of the implant connection was cleaned using 0.2% chlorhexidine (GUM Paroex 0.2%, Sunstar Suisse). Perforations were performed to increase blood supply to the remaining bone and the periimplant bone defects were filled using a double-layer graft:¹⁷ autologous bone on the implant surface (collected from a neighboring area using scrapers) and an alloplastic, resorbable bone graft substitute consisting of 100% beta-tricalcium phosphate (GUIDOR easy-graft CLASSIC) to fill the remaining gap and act as a stabilizing shell, that is, a tent-like structure. After defect filling, cover screws were inserted. Tensionless soft-tissue closure of the flap was performed with a 5-0 suture (**Fig. 2**). Sutures were removed two weeks after the intervention. Abutments and prostheses were cleaned according to Canullo et al. using ultrasound and an extraoral argon plasma device (Plasma R, Diener Electronic, Jettingen, Germany).¹⁴ One to two months thereafter, the cleaned prosthetic components were reinserted after microsurgical reopening.

Follow-up and maintenance

Before suture removal, the patients were advised to discontinue toothbrushing and to avoid trauma at the site of surgery. After the healing phase, the patients were placed on an individually tailored

Figs. 1a & b



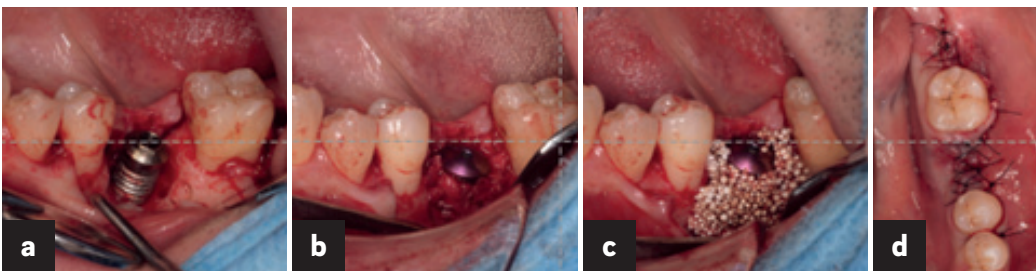
Figs. 1a & b

Preoperative radiograph and (b) intraoperative measurement of the bony defect.

Figs. 2a–d

Surgical phases: (a) degranulation of the defect, (b) autogenous bone graft apposition, (c) easy-graft apposition and (d) primary intention flap suturing.

Figs. 2a–d



maintenance care program. Motivation, reinforcement of oral hygiene instruction, supragingival instrumentation and antiseptic therapy were performed as needed. All of the patients were subsequently recalled every three months for data collection and maintenance therapy. Nonsurgical treatment with ultrasound plastic instruments and air polishing and erythritol powder was repeated every three months throughout the entire follow-up period (**Fig. 3**).

Clinical analysis

All of the clinical analysis were performed by a single trained clinician using a predefined standard protocol. The following clinical variables were assessed at six and 12 months with the aid of a periodontal probe with a millimeter scale (Hawe Neos Probe 1395, Hawe, London, U.K.):

- plaque index;
- bleeding on probing, evaluated as present if bleeding was evident within 30 s after probing or absent if no bleeding was observed within 30 s after probing;
- probing depth, measured from the mucosal margin to the bottom of the examined pocket;
- mucosal recession, measured from the implant shoulder or restoration margin to the mucosal margin; and

- clinical attachment level, measured from the implant neck to the deepest point of the periimplant pocket.

Probing depth, mucosal recession and clinical attachment level scores were recorded to the nearest millimeter at six aspects per implant.

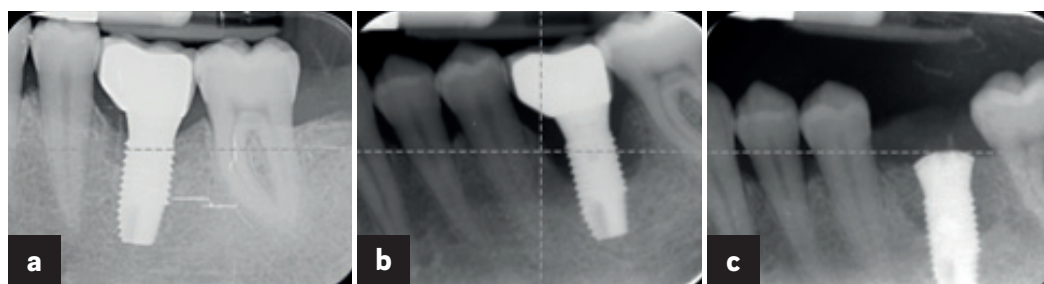
Radiographic analysis

Radiographic changes (bone gain or loss) were evaluated using periapical radiographs obtained at baseline and at six and 12 months using paralleling rings and silicone bites to reproduce the exact film position. Periimplant marginal bone changes were evaluated with a computerized measuring technique applied to digital radiographs.

The distance from the mesial and distal margin of the implant neck to the most coronal point where the bone appeared to be in contact with the implant was measured. Evaluation of the marginal bone level around the implants was performed using image analysis software (Scion Image for Windows, Version 4.02, Scion Corp., Frederick, Md., U.S.) able to compensate for radiographic distortion. The software calculated bone remodeling at the mesial and distal aspects of the implants. The mean of both values was used.

Figs. 3a–c

Radiographic sequence of the site at the time of periimplantitis detection and at the time of surgery.

**Figs. 3a–c**

Microbiological analysis

Sampling for microbiological analysis was performed by a single researcher. Samples were obtained from three types of sites in each patient: (a) the periimplant sulcus of each implant; (b) the gingival sulcus of the neighboring teeth; and (c) the connection's inside and the abutment surface of each implant.

Samples were obtained before the cleaning procedures and 12 months after treatment. Sampling was performed using the GUIDOR Perio-Implant Diagnostic Kit (Sunstar Iberia, Barcelona, Spain; provided by Institut Clinident, Aix-en-Provence, France), consisting of five sterile absorbent paper tips and an empty sterile 2 mL Eppendorf tube. Prior to subgingival plaque sampling, supragingival plaque was eliminated from the implants and teeth using a curette or cotton roll, without penetrating the gingival or periimplant sulcus. Cotton rolls were used for relative isolation and the sampling sites were dried with a pistol. The paper tips were inserted into the gingival or periimplant sulcus for 30 s.

One drop of RNA- and DNA-free water (Water Molecular Biology Reagent, code W4502, Sigma-Aldrich, St. Louis, Mo., U.S.) was placed inside the implant connection and the paper tips were inserted for 30 s. Quantitative real-time polymerase chain reaction (PCR) assays were carried out for total bacterial count and for ten pathogens at Institut Clinident: *Aggregatibacter actinomycetemcomitans* (Aa), *Porphyromonas gingivalis* (Pg), *Tannerella forsythia* (Tf), *Treponema denticola* (Td), *Prevotella intermedia* (Pi), *Peptostreptococcus micros* (Pm), *Fusobacterium nucleatum* (Fn), *Campylobacter rectus* (Cr), *Eikenella corrodens* (Ec) and *Candida albicans* (Ca).

Quantitative real-time PCR assays was performed in a volume of 10 μ L composed of 1 $\times$ QuantiFast SYBR Green PCR (Qiagen, Berlin, Germany), 2 μ L of DNA extract and 1 μ M of each primer. The species-specific PCR primers (Metabion, Martinsried, Germany) used in this study were provided by Institut Clinident. The bacte-

rial primers used were derived from previously published ribosomal 16S ribosomal RNA sequences^{15, 16} and were adapted to the real-time PCR conditions. The Ca primers used in this study were derived from 18S/28S ribosomal RNA sequences.

Assays were carried out on the Rotor-Gene Q thermal cycling system (Qiagen) with the following program: 95 °C for 5 min, followed by 40 cycles of 10 s at 95 °C, 10 s at 60 °C, and 35 s at 72 °C. A final melting curve analysis (70–95 °C in 1 °C steps for 5 s increments) was performed. Fluorescence signals were measured every cycle at the end of the extension step and continuously during the melting curve analysis. The resulting data were analyzed using Rotor-Gene Q Series Software (Qiagen).

Serial dilutions of bacterial standard DNA, provided by Institut Clinident, were used in each reaction as external standards for absolute quantification of the targeted bacterial pathogens. Standard bacterial strains used for standard DNA production were obtained from the DSMZ (Braunschweig, Germany), the Collection of Institut Pasteur (Paris, France) and from the BCCM/LMG Bacteria Collection (Ghent, Belgium): Aa (DSM No. 8324), Pg (DSM No. 20709), Tf (CIP No. 105220), Td (DSM No. 14222), Pi (DSM No. 20706), Pm (DSM No. 20468), Fn (DSM No. 20482), Cr (LMG No. 18530) and Ec (DSM No. 8340). A Ca standard DNA (DSM No. 6659) was also used as external standard for identification and semiquantification.

Statistical analysis

The statistical analysis was performed using a commercially available software program (IBM SPSS Statistics for Windows, Version 20.0, IBM Corp., Armonk, N.Y., U.S.). Mean values and standard deviations were calculated for each variable using the implant as the statistical unit. The data rows were examined with the Kolmogorov–Smirnov test and proven to be normally distributed. For the statistical evaluation of the chang-

Table 1

	Baseline	6-month follow-up	12-month follow-up	P-value [†]
Plaque index	0.36 ± 0.61	0.06 ± 0.02	0.00 ± 0.00	0.003
Bleeding on probing (%)	81.10 ± 12.40	21.09 ± 19.20	20.20 ± 16.80	0.000
Probing depth (mm)	7.2 ± 1.8	3.1 ± 1.2	3.3 ± 1.1	0.000
Mucosal recession (mm)	0.65 ± 0.51	-0.40 ± 0.20	-0.30 ± 0.20	0.002
Clinical attachment level (mm)	7.8 ± 1.8	3.5 ± 1.4	3.6 ± 1.7	0.003
Radiographic bone loss (mm)	4.2 ± 0.9	1.8 ± 0.6	1.7 ± 0.7	0.040

[†] Comparison within group (paired *t*-test)

es over time, the paired *t*-test was used. The α error was set at 0.05.

