Relationship Between Crestal Bone Levels and Crown-to-Implant Ratio of Ultra-Short Implants With a Microrough Surface: A Prospective Study With 48 Months of Follow-Up

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The aim of this cohort study was to investigate the relationship between crestal bone levels and crown-to-implant ratio of ultra-short implants, after functional loading. Sixty patients with single or partial edentulism and alveolar bone atrophy were enrolled and treated between December 2009 and January 2016. Without using bone-grafting procedures, patients were rehabilitated with ultra-short implants characterized by a microrough surface and a 6-mm length. Clinical and anatomical crown-to-implant (C/I) ratios and crestal bone levels (CBL) were measured after a follow-up period ranging from 12 to 72 months; all peri-implant and prosthetic parameters were recorded. The data collected were statistically analyzed ($P = .05$). A total of 47 patients with 66 ultra-short implants were completely followed up according to described protocol. The mean follow-up was 48.5 $\pm$ 19.1 months. The mean anatomical C/I ratio was 2.2, while the mean clinical C/I ratio was 2.6 $\pm$ 0.6 at baseline and 2.8 $\pm$ 0.6 at the last follow-up appointment. Mean CBL as calculated at the baseline was 0.7 $\pm$ 0.5 mm, while at the last appointment it measured 1.0 $\pm$ 0.5 mm. The overall implant-based success rate was 96.9%, and the mean peri-implant bone loss (PBL) was 0.3 $\pm$ 0.3 mm. No statistically significant relationship was found between anatomical or clinical C/I ratio and PBL. Ultra-short implants appear to offer a predictable solution for implant-prosthetic rehabilitation in patients with edentulism and bone atrophy. A high percentage of implants were successful, with minimal crestal bone loss. The high C/I ratio did not appear to influence either peri-implant bone loss or prosthetic complication rates.

Key Words: dental implants, ultra short implants, micro roughed surface, biomechanical evaluation

INTRODUCTION

Edentulism typically results in progressive resorption of the alveolar bone.[1,2] When advanced maxillary or mandibular bone atrophy has occurred, prosthetic rehabilitation with standard implants can be difficult or even impossible.[3] As a result, different strategies have been developed to enable implant placement when limited bone is available. Surgical interventions include bone grafts, guided bone regeneration, distraction osteogenesis, sinus floor elevation, and alveolar nerve transposition; tilted, pterygoid, and zygomatic implants have also been developed.[4,5]

Ten Bruggenkate et al[6] introduced the term "short implant" in a study involving 6mm-long osseointegrated implants that were placed and followed for 1 to 7 years.

However, the definition of short and ultra-short implant remains inconsistent in the literature. Classification of any implant as "short" or "ultra-short" requires consideration of the implant's intra-bone length.[7] In one recent meta-analysis, implants with an intra-bone length between 6 and 9 mm were defined as short, while implants with an intra-bone length less than or equal to 6 mm were defined as ultra-short.[8] Recently, short implants (<8–10 mm long) have been considered a therapeutic alternative for the implant-prosthetic rehabilitation of edentulous jaws that may provide surgical advantages including reduced morbidity, treatment time, and costs.[9,10]

Although the first studies of short implants showed lower success rates than those for standard implants,[11,12] later studies demonstrated success rates similar to those of longer devices,[3,13] as technical innovations in the implant surface and design helped to compensate for the unfavorable crown-to-implant ratio and lower surface available for osseointegration.[14] In recent years, short implants have also been used for

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the rehabilitation of extremely atrophic jaws, with predictable long-term results shown for both short and ultra-short implants.[8,15–18]

The aim of the present study was to investigate the relationship between peri-implant bone loss and crown-implant ratio when ultra-short implants with a micro-rough surface were placed and followed for up to 72 months.

Materials and Methods

Subjects

Inclusion criteria consisted of single, partial, or total edentulism, with a residual bone height of $\geq$5 mm in the upper jaw and $\geq$7 mm in the lower jaw. Bone width of $\geq$6 mm was required, along with a need for rehabilitation with a fixed implant-supported prosthesis. All patients had to accept treatment based on use of ultra-short implants.

Exclusion criteria were poor oral hygiene, heavy smoking (>20 cigarettes/day), alcohol or drug abuse, acute oral infection, American Society of Anesthesiologists physical status classification of IV or V, any history of radiotherapy in the oral maxillofacial area, recent chemotherapy, or pregnancy.

Other situations such as bruxism and clenching; smoking less than 20 cigarettes/day; diabetes; type IV bone (according to Lekholm and Zarb's classification[19]); class IV or V atrophy (according to Cawood and Howell's classification[1]); human immunodeficiency virus; hepatitis C virus; hepatitis B virus; osteoporosis; autoimmune diseases; benign or malign neoplasia; hematologic, hepatic, or kidney diseases; and corticosteroid therapies were not considered as exclusion criteria to evaluate the implant function under these unfavorable conditions.

Following these criteria, patients were enrolled in the study between December 2009 and December 2015. The patients were clearly informed about the nature and aim of the study, and all participants provided written informed consent for the scientific use of their anonymous data. The study was conducted in accordance with ethical guidelines for research on human beings.

All enrolled patients were treated between January 2009 and January 2016 using ultra-short (6 mm long) implants with a microroughened (sandblasted and etched) surface, following standardized surgical procedures.

Materials

Two types of implants were used. The first were cylindrical (K implants, WINSIX, BioSAFin, Ancona, Italy) with a sandblasted and etched surface, 6 mm length, and 1 of 2 diameters (4.5 and 5.2 mm). The second type was tapered (TTx implants, WINSIX, BioSAFin, Ancona, Italy), with a sandblasted and etched surface, 6 mm length, and 1 of 3 diameters (3.8, 4.5, and 5.2 mm). All implants had an external hexagon connection and a smooth machined collar of 0.7 mm. All were purchased from the manufacturer by the clinician.