Results

Ten patients were included in the study. A total of 13 implants were treated. During the entire observation period of 12 months, two patients failed to attend the scheduled recall sessions and, therefore, were excluded from the study. No patient reported any sign of swelling or pain two weeks after the surgery. The clinical and radiographic data are summarized in **Table 1**. Essentially, mean probing depth values were significantly reduced by 4.1 mm and 3.9 mm at six and 12 months, respectively. The surgical procedure was associated with a pronounced increase in mucosal recession and clinical attachment level; however, stable periimplant conditions at six and 12 months were reported. Mean bleeding on probing values were significantly reduced at six and 12 months. Before treatment, pus was present around four implants. At the end of the observation period, the tissue around the implants was in a healthy condition.

All of the patients presented with low plaque index values throughout the entire observation period. Radiographic analysis demonstrated a complete or semicomplete filling of the defect in all of the cases, with a significant bone gain at six and 12 months (**Fig. 4**). Microbiological analysis, in terms of total bacterial count and single pathogens, demonstrated a significant decrease of microbiological contamination in all of the test sites between baseline and the 12 months follow-up: at the sulcus, the neighboring teeth and the connection. The data are summarized in **Table 2**.

Discussion

The data reported in the present study showed a good short-term resolution of periimplantitis defects using the proposed surgical approach and concomitant dental hygienic treatment. The graft material proposed is self-stabilizing in the defect, which might suggest that the use of a membrane with the bone graft substitute can be omitted. This feature helped to stabilize the bone graft substitute *in situ* in a tentlike structure over the autologous bone in a double-layer graft technique, thereby providing and protecting space for bone regeneration around the dental implant. Application of autogenous bone to the implant surface below the biomaterial might increase the osteopromotive capability of the technique as reported before.¹⁷

In the present study, no barrier membrane was used in addition to the bone graft substitute. This was due to the previously mentioned qualities of the tested graft material. The presence of a collagen membrane might additionally prevent the invasion of connective tissue into the grafted site, but it does not provide any additional stabilization of the bone graft substitute. It must be noted, however, that the coverage with the intact periosteum might protect the graft material, allowing bone promotive cell diffusion into the grafted site.¹⁸ For this reason, in this preliminary study, preoperative marginal soft-tissue healing through professional oral hygiene (scaling) was achieved, applied by dental hygienists to resolve periimplant mucositis before treatment. Additionally, accurate soft-tissue management during the surgical phase was provided to minimize periosteum deficiencies.

Table 1

Clinical parameters (mean ± standard deviation) at baseline and at six months and 12 months (13 implants).



Figs. 4a–c

Sites preop	Total count	Aa	Pg	Tf	Td	Pi	Pm	Fn	Cr	Ec	Ca
Periimplant sulcus	137.000	0 ± 0	36.3000 ± 31.6000	0.3230 ± 0.1670	0.0524 ± 0.0232	4.1200 ± 1.9200	0.041500 ± 0.009800	3.4100000 ± 1.0800000	0.4404 ± 0.209	0.2630 ± 0.0870	0.00 ± 0.38
Neighboring teeth	885.000	0 ± 0	0.0212 ± 0.0121	0.0340 ± 0.0167	0.0000 ± 0.6200	2.1500 ± 0.9500	0.704000 ± 0.056900	0.4610000 ± 0.2160000	2.000 ± 0.780	2.4200 ± 1.0100	0.00 ± 0.04
Connection	9600.000	0 ± 0	0.0139 ± 0.0098	175.0000 ± 67.0000	18.3000 ± 7.0900	1.4200 ± 3.2000	9.900000 ± 4.320000	114.0000000 ± 56.2000000	40.300 ± 11.900	188.0000 ± 67.7000	0.00 ± 0.79
Sites postop											
Periimplant sulcus	2.565	0 ± 0	0.0000 ± 0.2600	0.2730 ± 0.0840	0.0000 ± 0.9000	0.0096 ± 0.000	0.001778 ± 0.000000	0.0034430 ± 0.0000000	0.000 ± 0.003	0.0000 ± 0.0023	0.00 ± 0.00
Neighboring teeth	20.200	0 ± 0	0.0000 ± 0.0900	0.0000 ± 0.2300	0.0000 ± 0.2100	0.0250 ± 0.0300	0.079500 ± 0.020000	0.0043900 ± 0.0000000	0.000 ± 0.021	0.2160 ± 0.0540	0.00 ± 0.00
Connection	2.872	0 ± 0	0.0000 ± 0.1100	0.0000 ± 0.1200	0.0000 ± 0.9800	0.0000 ± 0.2800	0.001095 ± 0.000000	0.0018225 ± 0.0000000	0.000 ± 0.000	0.000 ± 0.0030	0.00 ± 0.00
P-value											
Periimplant sulcus	0.0000	1	0.0000	0.0021	0.0011	0.000	0.0001	0.0000	0.0001	0.0024	0.897
Neighboring teeth	0.0000	1	0.0000	0.0000	0.8970	0.000	0.0000	0.0002	0.0000	0.0000	0.912
Connection	0.0001	1	0.0001	0.0000	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	0.563

Table 2

Figs. 4a–c

Clinical (occlusal and lateral) and radiographic view at the 12-month follow-up.

Table 2

Bacteria counts at different sites (values expressed in millions of colony-forming units).

Regarding the microbiological environment at the periimplant sulcus and neighboring teeth, a significant decrease of the bacterial load in terms of total count and single pathogens was observed. At the same time, these data corroborated a significant decrease of the clinical parameters indicative of a reduction of the periimplantitis. The data suggest that a preoperative full-mouth prophylaxis, a tailored program of maintenance, recall and reinforcement of home care, represents a prerequisite for successful soft- and hard-tissue healing. In fact, while preoperative oral district disinfection might be involved in the most considerable improvement of microbiological contamination (essential for a good surgical plan), a tailored program of oral hygiene might represent an essential criterion for the longitudinal maintenance of the periimplant soft- and

hard-tissue during healing. As documented by Renvert and Polyzois and Serino et al., decreasing of home maintenance might compromise the clinically achieved outcomes in the mid-term.^{19,4}

In the analysis of the bacterial contamination at the implant connection level, a statistically significant decrease of the total account was detected during the study. However, all of the connections still demonstrated a bacteriologically polluted environment until the end of the follow-up period. It could be speculated that more effective bacterial control at the implant connection level and in the periimplant sulcus would allow for longer protection of the defect site from the disruptive effects of bacterial presence. For this reason, a different technique providing decontamination and, therefore, maintenance of the condition might be suggested. In fact, as

documented by Paolantonio et al., chlorhexidine was demonstrated to maintain the implant connection decontamination for a period shorter than six months.²⁰

Limitations of the present study clearly relate to the study design itself: The short follow-up period and small sample size suggested to carefully handle the even promising reported outcomes. A further limitation is that only less challenging bone defects were included in this preliminary study; hence, the regenerative outcomes should be considered in light of this.

For this study, only contained circumferential or semicircumferential defects were included that represented the most predictive defect shape, as documented by Schwarz et al., compared with two- or one-wall bone defects.⁶ According to the literature, despite profuse efforts, massive soft-tissue shrinkage has been reported.⁶ For this reason, new surgical techniques should be applied to counteract this phenomenon. For this purpose, as suggested by Schwarz

et al., the use of a connective tissue graft might be effective in controlling soft-tissue architecture if adapted over the regenerated site.²¹ In addition, a new flap design, as reported by Zucchelli and Mounssif, might represent an alternative strategy.²² Furthermore, a study with a longer follow-up, larger sample size and different defect types should be designed to corroborate the findings of the present study. However, it can be concluded that, within the limitations of the present preliminary study, the proposed technique, in combination with a self-stabilizing graft material, offers promising results in the treatment of circumferential and semicircumferential bone defects around implants affected by periimplantitis, without the use of a barrier membrane.

Competing interests

The authors declare that they have no competing interests.

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The clinical effects of insertion torque for implants placed in healed ridges: A two-year randomized controlled clinical trial

Abstract

Objective

Several factors are involved in the achievement of implant primary stability, such as the insertion torque, the implant's macrogeometry, the surgical technique, and the bone quality and quantity. Implant primary stability is considered one of the key factors for osseointegration and is associated with insertion torque. Several studies have suggested that insertion torque values of 25–45 N cm could prevent micromovements that could impair the bone healing around the implants. The aim of the present randomized clinical trial was to evaluate and compare the clinical outcome for implants placed with a high insertion torque (50–100 N cm) and a regular insertion torque (within 50 N cm) in healed ridges after two years.

Materials and methods

Patients requiring implant therapy to replace missing teeth without the need for bone augmentation at the time of implant placement were selected for this study. All of the patients were divided according to a randomization list into two groups: high insertion torque (CT implants inserted with insertion torque ≥ 50 N cm) and regular insertion torque (Blossom CT implants with insertion torque < 50 N cm). The implants were left to heal submerged for three months and then restored with individualized abutments and cemented metal–ceramic crowns. Variables registered were insertion torque values, thickness of the buccal bone plate after implant osteotomy preparation, marginal bone level and facial soft-tissue level. All of the patients were followed for two years after implant placement, with recall visits at three, six, 12 and 24 months.

Results

116 implants were placed: 58 implants were allocated to each group, with mean insertion torque ranging from 20 N cm to 50 N cm for regular inser-

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tion torque and from 50 N cm to 100 N cm for high insertion torque. Three implants failed. Two implants showed at the 12-month evaluation a marginal bone loss > 1.5 mm and were thus considered unsuccessful.

Conclusion

Implants inserted with a high insertion torque in healed bone ridges showed more periimplant bone remodeling and facial soft-tissue recession than implants inserted with regular insertion torque after two years, both in the maxilla and in the mandible. The findings suggest that the clinician should pay attention to several factors in implant therapy, such as the thickness of the buccal bone, the corticalization of the surgical site, the implant's macrogeometry and the potential influence of insertion torque on implant therapy outcomes.

Keywords

Insertion torque, dental implants, buccal bone thickness, marginal bone resorption, soft-tissue recession.

Introduction

The use of dental implants is considered a safe and reliable procedure for replacing missing teeth. Several factors are involved in the achievement of implant primary stability, such as the insertion torque, the implant's macrogeometry, the surgical technique, and the bone quality and quantity. Primary stability is regarded as one of the main factors for the achievement of osseointegration, that is, secondary stability.¹ It has been observed that micromovements > 50–150 µm have a detrimental effect on bone formation around the implant surface, leading to the formation of fibrous tissue and consequently implant failure.² With implant primary stability being related to the mechanical connection between the implant and the bone, it could be influenced by the implant's design, the bone quality and quantity, and the surgical site preparation.^{3,4} Inserting an implant in an undersized implant site osteotomy requires considerable force, which is referred to as the insertion torque. The bone is an elastic tissue before exceeding the yielding point: It can tolerate a certain level of strain owing to a relaxation effect.⁵ When the strain exceeds the yielding point, bone microfractures can be observed; this could cause an ischemic necrosis⁶ and, consequently, bone resorption. High insertion torque protocols have been suggested to enhance and accelerate implant success, considered as being strictly relat-

ed to the bone–implant mechanical interlocking and primary stability.⁷ However, the compressive forces caused by a high insertion torque could delay or compromise the process of osseointegration.⁸ A modified thread design could significantly help to decrease the strain developed on the bone surface compared with the conventional thread design.⁹ Although the scientific literature is not uniform regarding the minimum insertion torque required to obtain successful osseointegration, values between 32 N cm and 50 N cm are recommended.¹⁰ One factor affecting the esthetic outcome of implants is buccal bone thickness after the implant site preparation. In healed ridges, 2 mm thickness is recommended, although there is insufficient scientific evidence to establish a threshold for minimum buccal bone thickness.^{11,12}

The primary objective of the present study was to evaluate and compare the clinical outcomes for implants placed with a high insertion torque (50–100 N cm) and a regular insertion torque (within 50 N cm) in healed ridges, in terms of changes at the marginal bone level. The null hypothesis was that there was no difference in the marginal bone level changes between the two groups; the alternative hypothesis was that there was a difference.

The secondary objective of this study was to analyze the correlation between the residual thickness of the buccal bone after implant osteotomy preparation and the facial soft-tissue level

changes. The null hypothesis was that there was no difference in the facial soft-tissue changes between the two buccal plate groups (thickness < 1 mm vs. thickness > 1 mm), against the alternative hypothesis that there was a difference.

The present study was designed according to the CONSORT Statement for parallel-group randomized trials.¹³

Materials and methods

Partially edentulous patients who were 18 years old or older and able to sign an informed consent form and required at least one single implant-supported delayed restoration were considered eligible for inclusion in the trial. All of the patients were recruited from the consultation clinic at the Dentistry Department of Versilia Hospital, University of Pisa, Pisa, Italy, from July 2011 to December 2012. This study was designed as a parallel-arm randomized controlled clinical trial and consecutively treated patients were included.

The exclusion criteria were

- history of systemic diseases that would contraindicate oral surgery;
- long-term nonsteroidal anti-inflammatory drug therapy;
- intravenous and oral bisphosphonate therapy;
- lack of occluding dentition in the area intended for the restoration;
- extraction sites with less than three months of healing;
- untreated periodontal disease;
- need for bone augmentation at the time of implant surgery;
- poor oral hygiene and compliance (presence of stains, calculus and plaque before surgery);
- pregnant or nursing;
- unwillingness to return for the follow-up examination; and
- smoking more than ten cigarettes per day (subjects who smoked fewer than ten cigarettes per day were requested to stop smoking before and after surgery; however, their compliance could not be monitored).

The study followed the principles outlined in the Declaration of Helsinki of 1975, as revised in 2013, on clinical research involving human subjects and was approved by the local ethics committee. Demographic data are summarized in **Table 1**. All of the patients received a thorough

explanation and had to complete a written informed consent form prior to being enrolled in the trial. Patients included in the study were accurately evaluated by examining the clinical aspects and periapical or panoramic radiographs and underwent computed tomography scan examination, if required. After the consent form had been signed, all of the patients underwent at least one oral hygiene session in order to provide a more favorable oral environment for wound healing. Impressions of the selected jaws were taken, in order to adequately plan the prosthesis and obtain a stable occlusion.

Clinical and radiographic evaluations were performed to select patients with an amount of bone adequate for implant placement. Patient recruitment and treatment were performed by two well-trained surgeons (AB and FA), who received training before starting the study. The training included calibration for surgical, prosthetic and follow-up procedures, as well as the management of any complications.

Patients were randomly allocated by opening a sequentially numbered envelope corresponding to the patients' recruitment numbers, either to the high insertion torque group or to the regular insertion torque group. The high insertion torque group received a self-tapping design implant (CT, Intra-Lock International, Boca Raton, Fla., U.S.), which had an insertion torque value ≥ 50 N cm. The regular insertion torque group received a modified cutting flute design implant (Blossom CT, Intra-Lock International), which had an insertion torque value < 50 N cm. The thread design of the two implants was identical, only differing regarding the cutting groove design.

A computer-generated restricted randomization list was created. One investigator (PT), who was not involved in the selection and in the clinical treatment of the patients, had access to this list and was aware of the random sequence. The information about the treatment of each patient was contained in sealed envelopes, sequentially numbered, identical and opaque. Envelopes were opened sequentially, after osteotomy preparation and before implant insertion. Treatment allocation was concealed to the investigators in charge of enrolling and treating the patients.

Surgical procedure

All of the patients received prophylactic antibiotic therapy (2 g of amoxicillin or 600 mg of clindamycin if allergic to penicillin 1 h prior to implant surgery). After local anesthesia (articaine with

Table 1

	Regular-IT group	High-IT group
Sample size	58(1)	58(2)
Age (years)	51.5 ± 8.2	51.3 ± 8.2
Age range (years)	31.0–68.4	38.8–65.8
Male–female ratio	19/39(1)	20(1)/39(1)
Incisor	1	1
Canine	7	8(1)
Premolar	29(1)	36(1)
Molar	21	13
Smoker–nonsmoker ratio	17/41(1)	18(1)/40(1)
Buccal bone thickness (mm)	0.97 ± 0.33	0.84 ± 0.36
Mean insertion torque (N cm)	30.3 ± 7.5	68.8 ± 9.0

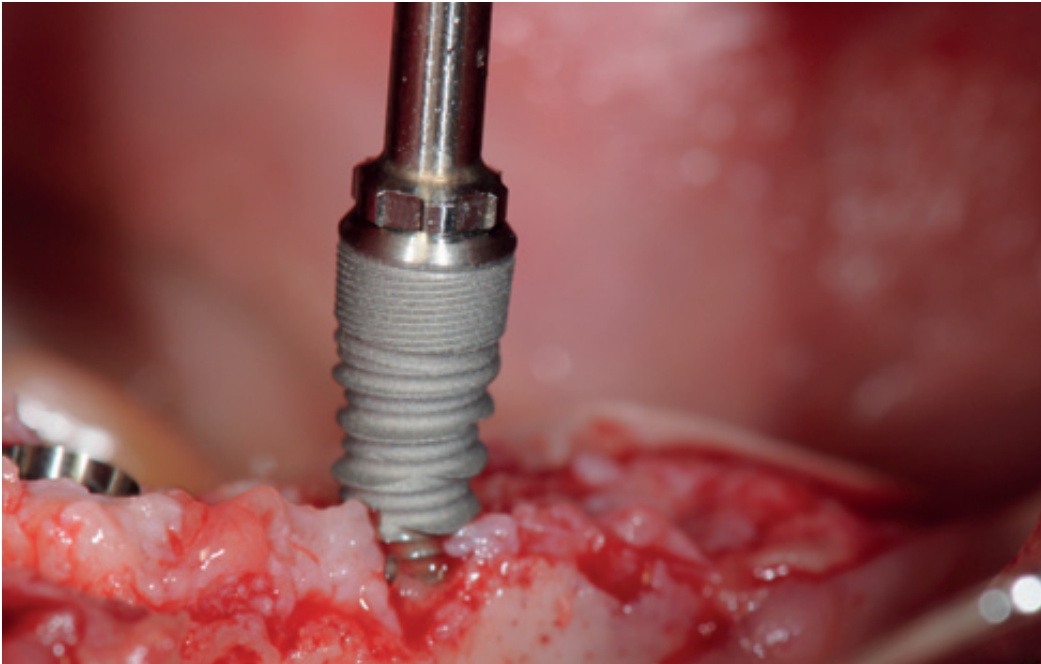
Table 1

Demographic data.

Fig. 1

Insertion of an implant of the regular-IT group.

Fig. 1



1:100,000 epinephrine) and rinsing with a 0.2% chlorhexidine mouthwash, a crestal incision and full-thickness flap elevation were performed in all of the patients.

The implant osteotomy preparation followed the manufacturer's recommendations. A surgical guide was used to prosthetically determine the implant position after the initial perforation of the cortical bone. A 2 mm twist drill was used with the surgical guide in order to achieve the position and angulation planned, and the osteotomy was widened according to the manufacturer's recommendations. After the final drilling, all of the surgical sites were prepared in the coron-

al part to as deep as 2 mm with a countersink drill. Implants were inserted with a surgical unit (ElcoMed, W&H Dentalwerk Bürmoos, Bürmoos, Austria; **Fig. 1**) at a calibrated maximum torque of 40 N cm at a predetermined 30 rpm. All of the implants were positioned at the bone crest level and were seated at the final position, utilizing for the last 2 mm a digital torque gauge (BTGE 10CN, Tohnichi Torque, Northbrook, Ill., U.S.). After positioning of the cover screw, the flaps were sutured using 4-0 silk stitches.

The patients were instructed to take anti-inflammatory therapy (ibuprofen 600 mg tablets t.i.d. for as long as required) and to rinse with a

0.2% chlorhexidine mouthwash (for 1 min b.i.d. for two weeks). The patients were recommended to avoid brushing and trauma and any removable prostheses were removed. After ten days, the sutures were removed and oral hygiene instructions were given.