Preoperative evaluation

Each patient was clinically and radiographically evaluated. Panoramic or periapical radiographs were taken as a preliminary measure. In some cases, a cone-beam computerized tomography (CBCT) scan was obtained to facilitate more accurate evaluation of the degree of atrophy and proximity to other anatomical structures. Clinical evaluation consisted of a complete analysis of the oral hygiene and soft-tissue conditions, residual teeth, and other factors that might be relevant for treatment planning.

Procedures

Antibiotic prophylaxis was amoxicillin and clavulanic acid, 1 g, 2 times/day for 5 days or azithromycin 600 mg/day for 3 days for patients who were allergic to penicillin. Anti-inflammatory therapy was also administered and consisted of 600 mg of ibuprofen 2 times/day for 3 days, beginning with 1 dose before surgery. Local anesthesia with mepivacaine 2% with epinephrine 1:50 000 was performed at the surgical site, then each patient rinsed with clorhexidine 0.2% for 2 minutes. Implant insertion was performed in healed sites following a 4-step procedure: elevation of a mucoperiosteal flap, preparation of the implant site, low-speed implant placement, and surgical flap suturing (Figures 1a through c, 2a and b).

The site preparation and implant placement varied depending on the bone density and volume and nearby anatomical structures. An osteotomic technique[20] was employed whenever a sinus lift or augmentation of bone density was needed. When the bone width was insufficient, a combination of standard preparation with drills and the alternative osteotomic technique was adopted. A standard technique described in a previous study[21] was used at sites where the bone volume was adequate, and bone density was Type 1 or 2.

In high-density bone, the site was tapped with drills if K implants were inserted, while drills with progressive diameters were used to insert tapered design (TTx) implants passively. Otherwise, the site was prepared according to the sequence of drills, as per the manufacturer's instructions.

Once the implants were inserted, they were torqued to 25–60 Ncm, cover screws were positioned, and the flaps were passively sutured to favor first intention healing. Patients were instructed to consume a liquid diet in the postsurgical period, maintain good oral hygiene to avoid infections, and rinse twice a day with clorhexidine 0.2% for 10 days.

To achieve osseointegration, the implants were allowed to heal submerged for 3 to 4 months in the maxilla and 2 to 3 months in the mandible. They were then restored with fixed cemented single crowns or partial prostheses.

All patients were enrolled in a follow-up program that included professional oral hygiene every 6 months and regular visits during which implants were clinically and radiographically evaluated.

After the 2 to 4 months of healing, the implants were surgically uncovered, and healing screws were positioned, saving as much keratinized tissue as possible.

One week later, functional load was applied (Figures 1d, 2c and d), using the abutment- duplication technique described by Cocchetto et al.[22] This consisted of duplicating the implant portion of a working cast prepared using double-pour or plastic base die systems for single or multiple crowns.