The implants were left to heal submerged for three months. Subsequently, the implants were exposed and impressions were taken using the ITAB transfer/abutment (Intra-Lock International) with an individual tray and polyvinyl siloxane material (Flexitime, Heraeus Kulzer, Hanu, Germany). Implant abutments were customized and definitive metal–ceramic crowns were cemented. Periapical radiographs were taken, with the parallel cone technique with a digital sensor (70 kVp, 7 mA), at baseline (immediately after implant insertion) and at three, six, 12 and 24 months after implant placement. The patients were enrolled in an oral hygiene program with recall visits every four months for the entire duration of the study and an independent observer performed all of the follow-ups.

Variables

Sample description variables

The sample was described by the following variables: age; sex; smoking habit; location, length and insertion torque of dental implant; and thickness of the residual buccal bone plate after osteotomy. The following numerical variables were evaluated:

- Insertion torque (IT): The IT was registered at the time of surgery by a digital torque gauge (BTGE 10CN), after each turn of 90° of the implant. Subsequently, the mean IT was calculated according to the values registered and to the number of turns required to fit the implant platform to the level of the crestal bone.
- Buccal bone thickness (BBT): The residual bone thickness on the buccal aspect of the implant osteotomy preparation was measured at baseline at the midfacial level of the buccal bone plate using a surgical caliper. Two groups were identified according to the BBT: Group A with a thickness < 1 mm and Group B with a thickness ≥ 1 mm.

Outcome variables

All other measurements were acquired immediately at the time of surgery (baseline) and at

three, six, 12 and 24 months after dental implant insertion. A single well-trained clinician, who was not involved in the surgical treatment, registered all of the measurements.

The following outcome variables were registered:

- *Periimplant marginal bone level (MBL)* at the mesial and distal sites: The distance between the reference point and the most apical point of the MBL was evaluated on intraoral radiographs. The reference point was the fixture platform. A paralleling device and individualized bite blocks, made of polyvinyl siloxane impression material, were used for the standardization of the X-ray geometry. Calibration was performed using the known thread pitch distance of the implants (pitch = 1 mm). Previous known values, such as fixture diameter and length, were used for calibration when the threads were not clearly visible on the radiographs. Measurements were taken to the nearest millimeter using computer software (UTHSCSA Image Tool, Version 3; University of Texas Health Science Center, San Antonio, Texas, U.S.). Changes at the MBL were evaluated for all of the mesial and distal aspects by subtracting the postoperative values from the respective baseline value ($n\Delta\text{MBL} = n\text{MBL}_{\text{Baseline}} - n\text{MBL}$, with n as mesial or distal). MBL represented the mean of the values measured at the mesial and distal aspects, and ΔMBL represented the mean of the variation in values measured at the mesial and distal aspects.
- *Facial soft-tissue level (FSTL)* was evaluated, measuring the distance between the level of soft tissue at the midfacial gingival level and a reference line connecting the FSTL of the adjacent teeth. Facial soft-tissue changes were calculated by subtracting the baseline value from the respective postoperative values according to the formula $\Delta\text{FSTL} = \text{FSTL} - \text{FSTL}_{\text{Baseline}}$.
- *Implant failure*, such as implant mobility and removal of implants caused by progressive bone loss or infection: The stability of each implant was evaluated at the delivery of the prosthetic restoration and one and two years after implant insertion. The stability of each crown was ascertained with two metallic handles of dental instruments. Survival and success rates were calculated according to the criteria suggested by Buser et al.¹⁴

Statistical analysis

Power analysis was employed to determine the sample size using a 0.05 significance level and a power of 80%, based on the results reported in a previous study concerning periimplant marginal bone loss.¹⁵ Sample size estimates, ranging from 23 to 168, were generated, comparing data on regular-IT and high-IT groups at the time of loading and after two years. A primary statistical evaluation was performed with multiway analysis of variance and multiple regression analysis (Database Toolbox and Statistics Toolbox, MatLab 7.0.1, MathWorks, Natick, Mass., U.S.). Post-hoc comparisons were performed with a *t*-test and the confidence interval was set at 95% (Statistics Toolbox). The level of statistical significance (*p*-value) was set at 0.05 for all analyses.

Results

One hundred and twenty implants were considered eligible for this study. Four patients were excluded (two required bone augmentation at the time of implant insertion; one refused to attend the recall visits; and one had excessive IT at the time of implant placement, so the osteotomy had to be widened with a countersink bur before implant insertion). The remaining 116 patients were allocated to two groups (58 to the regular-IT and 58 to the high-IT group), according to a randomization process. Each patient received one implant and the experimental sites were followed for two years. The patients' mean age at the time of the surgery was 51.5 ± 8.2 years in the regular-IT group and 51.3 ± 8.2 years in the high-IT group. Implants were inserted both in the maxilla and in the mandible, showing a homogenous distribution between the lower and upper jaws. Most of the sites were located in the premolar area, both for the regular-IT (29 implants) and for the high-IT (36 implants). The mean IT registered at the time of implant insertion was 30.3 ± 7.5 N cm for the regular-IT group and 68.8 ± 9.0 N cm for the high-IT group. The implant distribution is shown in **Table 1**.

After 24 months, one implant in the regular-IT group and three implants in the high-IT group were considered failures, since it was necessary to remove and replace the implants. The survival rate recorded in the regular-IT group was 98.2%, while in the high-IT group it was 94.8%.

The implant success rate was established according to Buser et al.,¹⁴ considering a marginal bone loss > 1.5 mm at 12 months a failure criterion. On that basis, after two years, one implant in the regular-IT group could not be considered successful, and the cumulative success rate in this group was 98.2%. In the high-IT group, the cumulative success rate was significantly lower (93.1%), since four implants did not fulfil the success criteria.

The MBL values were homogeneous at baseline between the two groups, as they depended on the final position of the implants in the healed bone ridges decided by the surgeon. The MBL values at baseline (maxilla: 0.14 ± 0.47 mm in the high-IT group and 0.12 ± 0.39 mm in the regular-IT group; mandible: 0.10 ± 0.24 mm in the high-IT group and 0.06 ± 0.17 mm in the regular-IT group) attested that the fixture platform was positioned at the bone crest level both in the maxilla and in the mandible (**Figs. 2 & 3**). Regarding the maxillary MBL values, after one year, the bone levels had decreased in both groups, showing a significant difference between the regular- and high-IT groups ($p = 0.0045$; **Figs. 4 & 5**). The difference between the two groups was still significant at the 24-month follow-up, being -0.79 ± 0.38 mm in the high-IT group and -0.55 ± 0.31 mm in the regular-IT group ($p = 0.0056$; **Figs. 6 & 7**). The Δ MBL emphasized the difference between the two groups after two years, being -0.93 ± 0.57 mm in the high-IT group and -0.67 ± 0.43 mm in the regular-IT group in the maxilla at the 24-month recall. In particular, the Δ MBL at 24 months in the high-IT group showed a slight increase in the MBL compared with the 12-month time point, but the difference between the high- and regular-IT groups was still significant ($p = 0.0095$). Differences in the effects of the IT appeared even more evident in the mandible. After one year, the MBL in the high-IT group was -1.23 ± 0.36 mm, and after 24 months, it was -1.21 ± 0.36 mm, showing that the MBL remained quite stable between the one- and the two-year recall visits. The MBL in the high-IT group had decreased to 1.31 ± 0.33 mm at the two-year follow-up; this value was similar to the Δ MBL at 12 months, attesting that the bone ridge around the implants in the high-IT group remained stable after a remarkable decrease in the first year. The MBL and Δ MBL values in the regular-IT group were completely dissimilar from the high-IT group values in the mandible. The MBL was -0.63 ± 0.31 mm at the 12-month follow-up and -0.68 ± 0.30 mm

Fig. 2

High-IT group: implant inserted in the maxilla, radiograph at baseline.

Fig. 3

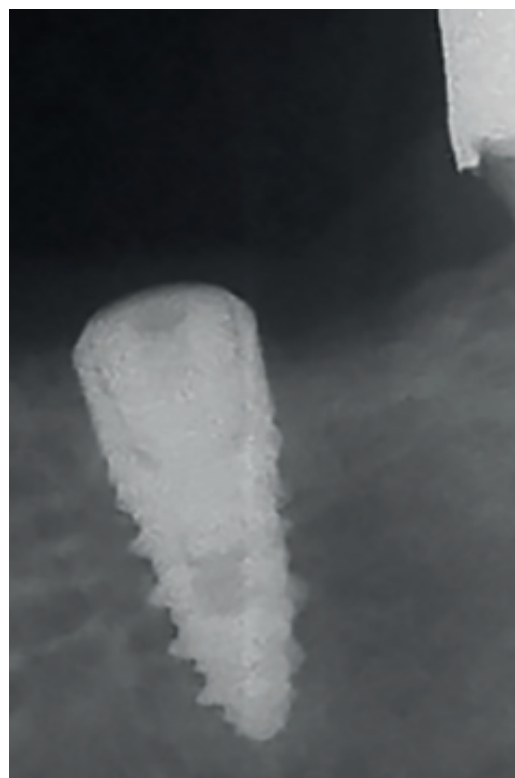
Regular-IT group: implant inserted in the mandible, radiograph at baseline.

Fig. 4

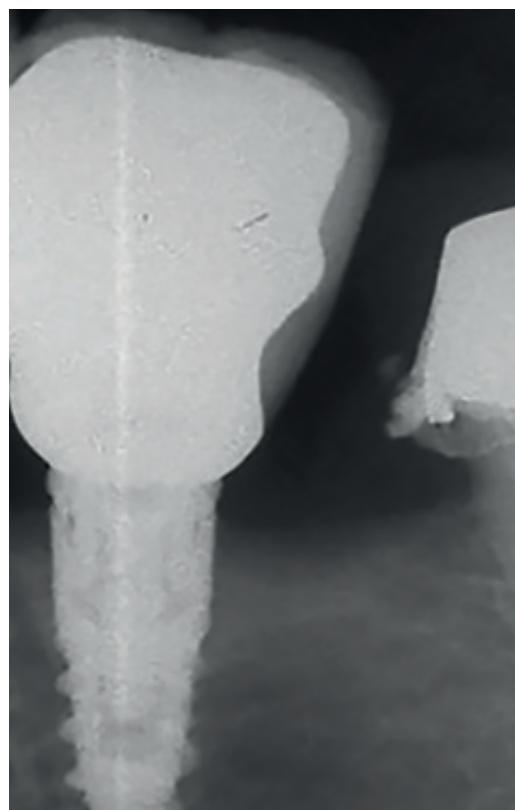
High-IT group: implant inserted in the maxilla, radiograph at 12 months.

Fig. 5

Regular-IT group: implant inserted in the mandible, radiograph at 12 months.

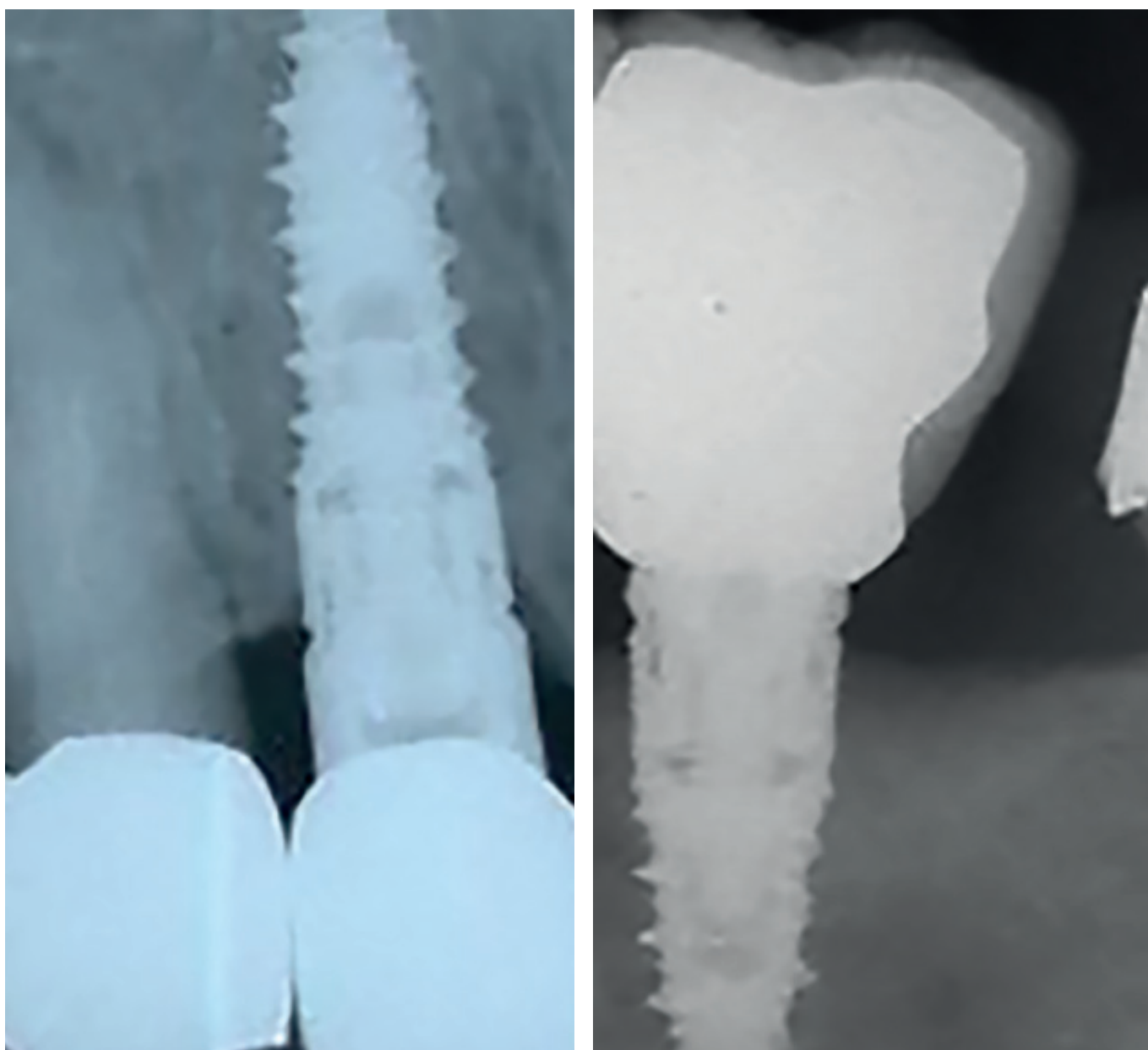


Figs. 2 & 3



Figs. 4 & 5

Figs. 6 & 7

**Fig. 6**

High-IT group: implant inserted in the maxilla, radiograph at 24 months.

Fig. 7

Regular-IT group: implant inserted in the mandible, radiograph at 24 months.

after 24 months. After the first year, the marginal bone around the implants remained stable, registering a decrease of 0.75 ± 0.28 mm at 24 months (**Table 2**).

The FSTL values were analyzed in the mandible and maxilla in the high-IT and regular-IT groups (**Table 3**). In the maxilla, the FSTL values at baseline were homogeneous for the two groups. After one year, a decrease in FSTL was registered in both groups (-0.60 ± 0.49 mm in the high-IT group and -0.07 ± 0.26 mm in the regular-IT group), but at the 24-month recall, both the regular-IT group and the high-IT group showed a slight increase. Despite this, the difference between the two groups was significant

at each time point. The Δ FSTL underlined the one-year decrease and the two-year increase in the soft-tissue level, besides the clear differences between the two groups at each time point.

The FSTL values in the mandible showed a decrease in both groups after 12 months (-0.90 ± 0.48 mm in the high-IT group and -0.13 ± 0.34 mm in the regular-IT group). After two years, the high-IT group remained stable, while the regular-IT group showed an increase in FSTL. The difference in Δ FSTL between the regular-IT and high-IT groups was significant at the one-year follow-up and even more evident at the two-year follow-up.

Table 2

	MBL (mm)	Baseline	3 months	6 months	12 months	24 months	Δ MBL (mm)	3 months	6 months	12 months	24 months
Maxilla	High IT	0.14 $\pm$ 0.47	-0.26 $\pm$ 0.56	-0.65 $\pm$ 0.48	-0.87 $\pm$ 0.44	-0.79 $\pm$ 0.38	High IT	-0.40 $\pm$ 0.46	-0.78 $\pm$ 0.55	-1.02 $\pm$ 0.59	-0.93 $\pm$ 0.57
	Regular IT	0.12 $\pm$ 0.39	0.12 $\pm$ 0.40	-0.27 $\pm$ 0.28	-0.57 $\pm$ 0.37	-0.55 $\pm$ 0.31	Regular IT	0 $\pm$ 0	-0.40 $\pm$ 0.43	-0.69 $\pm$ 0.45	-0.67 $\pm$ 0.43
	P-value	0.4865	0.005	0.001	0.0045	0.0056	P-value	0.005	< 0.001	0.0054	0.0095
Mandible	High IT	0.1 $\pm$ 0.24	-0.86 $\pm$ 0.29	-1.11 $\pm$ 0.36	-1.23 $\pm$ 0.36	-1.21 $\pm$ 0.36	High IT	-0.96 $\pm$ 0.18	-1.21 $\pm$ 0.31	-1.33 $\pm$ 0.33	-1.31 $\pm$ 0.33
	Regular IT	0.06 $\pm$ 0.17	0.03 $\pm$ 0.26	-0.36 $\pm$ 0.31	-0.63 $\pm$ 0.31	-0.68 $\pm$ 0.30	Regular IT	-0.03 $\pm$ 0.18	-0.43 $\pm$ 0.28	-0.7 $\pm$ 0.28	-0.75 $\pm$ 0.28
	P-value	0.6849	< 0.001	< 0.001	0.0001	0.0001	P-value	< 0.001	< 0.001	0.0001	0.0001

Table 3

	FSTL (mm)	Baseline	12 months	24 months	Δ FSTL (mm)	12 months	24 months
Maxilla	High IT	0.12 $\pm$.33	-0.6 $\pm$ 0.49	-0.5 $\pm$ 0.58	High IT	-0.75 $\pm$ 0.44	-0.62 $\pm$ 0.57
	Regular IT	0.07 $\pm$ 0.37	-0.07 $\pm$ 0.26	-0.03 $\pm$ 0.33	Regular IT	-0.14 $\pm$ 0.44	-0.10 $\pm$ 0.49
	P-value	0.6090	0.0001	0.0007	P-value	0.0008	0.0008
Mandible	High IT	0.16 $\pm$ 0.37	-0.9 $\pm$ 0.48	-0.96 $\pm$ 0.41	High IT	-1.06 $\pm$ 0.52	-1.13 $\pm$ 0.50
	Regular IT	0.13 $\pm$ 0.34	-0.13 $\pm$ 0.34	0 $\pm$ 0	Regular IT	-0.26 $\pm$ 0.44	-0.13 $\pm$ 0.34
	P-value	0.7200	0.0001	0.0001	P-value	0.0001	0.0001

Table 4

		FSTL at baseline	FSTL at 24 months	ΔFSTL at 24 months
Group A	High IT	0.11 ± 0.32	-1.03 ± 0.34	-1.14 ± 0.36
	Regular IT	-0.21 ± 0.42	0	-0.21 ± 0.42
	P-value	0.3423	0.0001	0.0001
Group B	High IT	0.17 ± 0.39	-0.5 ± 0.57	-0.67 ± 0.66
	Regular IT	0.06 ± 0.33	-0.02 ± 0.26	-0.09 ± 0.42
	P-value	0.2631	0.0001	0.0001

The FSTL and ΔFSTL were also examined around implants, dividing the results into Group A and Group B according to the thickness of the buccal bone after the osteotomy preparation, measured at the time of implant insertion (**Table 4**). The FSTL and ΔFSTL in the high-IT group showed differences between the values registered for Group A and in Group B. In fact, at the 24-month follow-up, the implants in Group A inserted with a high IT had greater soft-tissue recession (FSTL: -1.03 ± 0.34 mm; ΔFSTL: -1.15 ± 0.36 mm) compared with Group B (FSTL: -0.50 ± 0.57 mm; ΔFSTL: -0.67 ± 0.66 mm). Moreover, the BBT in the regular-IT group had an influence on facial soft-tissue behavior. In fact, the soft-tissue recession in Group A (-0.21 ± 0.42 mm) was greater than in Group B (-0.09 ± 0.42 mm) after two years.