First, an impression of the implant(s) was taken with a

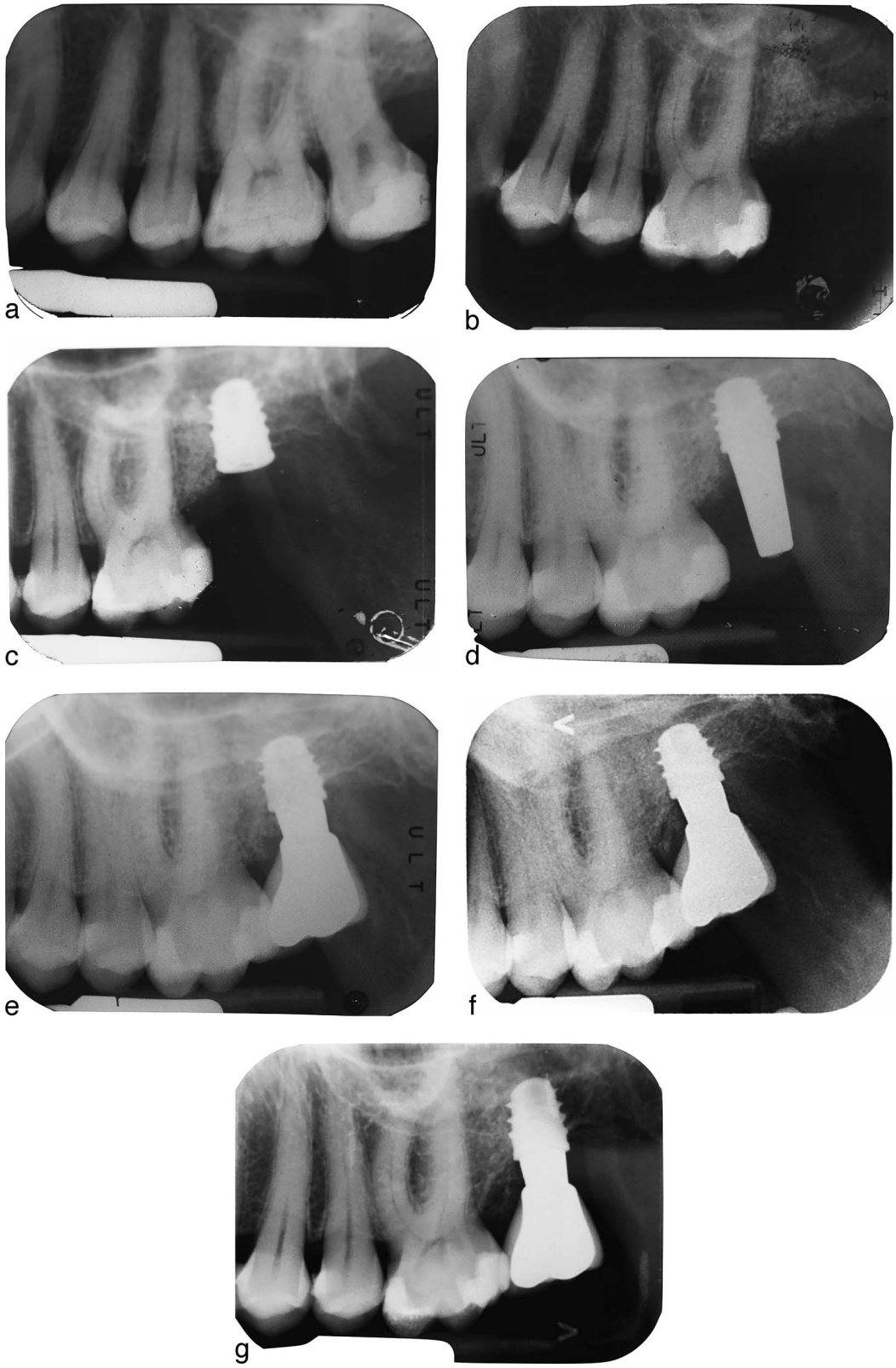


Figure 1. (a) Element #15 has to be extracted for periodontal problems. (b) Preoperative implant site #15. (c) Radiograph after implant surgery. (d) Radiograph after abutment connection. (e) Radiograph at delivery of definitive prosthesis. (f) Radiograph at 3-year follow-up. (g) Radiograph at 4-year follow-up.

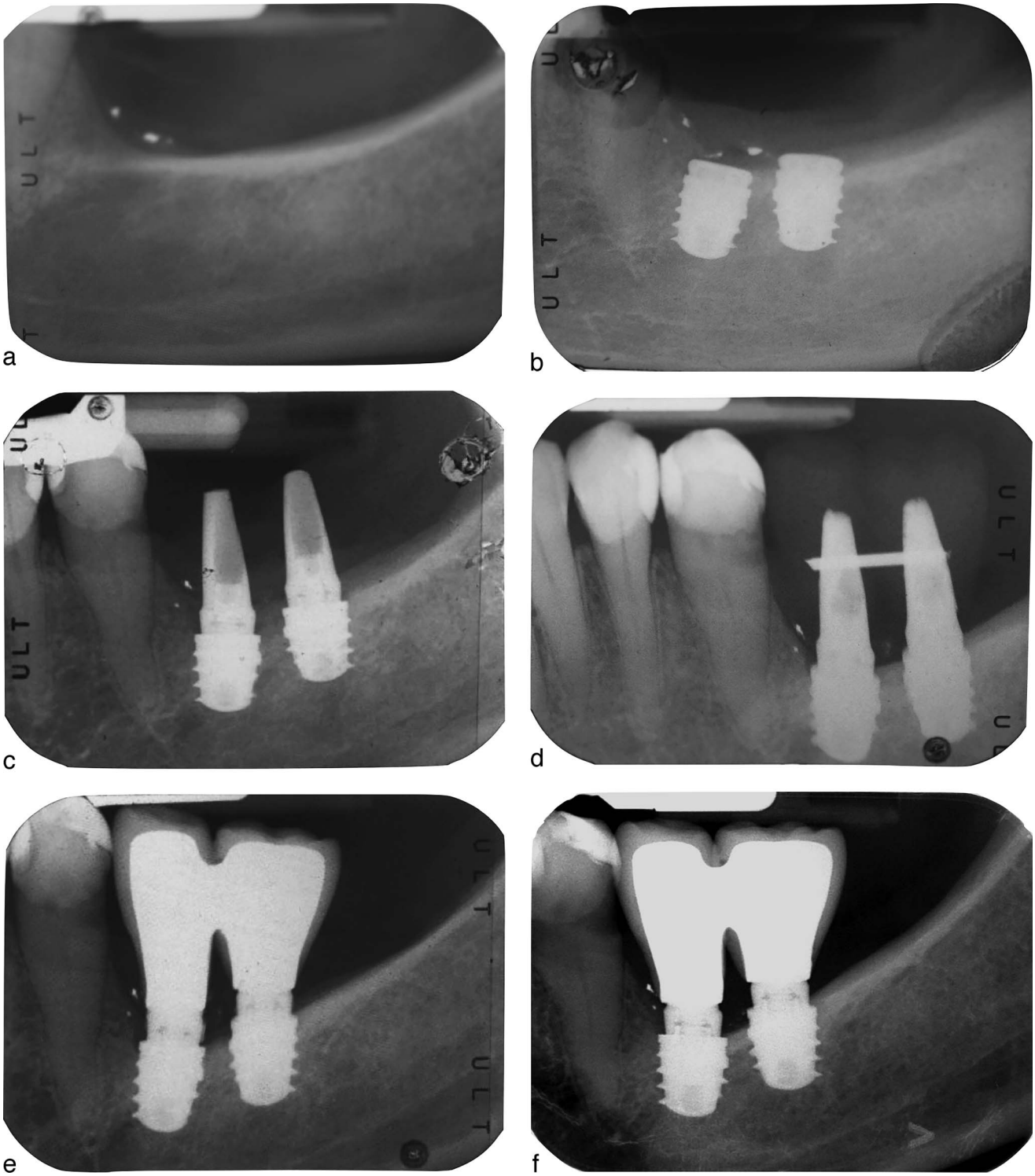


Figure 2. Continued. (a) Preoperative radiograph. (b) Postoperative periapical radiograph. (c) Radiographic examination after abutments connection. (d) Radiographic examination after provisional prosthesis. (e) Periapical radiograph taken at delivery of the definitive fixed dental prosthesis. (f) Radiograph after 3 years of functional load.

pickup technique, to enable fabrication of a master model that precisely captured the implant position(s).

Duplication was achieved using a high-precision addition silicon material and a low-shrinkage polyurethane resin. The duplicated implant abutment was used to finalize the fixed partial denture restorations after the originals were delivered to the patients, thus reducing time of clinical sessions and avoiding the stress caused by repeated dis- and reconnection of the healing caps. Use of a provisional resin prosthesis helped to condition the tissue adequately and achieve an optimal

Table 1

Anatomic distribution according to implant types*

Jaws	Site	N° K	Freq. (%)	Cum. Freq. (%)	N° TTx	Freq. (%)	Cum. Freq. (%)	Tot. Imp.	Freq. (%)	Cum. Freq. (%)
Maxilla	Up	4	10.3	89.7	2	7.4	92.6	6	9.1	90.9
	Um	21	53.8	53.8	11	40.7	40.7	32	48.5	48.5
Mandible	Lp	4	10.3	100	2	3.7	96.3	5	7.6	98.5
	Lm	10	25.6	79.4	12	44.5	85.2	22	33.3	81.8
	total	39	100	100	27	100	100	66	100	100

*Um indicates upper molar; Lm, lower molar; Up, upper premolar; Lp, lower premolar; K, cylindrical design; TTx, tapered design.

definitive prosthesis,[23] realized in gold-ceramic, zirconium-ceramic, or chrome-cobalt-ceramic. One to 6 months after delivery of the provisional prosthesis, a cement-retained definitive prosthesis was delivered (Figures 1e, 2e).

All implants were rehabilitated with fixed single crowns or partial bridges. The strict follow-up protocol required each patient to receive professional hygiene care, as well as clinical and radiographic examination 6 months after prosthetic loading and annually thereafter (Figures 1f and g, 2f).

Instrumentation/measurement

A database that included all the patients treated in the study was created, and the results were updated in April 2017.

From the radiographs taken at the time of implant insertion (crestal bone level insertion or CBL-ins), implant loading (CBL-bl), and the final follow-up visit (CBL-ctr), CBLs were calculated as the mean value between the mesial and distal CBLs. These were considered to be the distance between the implant shoulder and the first bone-implant contact on the radiograph, using imaging analysis software (ImageJ, National Institutes of Health, NIH, Bethesda, Maryland). Peri-implant bone loss (PBL) was calculated as the difference between the CBL at implant loading (CBL-bl) and the level after the maximum follow-up (CBL-ctr).

Peri-implant soft tissues also were clinically evaluated to detect the presence of mucositis or peri-implantitis. Modified gingival inflammation (mGI), probing pocket depth (PPD), bleeding on probing (BOP), and suppuration (pus) were registered. Any biological or prosthetic complications were recorded in the database.

For all implants, the crown/implant ratio (C/I ratio) was calculated from the radiographs.

This parameter allows us to evaluate the possible relationship between types of prosthetic restoration, PBL, and implant success, as shown in several studies.[15,24–27] Both anatomical and clinical C/I ratios were measured. The former was calculated as the ratio between the prosthetic manufacture length (from the implant shoulder to the top of the crown) and the implant length (6 mm). To obtain the clinical C/I ratio, the first bone-implant contact was considered the separation point between the crown and implant lengths.

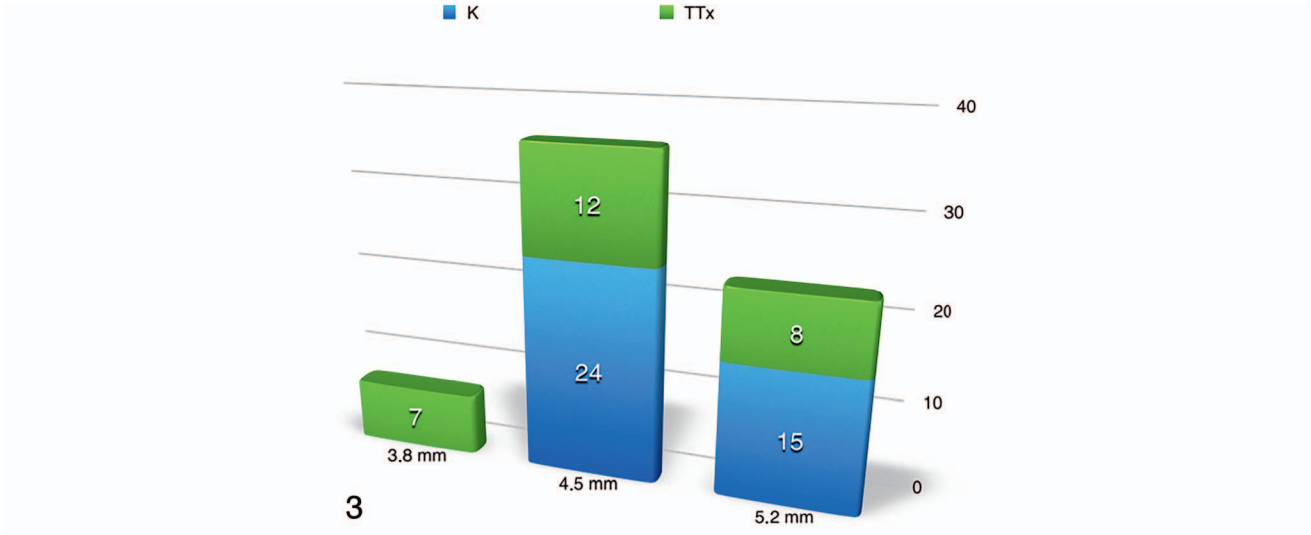
Also recorded were the sex and age of all patients at the time of implant insertion, smoking habits (number of cigarettes/day), systemic diseases (diabetes in particular), number of implants inserted and placement site(s), type of antagonist elements (implant prosthesis or natural teeth), implant macromorphology (K or TTx), implant diameter (3.8, 4.5, or 5.2 mm), insertion modality, date of insertion and functional loading, time of follow-up, date of any implant failures, prosthesis type (single crown, fixed partial, or full prosthesis), CBL at insertion time (CBL-ins), CBL at baseline (CBL-bl), CBL at the last follow-up control (CBL-ctr), anatomical C/I ratio, clinical C/I ratio at baseline and at the last control, and any prosthetic problems.