Discussion

The clinical and radiographic outcome of implants inserted with a high IT (50–100 N cm) and regular IT (< 50 N cm) in healed ridges were compared in this study. The outcome variables considered were FSTL, measured clinically, and MBL, analyzed through radiographs. Also, the influence of BBT after implant osteotomy on the facial soft-tissue changes was investigated. The implant cumulative success rate was registered in each group and all experimental sites were followed for two years. Only one implant per

patient was inserted, in order to exclude possible cluster effects on the implant outcome. Only nongrafted sites were included to eliminate the possible influence of a biomaterial previously grafted in the surgical sites, although implants inserted in grafted sites have been demonstrated to have survival rates similar to that of implants inserted in nonaugmented sites.^{16, 17}

Measures were taken at baseline and at three, six, 12 and 24 months, providing the possibility of analyzing the outcomes after both the first and the second year of follow-up. This would help in studying the hard- and soft-tissue changes after implant loading.

The achievement of good primary stability when inserting an implant has been found to be important, mostly when applying an immediate loading protocol.¹⁸ A higher IT makes the clinician feel more comfortable while inserting an implant, as it appears to mimic implant primary stability.^{19, 20}

In the present study, implants inserted with an IT that exceeded 50 N cm had more pronounced periimplant bone resorption and soft-tissue recession than implants with an IT within 50 N cm, and this result was more evident in the mandible. These findings are in line with that of other studies.²¹ In fact, implants inserted in the anterior maxilla with a high IT (ranging from 50 N cm to 80 N cm), immediately or early loaded, and followed for one year showed significant differences between the bone resorption at each time point.²¹

Table 2

MBL (mean ± standard deviation) and ΔMBL at 24 months in the maxilla and mandible for the high- and regular-IT groups.

Table 3

FSTL (mean ± standard deviation) and ΔFSTL at 24 months in the maxilla and mandible for the high- and regular-IT groups.

Table 4

FSTL (mean ± standard deviation) and ΔFSTL (mean ± standard deviation) in sites with BBT < 1 mm (Group A) and BBT ≥ 1 mm (Group B) for the high- and regular-IT groups.

However, a recent systematic review analyzing bone resorption, implant failure and bone-implant contact found no significant differences between implants inserted with a high or low IT.²² The same review stated that there is poor evidence regarding the correlation between excessive bone compression and bone resorption, but there is still no clear statement about the minimum IT necessary to obtain clinical success, even when considering immediate loading.²²

As the soft-tissue appearance significantly influences the esthetics of implants, its treatment is of great importance, although more research on the behavior of soft tissue around dental implants is required.

In our findings, significant differences were observed in soft-tissue changes too. In the high-IT group, the FSTL significantly decreased after one year and remained quite stable at the two-year follow-up. In the regular-IT group, the FSTL remained stable for the one year, and then it seemed to gain soft tissue, the difference between the two groups becoming more evident, both in the maxilla and in the mandible. If we consider the BBT, recession of the FSTL seemed to be significantly influenced by a BBT < 1 mm. Differences were evident within both of the experimental groups. In fact, the Δ FSTL in the high-IT group at 24 months was -1.15 ± 0.36 mm for Group A and -0.67 ± 0.66 mm for Group B. The Δ FSTL in the regular-IT group at 24 months was -0.21 ± 0.42 mm in Group A and -0.09 ± 0.42 mm in Group B.

These results are in line with that of other studies, which found 0–1 mm gingival recession at the buccal side of implants placed in post-extractive sites and restored after three weeks.²³ The same studies did not observe significant recession in sites with a thick gingival biotype; therefore, the FSTL seemed to be influenced not only by the bone but also by the tissue thickness.²³ The implants inserted in the present study were not immediately restored.

A key point of this study is the observation period: Two years is a relatively short follow-up in which to observe the behavior not only during the osseointegration period but also after the prosthesis delivery. Also, surgical sites were strictly selected, excluding the possible influence of bone augmentation; thus, only IT and BBT were studied. IT and bone resorption were measured via software, allowing precise and reliable comparisons.

Conclusion

The present randomized clinical trial analyzed the effect of IT on MBL and FSTL after two years. The effect of BBT on MBL after the implant osteotomy was investigated too. Implants inserted with an IT > 50 N cm showed significantly more bone resorption; this was evident after one year, but became even more marked at the two-year follow-up. The FSTL showed more evident recession in the high-IT group after two years, especially in implants with a BBT < 1 mm after osteotomy.

The findings of this study suggest that inserting implants with a high IT could be detrimental to soft- and hard-tissue outcome, even though the implant success rate was similar for the high-IT and regular-IT groups. Furthermore, the clinician should pay great attention during the preparation of the implant site, as a BBT > 1 mm could positively affect the long-term behavior of soft tissue. Although the randomization process lent reliability to the results, the findings of this study should be corroborated with a longer follow-up and a greater number of patients.

Competing interests

The authors declare that they have no competing interests.

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Histomorphometric analysis of bone healing at implants with turned or rough surfaces: An experimental study in the dog

Abstract

Objective

The objective of this study was to evaluate the influence of machined or moderately rough surfaces on osseointegration of implants.

Materials and methods

Three months after extraction of all mandibular premolars and first molars in six Labrador dogs, two implants, one with a novel turned surface (Combed) and a second with a moderately rough surface (ZirTi), were placed in each side of the mandible in the premolar region of each dog. The 3-D parameters to express roughness and density of peaks were $S_a = 1.399 \mu\text{m}$ and $S_{ds} = 0.065 \mu\text{m}^2$ for the ZirTi surface and $S_a = 0.600 \mu\text{m}$ and $S_{ds} = 0.314 \mu\text{m}^2$ for the Combed surface, respectively.

Abutments were attached and the flaps were sutured to allow non-submerged healing. The animals were sacrificed after four months of healing, and ground sections were obtained for histomorphometric assessments of the hard-tissue integration.

Results

All of the implants were osseointegrated. Mineralized bone-to-implant contact was $50.6 \pm 18.3\%$ and $56.3 \pm 18.6\%$, while bone density was $54.6 \pm 9.6\%$ and $43.0 \pm 9.0\%$ at the Combed and ZirTi surfaces, respectively. The difference between the two surfaces was statistically significant ($p = 0.046$) for both parameters evaluated.

Conclusion

Implant surface characteristics influence the degree of osseointegration of implants placed in the alveolar process.

Keywords

Animal study, bone healing, dental implants, osseointegration, bone levels, histometry, morphometry.

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Introduction

Osseointegration processes are influenced by many variables, and osseointegration has been found to proceed faster in animals compared with humans and in the spongiosa compared with the cortical bone.¹ Moderately rough surfaces have shown faster bone apposition compared with turned surfaces. Recently, various implant surfaces have been discussed with regard to osseointegration.² Mainly those of four brands represented frequently in the international market were addressed. It was shown that the different surface treatments of the implants led to different values of the 3-D average roughness over a surface (S_a value), as well as of the density of peaks (S_{ds}) and of the developed surface area ratio (S_{dr}). Different values of S_a and S_{dr} among the various surfaces were reported, including between 0.3 μm and 1.78 μm for S_a and between 24% and 143% for S_{dr} . It is interesting to note that the original Brånemark nontreated turned surface presented values of S_a of 0.9 μm and S_{dr} of 34%.²

A comparison of the sequential healing between turned and rough (sandblasted, large-grit, acid-etched; SLA) surfaces was performed in an experimental study in dogs.^{3,4} Troughs were created in the space between threads so that, after implant placement, a chamber was obtained, and only the tips of the threads were in contact with the pristine bone. It was demonstrated that osseointegration within the chambers proceeded faster and reached higher levels at the SLA compared with the turned surfaces.

The study of the healing of the hard tissue at untreated turned surfaces and at surfaces blasted with zirconia particles and subsequently acid etched still needs clarification. Hence, the aim of the present experiment was to compare osseointegration at turned and moderately rough surfaces after four months of healing.

Materials and methods

The research protocol was submitted to and approved by the local ethics committee for animal research at the University of the State of São Paulo, Araçatuba, Brazil.

Clinical procedures

Clinical procedures, histologic preparation and data regarding marginal soft- and hard-tissue

healing have been reported on previously.⁵ Briefly, six Labrador dogs (each approximately 23 kg and at a mean age of about three years) were used. At any of the surgical sessions, the animals were pre-anesthetized with Acepran (0.05 mg/kg; Univet-vetnil, São Paulo, Brazil) and sedated with Zoletil (10 mg/kg; Virbac, Fort Worth, Texas, U.S.) and Xilazina (1 mg/kg; Cristália Produtos Químicos Farmacêuticos, São Paulo, Brazil), complemented with ketamine (2.5 mg/kg, Cristália Produtos Químicos Farmacêuticos). Local anesthesia was also provided.