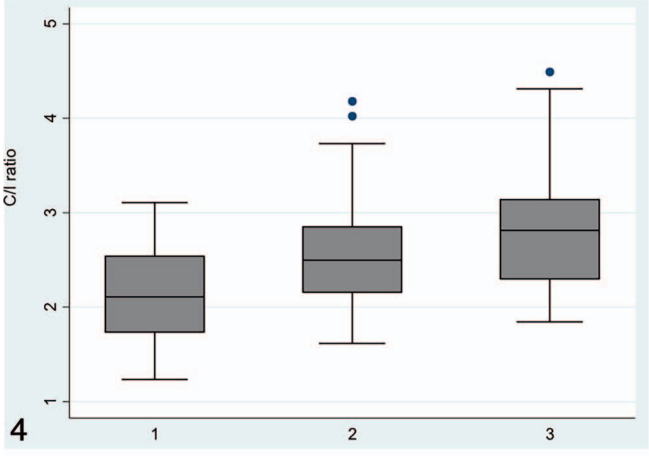
Implants that satisfied all criteria enumerated by Buser et al and later modified by Albrektsson and Zarb, were considered successful.[28,29] The criteria were absence of pain, disesthesia, or paresthesia at the implant site; absence of peri-implant infection, with or without suppuration; absence of implant mobility; and absence of more than 1.5 mm of bone loss in the first loading year and 1.2 mm/y after that. The implant survival rate was considered as the percentage of implants still in function at the final follow-up visit, even if not all success criteria were satisfied. It must be noted that when considering short and ultra-short implants, the concepts of survival and success can be correlated; peri-implant bone loss may result in a significant decrease in the osseointegrated portion of the implant, unlike what happens in longer implants.[30,31]

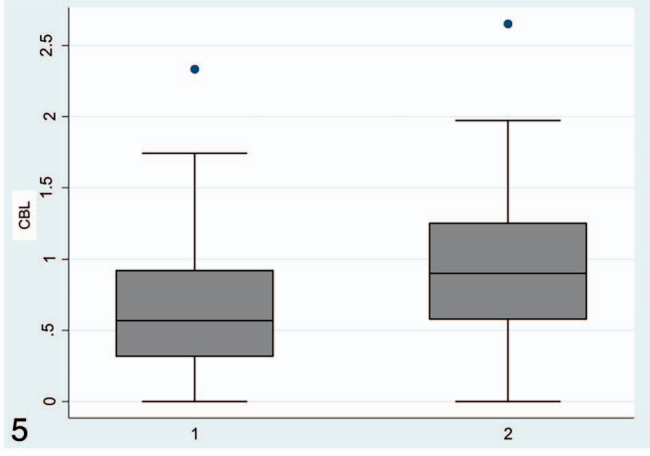
Statistical analysis

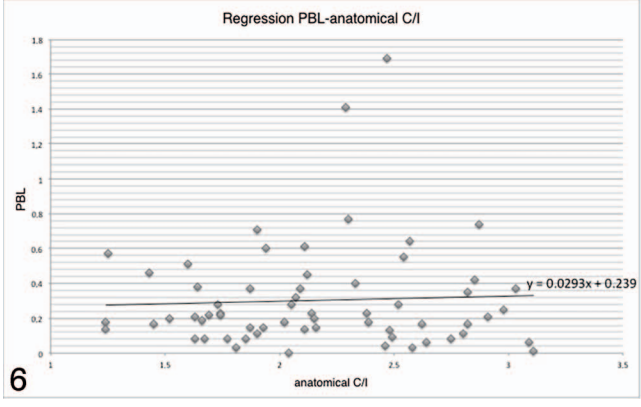
One blinded statistician was informed about the study design to decide the most adequate statistical analysis. Once data were collected, the same statistician independently performed the following tests. Since more than 1 implant was inserted in some patients, the data collected cannot be considered independent. The authors decided to use nonparametric tests and a generalized estimating equation (GEE) for bivariate and multiple analysis. Statistical tests performed were as follows:

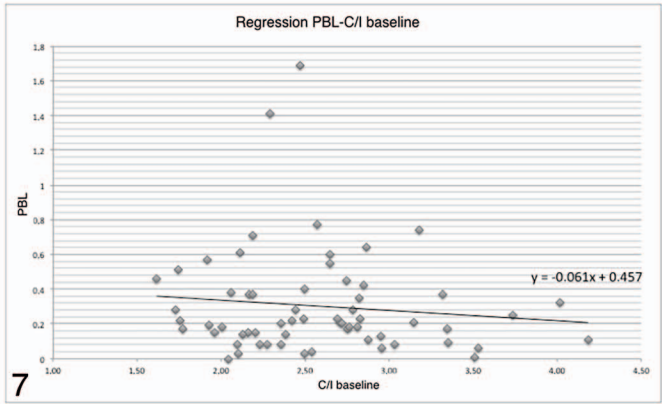
- Wilcoxon-Mann-Whitney nonparametric test to evaluate possible relationships between PBL and other parameters such as sex, upper/lower jaw, diabetes, smoking habits, prosthesis type, antagonistic element, osteotomic technique, and macromorphology
- Wilcoxon nonparametric test to compare peri-implant bone level at baseline (CBL-bl) to CBL at the last visit (CBL-ctr) (paired samples)
- Spearman nonparametric test to analyze the correlation between PBL and different quantitative parameters (anatomical C/I, baseline C/I, age, months of follow-up)
- Kruskal-Wallis test to evaluate the influence of implant diameter and site on PBL
- Bivariate regression analysis with generalized estimating equations to investigate the relationship between anatom-











Figures 3–7. Figure 3. Implant diameter distribution. **Figure 4.** Box and whiskers plot of crown-to-implant (C/I) ratio (1 = anatomical, 2 = clinical at baseline, 3 = clinical at latest follow-up). **Figure 5.** Box and whiskers plot of crestal bone levels (CBL) at baseline (1) and at latest follow-up visit (2). **Figure 6.** Bivariate regression analysis with generalized estimating equations to explore the possibility of a relationship between anatomical C/I ratio and peri-implant bone loss (PBL). **Figure 7.** Bivariate regression analysis with generalized estimating equations to explore the possibility of a relationship between clinical C/I ratio at loading time (C/I-bl) and PBL.

ical C/I ratio and PBL or clinical C/I ratio at the time of loading (C/I-bl) and PBL

- Multiple regression analysis with generalized estimating equations to evaluate the correlation between different variables (site, diameter, C/I-bl, anatomical C/I, design) and PBL

The results were analyzed with the following *P* values: *P* value <.10: 90% significance; *P* value <.05: 95% significance; *P* value

TABLE 2

Characteristics of failed implants (design type, diameter, sites, type of prosthesis, clinical C/I ratio, failure time, other information)*

Implants	Design	Ø (mm)	Site	Prosthesis	Clinical C/I BL	Failure Time	Other Information
1	K	4.5	2.5	—	—	Failure of integration	Heavy smoker
2	TTx	5.2	1.6	—	—	Failure of integration	Same patient of implant n°4, heavy smoker
3	K	5.2	2.6	Partial bridge	2.08	16 mo after loading	—
4	TTx	4.5	3.6	Overdenture	4.48	6 mo after loading	Poor oral hygiene

*C/I indicates crown-to-implant; BL, bone loss; K, cylindrical design; TTx, tapered design.

$<$.01: 99% significance. Significance level was fixed at $P = .05$ for the results of this study.

The statistical tests were performed with Stata 12 software (StataCorp LP, College Station, Tex).[15]

RESULTS

A total of 47 patients (31 female and 16 male) were included in the study. The mean age at insertion time was 60 $\pm$ 9 years (median 63; range 39–81 years). Five patients were affected by diabetes and ten10 were smokers, 5 of whom smoked more than 10 cigarettes/day.

The 47 patients were treated with a total of 66 implants: 31 subjects received only 1 implant, 13 patients received 2, and 3 patients each received 3 implants. Of the 66 implants, 27 were TTx implants, while 39 were K implants. Thirty-nine implants (59.1%; 14 TTx and 25 K) were placed in the upper jaw, while 27 (40.9%; 13 TTx and 14 K) were placed in the mandible. Table 1 shows the anatomical location of the implants.

Implant diameters ranged from 3.8 mm to 5.2 mm: 7 were 3.8 mm in diameter, 36 were 4.5 mm, and 23 were 5.2 mm (Figure 3). Two implants failed to osseointegrate and were removed before prosthesis delivery, resulting in an osseointegration rate of 96.97%. A total of 64 implants were thus loaded and followed up, according to the pre-established protocol.

During the follow-up period, 2 implants were removed (Table 2), one 6 months after the prosthesis delivery and one during the second year of the follow-up period. Both of these implants showed clinical signs of peri-implantitis. The survival rate for the period between functional loading and the final follow-up appointment was 96.9%.

All 62 implants surviving to the final follow-up visit met the success criteria, resulting in a success rate of 96.9% (equal to the survival rate). The survival and success rates were respectively 97.3% and 97.3% for maxilla, and 96.3% and 96.3% for mandible.

Mean follow-up for the 62 implants was 48.5 $\pm$ 19.1 months (median: 48; range 12–72 months). The distribution of implants according to follow-up time is shown in Table 3.

The mean CBL at different time points is shown in Table 4. The PBL between the baseline (prosthesis delivery) and the last follow-up appointment was 0.3 $\pm$ 0.3 mm.

The mean anatomical C/I ratio was 2.2 $\pm$ 0.5. The mean clinical C/I ratio at baseline was 2.6 $\pm$ 0.6, while at the last follow-up, it was 2.8 $\pm$ 0.6 (Figure 4).

Regarding the type of prosthesis, the 62 implants were rehabilitated with 37 partial fixed bridges, 11 single crowns, and 1 complete overdenture. In the opposing jaw, the antagonist of the implants most frequently was an implant-supported prosthesis (54.8%); in 45.5% of the cases, it was a natural tooth. No patient had a removable prosthesis.

During the follow-up period, only 2 cases of prosthetic complication (3.1%) were observed (loosening of 2 abutment-implant connection screws).

Statistically significant differences were found between mean CBL measured at baseline and CBL at the latest visit of follow-up (P value $<$ .0001) (Figure 5).

As reported in Tables 5 and 6, PBL was not influenced by any patient or implant parameters, such as sex, smoking habits, diabetes, type of prosthetic rehabilitation, site, or implant design. No statistically significant influence of other parameters on PBL was observed.

The statistical analysis also did not reveal any significant relationship between anatomical C/I ratio and PBL or between clinical C/I ratio at baseline (C/I-bl) and PBL (Table 6, Figure 6, Figure 7). Correlations between different variables (site, diameter, C/I-bl, anatomical C/I, design) and CBL also were not statistically significant (Table 6).

TABLE 3

Distribution of implants according to yearly follow-up time from 12 to 72 months*

Follow-up (mo)	Implants in Situ	Failed Implants	Failure (%)	CSR %
12–23.9	63	1	1,6	96.8
24–35.9	46	0	0	96.8
36–47.9	41	0	0	96.8
48–59.9	36	0	0	96.8
$\geq$ 60	17	0	0	96.8

*CSR indicates cumulative success rate.

DISCUSSION

Different studies have asserted that short implants may represent a possible solution for the rehabilitation of edentulous patients.[32–38] Some randomized controlled trials also have demonstrated that short implants have the same efficacy as longer devices when they are inserted in augmented bone.[32,33] In recent literature, however, only a few studies[39–43] have included ultra-short implants, that is, those with $\leq$6 mm length.[8] Moreover, some of the latter studies have had a short follow-up period.[39,42] In contrast, the present study followed a total of 66 ultra-short implants for a mean of 4 years, a more meaningful period for evaluation of survival and success rates

Table 4

Crown-to-implant (C/I) ratio, bone level, bone loss*

	Anatomical C/I	Clinical C/I (Baseline)	Clinical C/I (Follow-up)	CBL (Surgery)	CBL (Baseline)	CBL (Follow-up)	PBL
Mean ± SD	2.16 ± 0.50	2.57 ± 0.56	2.78 ± 0.62	0.34 ± 0.46	0.68 ± 0.53	0.98 ± 0.54	0.30 ± 0.30
Median (range)	2.11 (1.24–3.11)	2.50 (1.62–4.18)	2.81 (1.85–4.49)	0.10 (0.00–1.91)	0.57 (0.00–2.33)	0.90 (0.00–2.65)	0.21 (0.00–1.69)

*CBL indicates crestal bone loss; PBL, peri-implant bone loss.

of this kind of implant-prosthetic rehabilitation. Some authors have asserted that major bone loss is observed in the first 12 months after prosthetic loading,[44,45] since during this period the bone-implant interface is more sensitive to stresses.[46]

The success rate in the present study was 96.9%, the same as the survival rate, as calculated from the time of prosthetic delivery to the final follow-up appointment. These values are comparable to those reported in published studies of ultra-short implants, in which the survival rate ranges from 86.7%[47] to 98.0%[43] and the success rate from 93.8%[6] to 97.5%,[18] with variable follow-up (1–10 years) (Table 7).