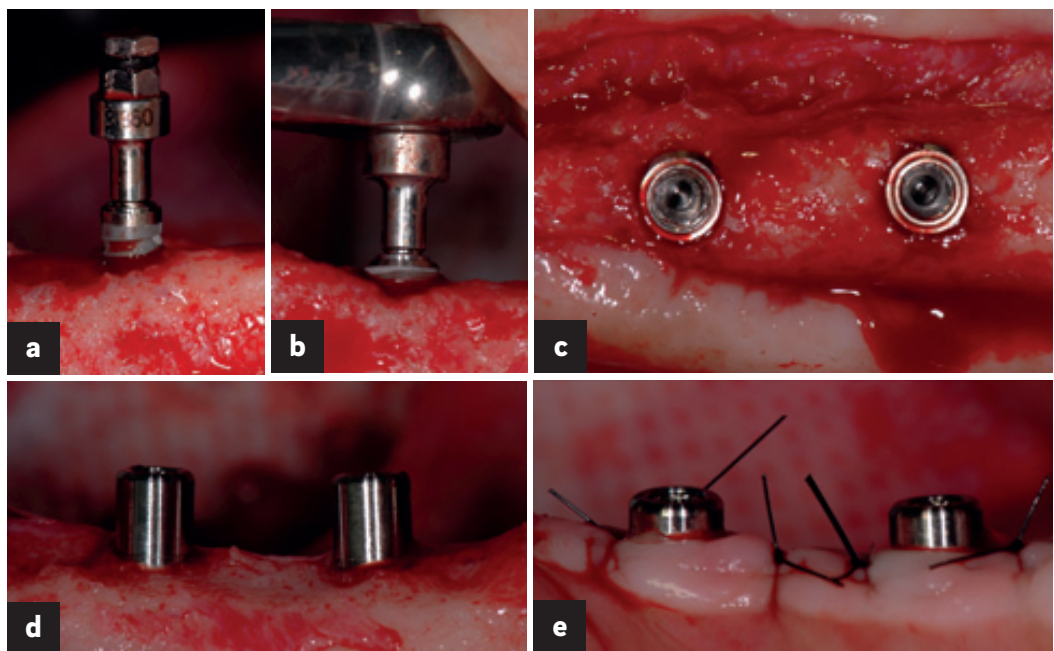
All premolars and first molars were extracted at both sides of the mandible. After three months of healing, an incision in the center of the alveolar crest was performed and full-thickness mucoperiosteal flaps were elevated. Two osteotomies were prepared in each side of the mandible in the premolar region and two 10 mm long and 3.8 mm wide titanium Premium (**Fig. 1a**) or Platform Premium (**Fig. 1b**) implants (Sweden & Martina, Due Carrare, Italy) were placed in the right and left sides of the mandible, respectively (**Fig. 1c**). The anterior implants had a turned surface (Combed, Sweden & Martina), while the posterior implants had a moderately rough surface (ZirTi, Sweden & Martina).

The ZirTi surface was first sandblasted using particles of zirconia and subsequently acid etched, while the Combed surface was obtained by a particular tooling process, developed and controlled to achieve a more homogeneous and rough surface in comparison with standard machined surfaces. The 3-D parameters to express roughness and density of peaks were $S_a = 1.399 \mu\text{m}$ and $S_{ds} = 0.065 \mu\text{m}^2$ for the ZirTi surface and $S_a = 0.600 \mu\text{m}$ and $S_{ds} = 0.314 \mu\text{m}^2$ for the Combed surface, respectively.

Abutments were attached at the top in the implants (**Fig. 1d**) and the flaps were adapted around the abutment-implant units to allow non-submerged healing (**Fig. 1e**). After the surgical procedures, the animals received ketoflex 1% (0.02 mL/kg; Cetoprofeno, Biofarm Química e Farmacêutica, Jaboticabal, Brazil) and Pentabiotico (Fort Dodge Animal Health, Campinas, Brazil). The animals were kept in kennels and on concrete runs at the university's field laboratory with free access to water and fed with moistened balanced dog food. The wounds were inspected daily for clinical signs of complications, and the abutment cleaned. Sutures were removed after two weeks. The animals were euthanatized four months after the surgery, applying an overdose

Figs. 1a–e

Clinical view of the surgical procedures. (a) Premium and (b) Platform Premium implants during placement. (c) Implants placed in the alveolar bone crest. (d) Abutments attached at the top of the implants. (e) Flaps adapted around the abutment–implant unit to allow nonsubmerged healing.



Figs. 1a – c

Figs. 1d & e

of thiopental (Cristália Produtos Químicos Farmacêuticos, Campinas, Brazil) and subsequently perfused with a fixative (10% formaldehyde) through the carotid arteries.

determined. For this aim, a point-counting procedure was applied⁶ and a lattice with squares of 50 μm was superposed over the tissue at 200 $\times$ magnification.

Histological preparation

The implants and surrounding tissue were dehydrated in a series of graded ethanol solutions and subsequently embedded in resin (LR White, hard grade, London Resin Company, Berkshire, U.K.) and polymerized. The cuts were performed along the buccolingual plane following the long axis of the implants using a diamond band saw fitted in a precision slicing machine (Microslice 2, Ultratec, Santa Ana, Calif., U.S.) and then thinned. The histological slides were stained with Stevenel's blue and alizarin red and examined under a standard light microscope for histometric analysis.

Histometric evaluation

Under an Eclipse Ci microscope (Nikon, Tokyo, Japan), equipped with a DS-Fi2 (Nikon) digital video camera connected to a computer, the percentage of mineralized bone-to-implant contact (MBIC%) between the most coronal bone-to-implant contact (B) and the apex of the implant (A) was evaluated at 100 $\times$ magnification. Moreover, the percentages of mineralized bone (MB%) and soft tissue contained in a region included between B and A and between the body of the implant to a distance of about 0.6 mm from it were

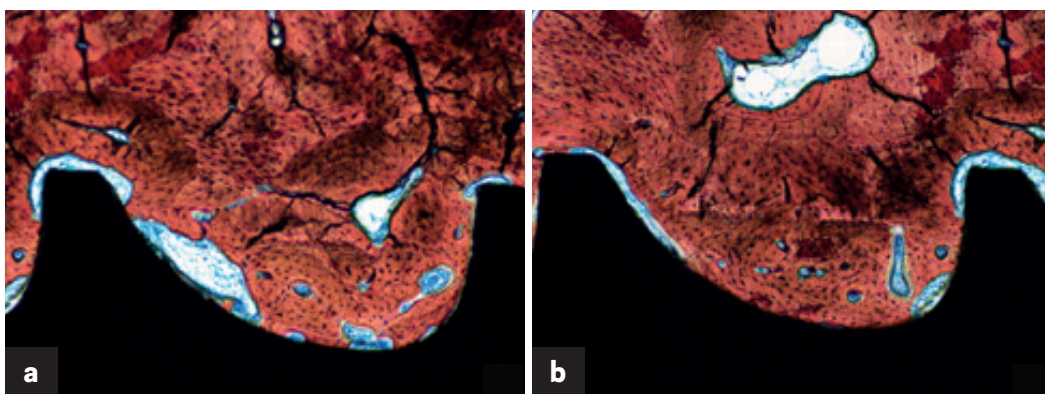
Data analysis

Mean values between the two implants included in each group were obtained for both MBIC% and MB% in each dog. An $n = 6$ was obtained. Differences between the two implant surfaces were analyzed using IBM SPSS Statistics (Version No 19.0; IBM Corp., Armonk, N.Y., U.S.) and applying the Wilcoxon signed-rank test for dependent variables. The level of significance was set at $p = 0.05$. A correlation between MBIC% and MB% was also calculated for all 24 implants, as well as for the 12 implants of each group.

Results

After four months of healing, no complications were observed and no implants had been lost. All of the implants were available for histological analysis. Data illustrating the outcomes at the marginal soft and hard tissue around the implants were previously described.⁵ **Table 1** reports the mean values and standard deviations, as well as medians and 25th and 75th percentiles. In the text, only mean values $\pm$ standard deviations are reported.

Figs. 2a & b



Figs. 2a–d

Photomicrographs of ground sections illustrating the healing after four months at the Combed surface. Stevenel's blue and alizarin red stain. 100× magnification.

Table 1

Mean value (standard deviation) and median (25th and 75th percentiles) of MBIC% and MB%. (n = 6)

Figs. 2c & d

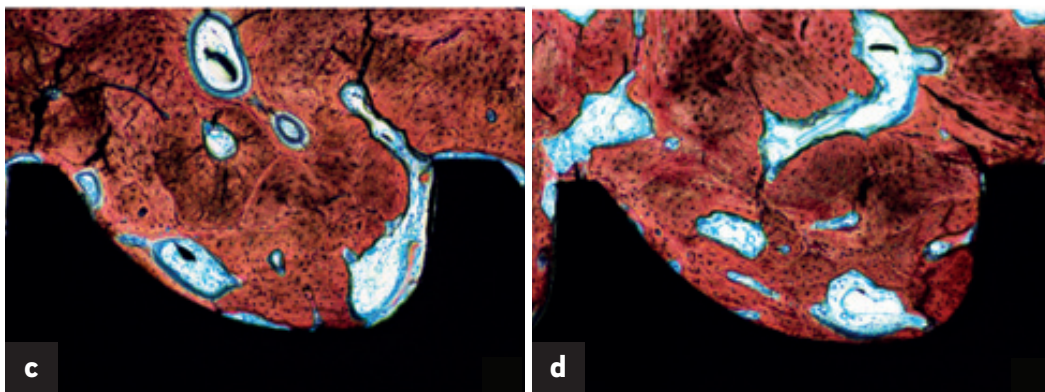


Table 1

	MBIC%		MB%	
	Turned	Rough	Turned	Rough
Mean (SD)	50.6* (18.3)	56.3* (18.6)	54.6* (9.6)	43.0* (9.0)
Median (25 th ; 75 th)	58.2 (44.1; 60.4)	62.7 (57.1; 66.0)	55.1 (51.5; 61.6)	44.5 (36.5; 49.9)

* p < 0.05.

The implants were well integrated into the mature bone, represented by mature lamellar bone and bone marrow surrounding the implant surface (**Figs. 2 & 3**). MBIC% was $50.6 \pm 18.3\%$ and $56.3 \pm 18.6\%$ at the Combed and ZirTi surfaces, respectively. The differences between the two surfaces were statistically significant ($p = 0.046$).

Bone density that was evaluated to a distance of about 0.6 mm from the implant surface and between the most coronal level of osseointegration (B) and the apex of the implant (A) was $54.6 \pm 9.6\%$ and $43.0 \pm 9.0\%$ at the Combed and ZirTi surfaces, respectively. The difference between the two surfaces was statistically significant ($p = 0.046$).

An outlier for MBIC% was identified (one dog), the values being below the first quartile. Data excluding the outlier are reported in **Table 2**. A statistically significant difference was no longer identified.

The correlation between MBIC% and MB% when all of the implants were taken into account yielded $r = 0.3$. However, if the groups of implants with different surfaces were considered separately, the values for the Combed and ZirTi surfaces were $r = 0.80$ and $r = 0.02$, respectively.

Discussion

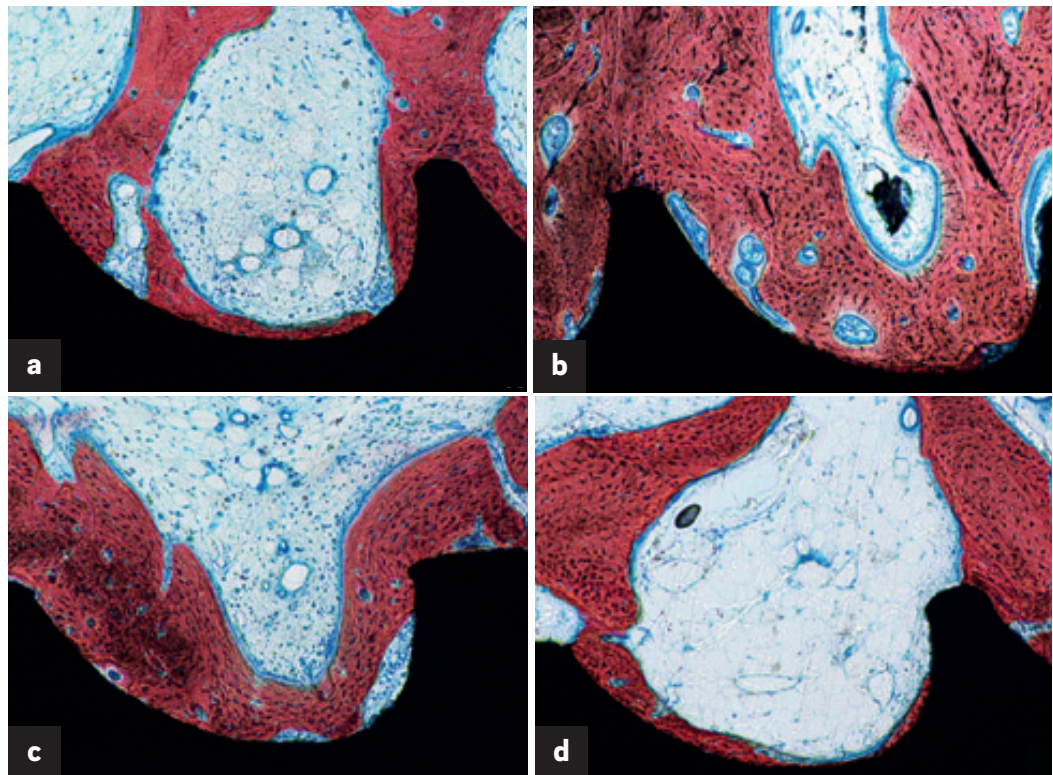
Moderately rough surfaces have been shown to yield superior osseointegration potential compared with that of smooth surfaces.² In an experiment in dogs, troughs were prepared around standard implants so that, after placement, chambers resulted between the implant body and the recipient bone.^{3,4} Moderately rough (SLA) and turned surface implants were used. A more rapid new bone apposition at the SLA compared with the smooth surface implants was observed.

Figs. 3a–d

Photomicrographs of ground sections illustrating the healing after four months at the ZrTi surface. Stevenel's blue and alizarin red stain. 100× magnification.

Table 2

Mean value (standard deviation) and median (25th and 75th percentiles) of MBIC% without the outlier. ($n = 5$)



Figs. 3a & b

Figs. 3c & d

	MBIC%	
	Turned	Rough
Mean (SD)	57.1 (10.5)	63.3 (5.5)
Median (25 th ; 75 th)	59.6 (56.8; 60.6)	64.5 (61.0; 66.5)

Table 2

* $p < 0.05$.

After 12 weeks of healing, bone-to-implant contact was slightly below 60% at the SLA (percentage deduced from the graph in the article) and 36.8% at the turned surfaces. It has to be noted that the S_a of these surfaces was $2.29 \pm 0.59 \mu\text{m}$ for the SLA and $0.35 \pm 0.17 \mu\text{m}$ for the turned surfaces, respectively.⁴

In the present experiment, the roughness of the two surfaces used was different from that previously described. In fact, S_a was about $0.6 \mu\text{m}$ for the Combed and about $1.4 \mu\text{m}$ for the ZrTi surfaces. This different roughness yielded different osseointegration, namely $50.6 \pm 18.3\%$ and $56.3 \pm 18.6\%$, in which the high standard deviation was mainly related to the presence of an outlier.

However, in the present study, the difference in MBIC% between the two surfaces was smaller than 6%, while in the previously discussed study,⁴ the difference was about 20%. This may be partly related to the differences in roughness of the

two surfaces, but also to the different models used. In that study, a chamber was prepared around the implant body so that only the pitches of the threads were in contact with the pristine bony beds. This yielded a primary bone-to-implant contact to the parent bone of about 6.3–6.5%, as measured on the day of implant placement. Bone apposition had to cover a distance of 0.4 mm to reach the inner side of the chamber. It was shown that this bone apposition on to the implant surface proceeded faster at the rough compared with the turned surfaces. In the present study, no modifications were applied to the implant configuration so that a higher primary contact of the implant surface to the bone bed was expected. In fact, in another dog study, similar implants were used and, after five days of healing, an MBIC% of about 32% was observed.⁷ This higher bone-to-implant contact area may have resulted in greater osseointegration at the turned implants used in the present study com-

pared with that used in the above-mentioned study.

It is important to consider that MBIC% represents a percentage and not an absolute value of mineralized bone in contact with the implant surface. Even though the MBIC percentages may be similar among surfaces with different 3-D parameters, the absolute values may be dissimilar owing to the different roughness of the surfaces. In the present study, bone density around the implant surfaces was found to be higher at the turned ($54.6 \pm 9.6\%$) compared with the moderately rough ($43.0 \pm 9.0\%$) surfaces. It was found that the correlation between MBIC% and MB% was low ($r = 0.3$) when all of the implants were taken into account. However, when the two groups of implants, Combed and ZirTi surfaces, were considered separately, $r = 0.8$ and $r = 0.02$ were observed, respectively. This gave rise to the speculation that the surface configuration influenced not only the osseointegration, but also the response of the tissue in close vicinity to the implant surface.

This outcome of the present study is in agreement with that of a previously discussed study.⁴ In that study, after six, eight and twelve weeks of healing, a higher amount of mineralized tissue within the chamber at the turned compared with the rough surfaces was found. Moreover, during the same periods of healing, it was observed that the percentage of mineralized tissue was increasing within the chamber of the turned surface, while it remained quite stable within the chamber of the rough surface.

It has to be observed that the present study reports data on healing after four months and without loading. Longer periods of healing may yield different results. Moreover, the load may influence the healing as well.⁸

A further limitation of the present study is the lack of standardization of the sites, the implant with the Combed surface being placed consistently about 10 mm more mesially in the premolar region of the alveolar process compared with the ZirTi surface.

In conclusion and within the above-mentioned limitations of this study, it has been shown that the surface characteristics of implants affected the degree of osseointegration. Both the turned and the moderately rough surfaces were osseointegrated to a similar degree after four months of healing, with the moderately rough surface providing only modestly better osseointegration. However, the osseointegration process before four months at the turned surfaces still requires greater elucidation.

Competing interests

The authors declare that they have no conflict of interest regarding the materials used in the present study.

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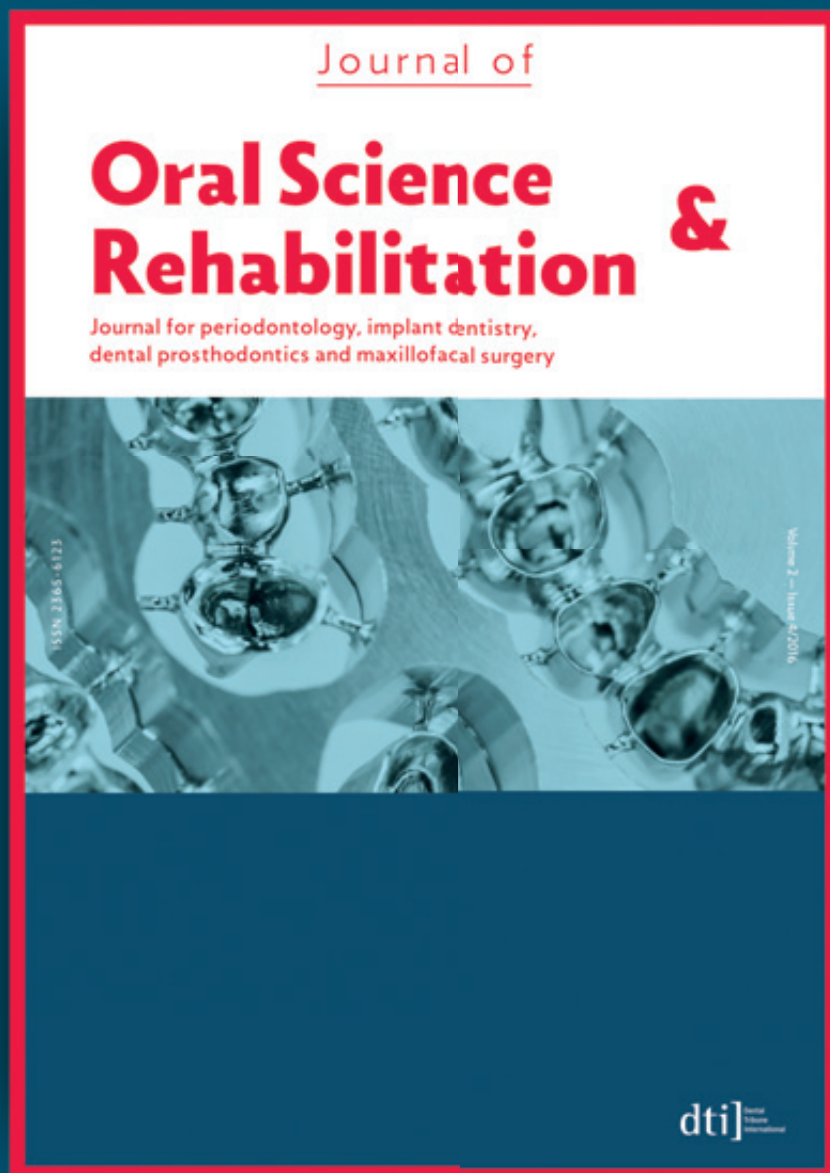
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