Some studies have reported a survival rate of less than 80.0%, but almost all included short or ultra-short implants with a machined surface and low roughness.[48–51] The great importance of the micromorphology of these implants for obtaining success and survival rates comparable to those of longer ones is thus evident. The surface of the implants used in the present study has a moderate roughness (Sa = 1.4), which leads to an acceptable risk of peri-implantitis.[52]

In the systematic review of Srinivasan et al of 12 studies published from 1998 and 2011,[53] 6 mm-long implants with a similar surface showed survival rates between 93.7% and 97.6%. Rossi et al[54] published a cohort prospective study in 2015 with 5 years' follow-up in which 40 implants with a sand-blasted surface and 6 mm length were inserted. A survival rate of 95.0% was calculated from insertion to the end of follow-up, while the survival rate was 100.0% from the time of prosthetic loading through follow-up.

Regarding peri-implant bone loss, measured from prosthetic delivery to the last follow-up control visit, values for implants similar to those used in the present study vary considerably, ranging from 0.1 mm after 5 years of follow-up[47] to 0.2 mm after 3 years of follow-up[43] to up to 0.7 mm at 5 years after prosthetic loading.[54] The results of the present study (mean PBL between surgery and the final follow-up appointment 0.6 ± 0.4 mm; PBL between the baseline or prosthesis delivery and the final follow-up 0.3 ± 0.3 mm) are consistent with the values reported in the literature.

Two implants were lost during the reopening surgery, before prosthetic loading, while 2 others were removed after 6 and 16 months of load respectively. The first two probably failed to osseointegrate, while the failure of the last two was probably due to a lack of osseointegration and peri-implantitis, respectively. Early failure is common when short and ultra-short implants are used, with many authors reporting similar results.[7,25,53]

In some studies, a higher failure percentage is reported for implants placed in the posterior upper jaw, because of the low bone density and high chewing forces in this area.[20,53,55,56] Renouard and Nisand suggested that surgical preparation, which conforms to bone quality and rough implant surfaces, and careful patient selection were necessary to obtain comparable survival rates for short or longer implants.[3] The importance of site preparation for short implants that takes into

Table 5

Statistical analysis of the relation between peri-implant bone loss and other parameters

Variable	*P* Value
Sex	.5275
Smoking habits	.4925
Diabetes	.5285
Opposite elements	.3115
Splint/single crown	.0847
Alternative osteotomic technique	.6034
Implant design	.7466
Site (upper/lower jaw)	.4666
Diameter	.1542
Site	.3659
Diameter	.1542
Site	.3659

Table 6

Statistical analysis of the relationship between peri-implant bone loss (PBL) and other parameters (implant diameter, patient age, months of follow-up, and anatomical and clinical crown-to-implant [C/I] ratio). Moreover, correlation between anatomical C/I ratio and PBL and between clinical C/I ratio at loading time (C/I-bl) and PBL; finally, correlation between crestal bone levels and anatomical and clinical C/I ratio, implant diameter, and sites*

	Spearman's Coefficient	*P* Value
PBL : diameter	0.187	.146
PBL : age	0.098	.450
PBL : months of follow-up	−0.025	.846
PBL : anatomical C/I	−0.027	.837
PBL : clinical C/I (BL)	−0.102	.429
PBL : anatomical C/I	0.029	.666
PBL : clinical C/I (BL)	−0.061	.195
PBL : Anatomical C/I	0.197	.083
PBL : Clinical BL C/I	−0.173	.144
PBL : Diameter	−0.005	.953
PBL : Up	0.263	.238
PBL : Lp	0.125	.190
PBL : Um	0.074	.446
PBL : Lm	0.137	.182

*BL indicates bone loss; Up, upper premolar; Lp, lower premolar; Um indicates upper molar; Lm, lower molar.

TABLE 7

Literature about short and ultra-short implants, regarding follow-up, peri-implant bone loss (PBL), survival rates (SSR), and success rates (SR)

Studies	Length (mm)	Follow-up (y)	PBL (mm)	SSR (Load)	SSR (Surgery)	SR
Ten Bruggenkate et al[6]	6	6	-	-	97%	93.8%
Friberg et al[34]	6–7	10	0.9 ± 0.6	-	92.3%	-
Renouard and Nisand[35]	6–8.5	2–3	0.44 ± 0.52	-	94.6%	-
Arlin[39]	6	2	-	-	-	94.3% (surgery)
Misch et al[63]	7–9	1–5	-	100%	98.9%	100% (load)
Malò et al[36]	7–8.5	1–9	1.8 ± 0.8 (7 mm)	-	96.2% (7 mm)	98.1% (7 mm)
Deporter et al[41]	5	1–8	-	-	92.3%	-
Fugazzotto[37]	6–9	6–7	-	-	-	98%
Lai et al[38]	≤8	5–10	0.63 ± 0.68	-	97% (6 mm)	-
Rossi et al[47]	6	5	0.7 ± 0.6	100%	95%	-
Rossi et al[54]	6–10	5	0.14	90%	86.7%	-
Malchiodi et al[15,64]	5–7	3	0.48 ± 0.29	98.1%	-	98.1%
Malchiodi et al[21]	6	2–3	0.44 ± 0.72	100%	97%	97.1% (load) 94.1% (surgery)
Anitua et al[16]	≤8.5	10	1 ± 0.7 M 0.9 ± 0.6 D	98.9%	98.9%	98.9%
Slotte et al[40]	4	5	0.53 ± 0.08	92.2%	-	-
Calvo-Guirardo et al[42]	4–10	1	0.71 ± 0.11 (4 mm)	-	97.5%	97.5% (surgery)
Sahrmann et al[43]	6–10	3	0.0.62 (6 mm)	98% (6 mm)	98% (6 mm)	-
Present study	6	1–6	0.30 ± 0.30	93.9%	96.9%	96.9%

consideration the bone density also was stressed by Annibali et al in another systematic review.[14]

In the present study, an alternative osteotomic technique[20] was adopted when the bone density was low, while sites were tapped when bone showed greater density, to limit the complications connected to inadequate primary stability. This surgical approach permitted placement of both types of implants, with different macro-morphologies, in the upper and lower jaws. The two different designs yielded similar results for crestal bone levels and peri-implant bone loss.

The authors did pay great attention to guaranteeing the presence of at least 1–1.5 mm of bone thickness around each implant, both at the vestibular and lingual/palatal aspects. This was obtained by the choice of implant diameter, adaptation of the site preparation, and decision regarding implant placement depth.

An important consideration when using short and ultra short implants in atrophic jaws is the unfavorable C/I ratio. An increase of prosthetic complications, such as loosening of the abutment-implant screw, has been associated with such ratios.[57]

In the present study, however, only 2 cases of screw loosening were recorded throughout the follow-up period. Screw loosening typically is due to the progressive increase in stress at the implant-abutment interface, which induces a decrease of the preloading torque. This mechanism leads to the creation of a gap between the implant and abutment interface and detrimental rotational movement.[58] In the present study, the prosthetic protocol (strictly controlled torque when tightening the abutment-implant screws and use of the abutment-duplication technique[17]) optimized the implant-abutment connection and resulted in a very low number of complications.

Another consequence of an increase in the C/I ratio is the risk of overloading and consequent loss of crestal bone. The presence of a correlation between peri-implant bone loss and C/I ratio is still a controversial question in literature. A study published by Malchiodi et al[15] investigated the possible relationship between C/I ratio, implant success rate, and bone loss. One hundred fifty-one patients received 280 implants with a sintered porous surface. In 27% of cases, 5 mm-length implants were inserted and monitored for 36 months. The mean anatomical C/I ratio was 1.8 ± 0.7 (range: 0.9–4.3), while the mean clinical C/I ratio at baseline measured 2.1 ± 0.8 (range: 1.0–4.8). The results showed a positive correlation between C/I ratio and bone loss ($P < .001$).

Tawil et al[59] analyzed 262 short implants, divided into different groups according to C/I ratios (ranging from <1 to >2). Peri-implant bone loss was measured in the different groups to identify any potential influence of this prosthetic parameter on the implants' survival rate. No significant difference could be found among the various groups with respect to peri-implant bone loss ($P = .150$). The authors concluded that increased C/I values do not seem to be a major risk factor in cases of favorable loading.

A recent systematic review analyzed 13 scientific articles and found an inverse correlation between C/I ratio and crestal bone loss, with a possible protective effect of high C/I ratios on bone levels.[27] According to Blanes et al,[24] there is not sufficient data in the literature to prove a positive or negative effect of C/I ratio on the rates of success and prosthetic complications. In a cohort retrospective study, Birdi et al examined 309 ultra-short implants with a mean follow-up of about 21 months. They concluded that C/I ratio does not influence peri-implant bone loss or implant success.[26]

Ghariani et al obtained similar results 1 year after prosthetic loading.[60] The results of the present study agree with these publications, since a statistically significant correlation between C/I ratio and crestal bone loss was not found. The lack of statistical significance may be a result of the low number of

implants analyzed in the present study. Nevertheless, for realization of a long-term successful implant-supported rehabilitation, it is important to avoid overloading during function. Crown length thus should be limited.[61]

As for the biomechanical behavior of osseointegrated implants, different studies have demonstrated that the use of splinted implants can be an advantage for the success of implant rehabilitation, because the splinting better distributes chewing forces.[62,63]

High success rates have been reported after 3 to 5 years of follow-up for short implant rehabilitations with single crowns by many publications in recent years.[38,43,54]

In one systematic review, the authors reported a high cumulative success rate for short implants supporting both single crowns and partial fixed bridges.[14] Similarly, in the present study, no statistical differences were observed in peri-implant bone loss between ultra-short implants supporting single crowns and those supporting partial fixed bridges.

Although the results reached in the present study are encouraging, additional studies that include more implants should be undertaken to draw more reliable conclusions. Moreover, longer follow-up (more than 5 years) is preferable to analyze the biomechanical and biological behavior of ultra-short implants over the long term. More comparative studies that investigate the efficacy of shorts and ultra-shorts implants with different C/I ratios are needed.[15,21,64,65]; only 1 study is published about the role of C/I ratio with different implant length.[66]

Conclusions

This study confirmed that ultra-short implants with a micro-roughened surface can be a viable solution for rehabilitating single or partial edentulism in posterior atrophic areas. Stable crestal bone levels and a high implant success rate confirm the predictability of this kind of implant-prosthetic rehabilitation. A high C/I ratio did not appear to influence either peri-implant bone loss or prosthetic complication rates.

Abbreviations

BOP: bleeding on probing
C/I: crown-to-implant
CBCT: cone-beam computed tomographyic
CBL: crestal bone levels
CBL-bl: crestal bone levels at implant loading
CBL-ctr: crestal bone levels at the final follow-up visit
CBL-ins: crestal bone levels at the time of implant insertion
GEE: generalized estimating equation
mGI: modified gingival inflammation
PBL: peri-implant bone loss
PPD: probing pocket depth

Note

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